DEVELOPMENT OF A MODEL FOR PERFORMANCE MEASUREMENT IN JUST-IN-TIME ENABLED MANUFACTURING ENVIRONMENTS

YASANGIKA GAYANI SANDANAYAKE

MARCH 2009

DEVELOPMENT OF A MODEL FOR PERFORMANCE MEASUREMENT IN JUST-IN-TIME ENABLED MANUFACTURING ENVIRONMENTS

YASANGIKA GAYANI SANDANAYAKE

A thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton for the degree of Doctor of Philosophy

MARCH 2009

> This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purpose of assessment, publication or for any other purpose (unless otherwise indicated). Save for any express acknowledgements, references and/or bibliographies cited in the work, I confirm that the intellectual content of the work is the result of my own efforts and of no other person.

Signature :

Date : 20th March 2009

ABSTRACT

In this era of globalisation and fierce competition amongst businesses, there is a need to improve advanced operations management philosophies such as just-in-time (JIT) manufacturing to enhance business performance. Literature review shows that there is no mechanism so far to identify key JIT drivers relevant to a given organisation and its production processes, and their impact on enterprise performance. The research carried out here therefore involved the development of a generic performance measurement model to identify and capture the influence of JIT practices on enterprise performance.

A conceptual performance measurement model, which was designed based on comprehensive literature review and informal interviews/discussions with both academic researchers and industry practitioners describes the link between JIT drivers (X_i) and measurable performance (Y). This mathematically determined model is aimed at assisting managers in the systematic identification of the influence of key JIT drivers on enterprise performance using a multidimensional tool such as the extended balanced scorecard.

The case study approach was selected as the most suitable methodology for testing and validating the conceptual model in JIT enabled production plant and was applied to the production process of Denso Manufacturing (UK) Ltd., a global automotive component manufacturer. A novel eight-step implementation procedure was designed to collect data, which were analysed and validated by design of experiments, linear mathematical modelling, computer based dynamic simulation and analytic hierarchy process tool. The performance measurement model was then successfully applied to a non-automotive component production plant (Risane Ltd.).

In conclusion, the performance measurement model can now be suitably applied to JIT enabled manufacturing environments using relevant organisation specific JIT drivers and key performance indicators to optimise system performance. The contribution to knowledge is an innovative, user friendly, robust and multidimensional performance measurement model enabling industry practitioners to optimise JIT processes with substantial performance enhancement. The model could also be applied by future researchers to other operations management philosophies and industries, and at a higher level could be developed into a self-optimising software package, which will enable rapid determination of the key control parameters needed to optimise process performance just in time.

ACKNOWLEDGEMENTS

I am indebted to many people who supported me throughout this study. Firstly, I would like to extend my profound gratitude to my Director of Studies, Dr. Chike Oduoza. I have been honoured to work with such an enlightened individual. I could not have imagined having a better advisor and a mentor for my PhD. Without his support, perseverance and perceptiveness, I would never have finished this research.

Thanks are also due to my second supervisor, Prof. David Proverbs and other colleagues for many useful discussions, arguments and inspirations. I owe special thanks to all of the employees from Denso Manufacturing (UK) Ltd. and Risane Ltd. who provided valuable information and support during case studies. In particular Mr. Phil Tomlinson, Mr. Simon Balderson and Mr. Paul Sansom for arranging case study organisations, site visits and interview sessions.

I am also grateful to Dr. Fiona Berryman and Mrs. Kumudini Nallaiah for devoting their valuable time for some editing and to Mr. Remigus Onuoha for his support on simulation modelling and programming. I would also like to extend my thanks to all my friends at the University of Wolverhampton, UK and at the University of Moratuwa, Sri Lanka. In particular, I would like to thank the President's Fund, Sri Lanka for their financial support in academic year 2003/04.

I owe special thanks to my dear mother Mrs. Malanie Sandanayake and my father Mr. M. Sandanayake, who went through so many hardships to get me to where I am now. Without them, I would not be here. I also express my deepest gratitude to my sister Thanuja and brother-in-law Nandika.

Finally, I am so grateful to my dear husband, Lakshman, for encouraging me to start this PhD. His patience and support was immense throughout these years.

TABLE OF CONTENTS

CHAPTER 7: TESTING AND VALIDATION OF PERFORMANCE MEASUREMENT MODEL – A CASE STUDY 164

CHAPTER 8: APPLICATION OF PERFORMANCE MEASUREMENT MODEL IN A NON-AUTOMOTIVE PRODUCTION ENVIRONMENT 225

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AHP	Analytic Hierarchy Process
BSC	Balanced Scorecard
CI	Continuous Improvement
CIGMA	Co-operated Information System for Global Manufacturing
DMUK	Denso Manufacturing (UK) Limited
DoE	Design of Experiments
EFQM	European Foundation for Quality Management
HRM	Human Resource Management
JIT	Just-in-Time
KPI	Key Performance Indicators
MAS	Management Accounting System
PDCA	Plan-Do-Check-Act
PMQ	Performance Measurement Questionnaire
PMS	Performance Measurement System
PT	Process Time
SMART	Strategic Management Analysis and Reporting Technique
SME	Small and Medium Enterprise
SMED	Single Minute Exchange of Dies
TPM	Total Productive and Preventive Maintenance
QC	Quality Control
TQM	Total Quality Management
TT	Takt Time
UK	United Kingdom
US	United States

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND TO RESEARCH

Under intensive global competitive pressure, most companies around the world have applied innovative thinking to management and begun to examine technology that can lead to improved manufacturing flexibility, product quality and production cost (Brox and Fader, 2002 and Chu and Shih, 1992). Time-based competition is one of the most important recent trends in a business environment and Just-in-Time (JIT) philosophy plays an increasingly prominent role in the modern industrialised era (Fullerton *et al.*, 2003). JIT is an all-inclusive organisational philosophy designed to achieve high volume production using minimum inventory at the right time and based on planned elimination of all waste and continuous improvement (Fullerton and McWatters, 2001, Peng and Chuan, 2001a and Oral *et al.*, 2003).

Although most academics and practitioners agree that JIT is composed of a set of techniques such as kanban, JIT purchasing, total quality management, line balancing, set-up time elimination plans, supplier integration, integrated product and process design, total productive and preventive maintenance, group technology, focused factory, multifunction employee and employee training, no universal set of elements about this philosophy has been established to optimise system performance (White and Ruch, 1990). Womack and Jones (1996) identified three key principles of JIT as a commitment to continuous improvement, implementation of customer pull production rather than organisational push production and elimination of all kind of wastes. JIT plants place a higher priority on non-financial performance measures than non-JIT plants (Callen, *et al.*, 2000). JIT's focus on excellence through continuous improvement requires a performance measurement system that evaluates the changes in quality, setup times, defects, rework and throughput times (Fullerton and McWatters, 2002).

The quest for a versatile performance measurement system (PMS) in the manufacturing industry and especially for JIT enabled system, therefore has been an important agenda item over the last few decades (Folan and Browne, 2005, Pun and White, 2005 and Sandanayake and Oduoza, 2008). PMS forms an integral part of management control systems and it is used to gauge the performance of a company, department, plant, cell and individuals. Performance Measurement Systems (PMSs) are most successful when they are integrated with the company mission, vision, values and strategy (Medori and Steeple, 2000 and Pun and White, 2005). Neely *et al.* (1995) defined PMS as a set of metrics used to quantify both the efficiency and effectiveness of processes. According to Lohman *et al.* (2004), performance measurement is an activity that managers perform in order to reach predefined goals that are derived from the company's strategic objectives.

Performance measurement system in a JIT environment must provide the requisite measures and control to support management decision making in terms of JIT strategies. In a JIT environment, the PMS should be linked to critical success factors at all organisational levels (Fullerton and McWatters, 2002) but, as Mia (2000) discusses, the need for a PMS is particularly important at the operational level of the organisation. Moreover, to date, relatively little research has determined what PMS is consistent with the adoption of JIT philosophy.

Clinton and Hsu (1997) argued that the balanced scorecard (BSC) could be a useful tool in systematising the management control system to accommodate radical changes in activities that are brought on by implementation of a JIT manufacturing system. The BSC approach introduced by Professors Robert Kaplan and David Norton as a performance measurement tool, makes management accounting information more elaborate (Mia, 2000). Mia agreed that the BSC approach incorporates qualitative, quantitative, financial and non-financial information on typical performance indicators such as operating income, revenue growth, cost controls, yield, lead time, time to market, market share, customer response and satisfaction, product reliability, quantity of defective products shipped to customers, and the ratio of good output to total output.

Empirical research so far involving the study of performance measurement in JIT production environments consists primarily of mass scale questionnaire surveys (White, 1993, Upton, 1998, Callen, *et al.*, 2000, Fullerton and McWatters, 2001 and Ahmad, *et al.*, 2004) and case studies of specific organisations (Rangone, 1996, McLachlin, 1997, Rahnejat and Khan, 1998 and Mistry, 2005). More recently, some studies have also described simulations and mathematical modelling in JIT research (for example Fernando and Luis, 2002, Fullerton *et al.*, 2003, Ozbayrak *et al.*, 2004 and Polat and Arditi, 2005 among others). Mathematical modelling of JIT generally focuses on relationships between changes in various production factors and the corresponding specific production performance measures. To foster manufacturing strategies such as JIT, PMS may need to link JIT techniques with company goals, strategy, critical successes factors and key performance indicators (KPIs) (Sandanayake and Oduoza, 2008). The next section presents the research problem and rationale.

1.2 PROBLEM STATEMENT AND RATIONALE

The study of Laugen *et al.* (2005) on 'which manufacturing practices are used by the best performing organisations' found that most research has failed to investigate the effect of best practices on performance, and also less is known about the extent to which they are indeed generic. Various research studies have been carried out to investigate and measure performance in a JIT environment.

White and Ruch (1990), White (1993) and White and Prybutok (2001) made an empirical assessment of JIT practice and also surveyed implementation amongst US manufacturers. These studies focused on implementation differences between small and large US manufacturers using the ten management practices supposedly constituting the JIT concept. Brox and Fader (1996, 1997 and 2002) assessed the impact of JIT based on economic theory and also the impact of JIT management strategies on plant level productivity applying variable cost function estimates. Callen *et al.* (2000) and Callen *et al.* (2001 and 2002) also carried out an empirical analysis of performance consequences of in house productivity measures such as total productivity, labour productivity and return on investment on JIT plants and found that these measures are related to plant efficiency and profitability. Huson and Nanda (1995) studied the impact of JIT on firm performance in the US and came to a conclusion that JIT adopted firms reduced labour content in facilities, increased inventory turnover and enhanced earnings. Boyd (2001) and Pandya and Boyd (1995) appraised JIT in the manufacturing industry using financial measures and found that inventory turns, net income and earnings per share are significantly affected by the time of JIT implementation and experience.

Moreover, Oliver *et al.* (1996) found that automotive industry in Europe as a whole lags Japan and USA, but that within Europe there are enormous variations in performance on a country-by-country basis. The Andersen Consulting took five and half days of management time to complete questionnaire for systematic comparison of performance between plants in each product area and to profile the management practices of each plant in order to gauge the extent to which lean/JIT production principles were implemented (Oliver *et al.,* 1996). Karlsson and Ahlstrom (1996) developed a conceptual model to find out measurable determinants of what constitutes lean production system in a manufacturing company (Refer to Figure 4.2).

All the aforementioned key studies have assessed the impact of limited JIT techniques on aspects of productivity and performance in US firms without conclusive and substantiated results. According to Fullerton and McWatters (2001), the implementation of JIT by the US firms has been in a relatively slow and ad hoc manner; the implementation lag has been attributed to a number of factors including a firm's resistance to change, a lack of understanding of JIT methods, an incompatible workforce and workplace environment, a non-supportive supplier and an inadequate PMS. Moreover, empirical studies that examine the direct relationship between JIT implementation and financial performance have reported mixed results (Fullerton and McWatters, 2001 and Fullerton *et al.*, 2003).

According to Kazazi and Keller (1994) little research has been reported on the quantitative tangible and intangible benefits of JIT implementation. Despite the availability of the various approaches to develop PMS, none of the past researchers attempted to quantify the effects of the various factors on performance (Suwingnjo *et al.*, 2000). There is therefore no evidence in the literature of any mechanism to quantitatively relate JIT techniques and practices with measurable performance in a manufacturing environment (Sandanayake and Oduoza, 2008). The obvious assumption is that an increase in financial performance would be attributable to a successful JIT initiative but this cannot be corroborated (Fullerton *et al.*, 2003 and Ahmad *et al.*, 2004). Ahmad *et al.* (2004) further argued that since a company's financial results are influenced by many factors, it is difficult to claim that one factor alone is the main cause of any improvement in financial performance.

A major characteristic of JIT implementation is that there are no universally accepted JIT techniques, as they seem to vary from organisation to organisation, culture to culture and also from industry to industry. Galbraith (1977) stated that “not all organisations can or should implement the same set of JIT practices.” Further criticism is that definition of JIT and lean production itself is vague and confused (Bartezzaghi, 1999). Another shortcoming from previous research in this area is the lack of a comprehensive and elaborate PMS to assess success, failure or impact of JIT practices on total enterprise performance. There is therefore, a void in the literature on JIT techniques of a suitable tool to measure its impact on performance.

Traditionally, performance has always been measured only from the financial perspective. The disadvantage of this approach is that it tends to ignore performance in terms of business innovation and growth, customer, employee, supplier, socio-environmental groups and internal business processes perspectives. These are key drivers of financial performance and are essential in the present day manufacturing practices.

The research question therefore is, *“in the present day manufacturing setting, is there a generic performance measurement system suitable for the evaluation and assessment of just-in-time enabled processes?”*

In this era of globalisation and fierce competition amongst businesses there is a need to evaluate the real impact of operational philosophies on business performance. This study will therefore develop a robust, comprehensive performance measurement tool enabling a multidimensional assessment of the impact of JIT techniques on enterprise performance. The outcome from the study will provide a performance measurement model and implementation procedure for the successful implementation of JIT techniques in production environments.

1.3 RESEARCH AIM AND OBJECTIVES

The main aim of this research is:

> "*to develop a generic performance measurement model to identify and capture the influence of just-in-time manufacturing techniques on the performance of manufacturing enterprises*"

The model will guide industry practitioners and academic researchers on the relevant JIT parameters making the maximum impact on production performance in a JIT enabled manufacturing environment.

The project is broken down into the following measurable objectives:

1. Critical review of the literature related to:
    (a) JIT philosophy and its applicability in the UK; goals and elements of JIT; and problems associated with implementation
    (b) financial and multidimensional PMSs implemented in manufacturing industry
    (c) PMSs used in JIT environments; quantitative PMSs and simulation studies in JIT production environments
2. Conduct informal interviews and discussions, plant visits and observe production in practice to appreciate key variables and drivers of JIT and their resultant impact on enterprise performance in the present day, global manufacturing environment. There seems to be no universally agreed variables driving this concept as it is thought to be both organisational and national culture dependent. The interviews and discussions will further enable the identification of an extensive set of JIT techniques and key performance indicators for performance measurement in JIT enabled manufacturing environments.
3. Develop a conceptual model for performance measurement in manufacturing environments by linking JIT drivers and KPIs to a restructured extended BSC, which is capable of assessing enterprise performance not only from economic and financial standpoints but also based on impacts on customer,

employee, supplier, innovation and growth, environmental as well as internal business processes perspectives.

4. Develop a performance measurement model implementation procedure to capture the influences of JIT practices on operational and enterprise performance of JIT enabled manufacturing environments, assessed by a robust performance measurement tool.
5. Test and validate conceptual performance measurement model in a case manufacturing environment. Identify key JIT drivers and KPIs; establish a measurable cause and effect relationship between JIT practices and perceived output using techniques such as design of experiments, linear mathematical modelling and simulation and thereby assess the impact of key JIT variables on operational performance. Typical dynamic simulation software such as ProModel will be used to model and simulate the effect of parameters on relevant outputs. Assess the impact of key JIT drivers on organisational performance using a multi-criteria decision making tool such as analytic hierarchy process analysis.
6. Apply the multidimensional performance measurement model to another manufacturing industry environment.
7. Draw conclusions and make recommendations.

1.4 RESEARCH APPROACH

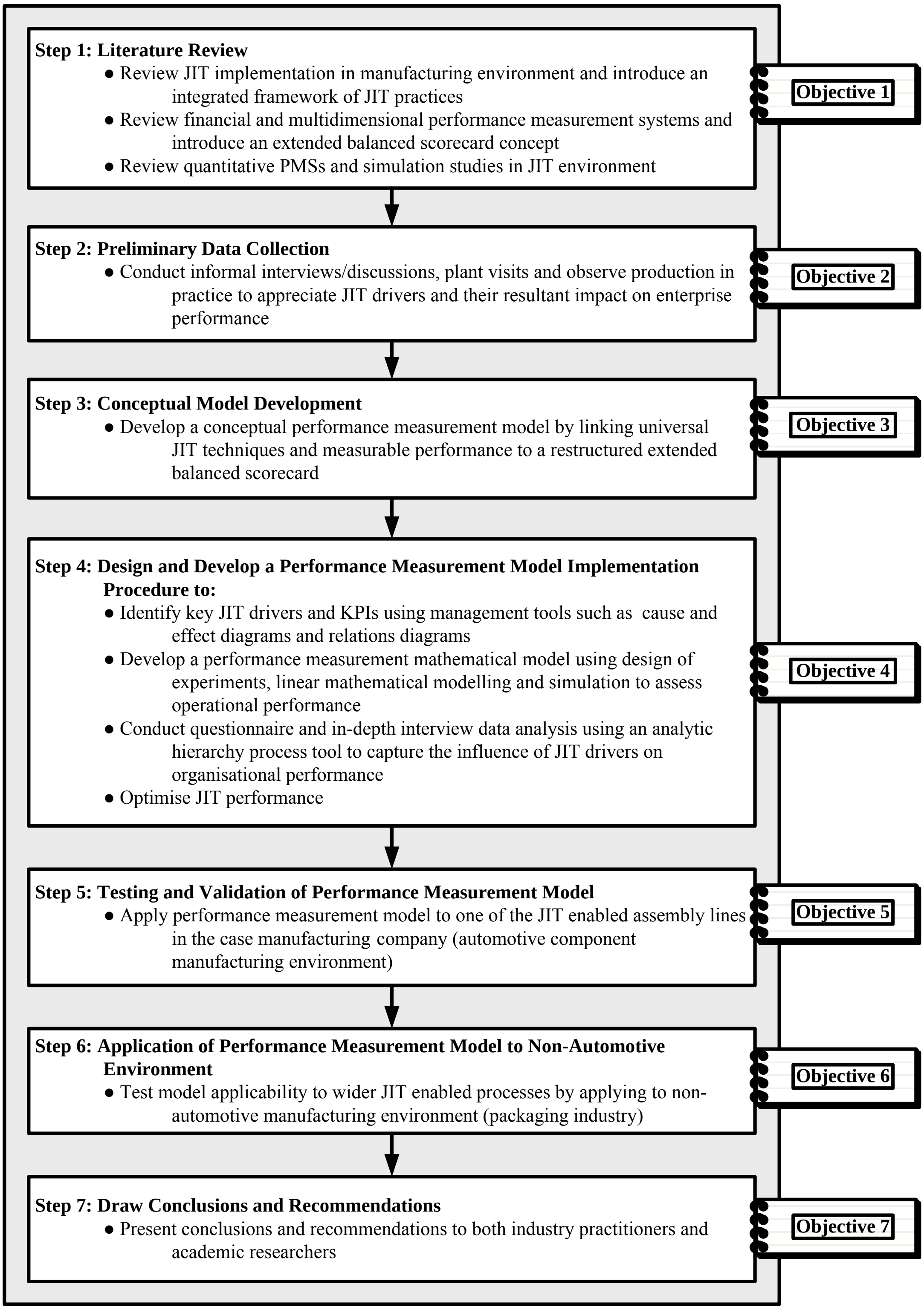
The main goal of this research is to design and develop a robust, multidimensional and elaborate performance measurement model to identify and capture the influence of JIT practices on enterprise performance. This research used multi-method approach to collect, analyse and validate data in order to achieve the aforementioned aim and objectives. Multi-research approaches and data analysis tools used in the past by key researchers working in the fields relevant to this study is given in Table 5.2.

The needs of this research indicate that the best research approach is a case study. The methodology adopted starts with a review of existing literature to develop a theoretical understanding prior to empirical study. A comprehensive literature review and data gathered from informal interviews and discussions were then used to develop a conceptual performance measurement model. The next stage involved the development of a performance measurement model implementation procedure for a JIT enabled manufacturing environment. Data gathered from informal interviews and discussions, and literature review also were instrumental in the design and development of a performance measurement procedure.

The next step of the study involved testing and validation of the conceptual performance measurement model by its application to a JIT enabled production line in the case manufacturing company. Despite the benefits to be gained from the case study approach, its mode of application in practice was not easily determinable. For instance, finding suitable collaborative companies and the data collection process using observations, participation, documentation, interviews and questionnaires were time consuming. The researcher's interviewing skills and ability to interact with different personnel was paramount. A multidimensional PMS capable of assessing performance in a JIT environment based on a restructured extended BSC was developed for a large-scale automotive component manufacturing company.

The literature review of Brown and Inman (1993) on applicability and optimal implementation procedure of JIT to the small and medium enterprises (SMEs) found that the use of JIT in SME is relatively sparse. Hence, the performance measurement model was then applied to a small and medium non-automotive enterprise using the eight-step performance measurement process to test its applicability to wider JIT processes.

The summary of the research approach adopted, objectives and deliverables is illustrated in Figure 1.1.



Step 1: Literature Review

- Review JIT implementation in manufacturing environment and introduce an integrated framework of JIT practices
- Review financial and multidimensional performance measurement systems and introduce an extended balanced scorecard concept
- Review quantitative PMSs and simulation studies in JIT environment

Step 2: Preliminary Data Collection

- Conduct informal interviews/discussions, plant visits and observe production in practice to appreciate JIT drivers and their resultant impact on enterprise performance

Step 3: Conceptual Model Development

- Develop a conceptual performance measurement model by linking universal JIT techniques and measurable performance to a restructured extended balanced scorecard

Step 4: Design and Develop a Performance Measurement Model Implementation Procedure to:

- Identify key JIT drivers and KPIs using management tools such as cause and effect diagrams and relations diagrams
- Develop a performance measurement mathematical model using design of experiments, linear mathematical modelling and simulation to assess operational performance
- Conduct questionnaire and in-depth interview data analysis using an analytic hierarchy process tool to capture the influence of JIT drivers on organisational performance
- Optimise JIT performance

Step 5: Testing and Validation of Performance Measurement Model

- Apply performance measurement model to one of the JIT enabled assembly lines in the case manufacturing company (automotive component manufacturing environment)

Step 6: Application of Performance Measurement Model to Non-Automotive Environment

- Test model applicability to wider JIT enabled processes by applying to non-automotive manufacturing environment (packaging industry)

Step 7: Draw Conclusions and Recommendations

- Present conclusions and recommendations to both industry practitioners and academic researchers

Figure 1.1: Outline of Research Approach, Objectives and Deliverables

1.5 SCOPE AND LIMITATIONS OF RESEARCH

Literature review, preliminary interviews and discussions showed that there were no universally applicable JIT techniques. The techniques seemed to vary with the performance priorities from one company to another and hence the chosen PMS was unique to a specific business. It is therefore not possible to develop a PMS with identical JIT techniques and KPIs applicable to all production processes. However, the performance measurement model presented in this study can be suitably amended and applied to any JIT enabled production environment to build a plant specific PMS.

One constraint which occurred during testing, validation and application of the performance measurement model in automotive and non-automotive production environments was that it was not possible to interview customers, suppliers and external socio-environmental groups to get their views, due to company restrictions and their locations. However, internal managers were carefully chosen for the structured interviews to include those who had direct contact with customers, suppliers and external groups, for example, managers from Customer Care, Purchasing and Environment Departments. Thus, the impact of a lack of direct contact between the researcher and external parties was minimised.

The scope of this study is limited to manufacturing industry. However, in the future, it could be extended to other industries such as the construction and services sector. This would determine its wider applicability to other production and service environments.

1.6 THESIS OUTLINE

The thesis consists of nine chapters; a brief overview of chapter content is as follows:

Chapter One outlines the background to the research together with the research question, aim and objectives and research approach. This chapter further presents scope and limitations of the research and the thesis outline.

Chapter Two presents the literature review of JIT philosophy in manufacturing environments. This chapter also provides the rationale for selecting JIT philosophy for this research. The JIT goals, their implementation in the UK, JIT elements (techniques) and pre-requisites of implementation are presented. Chapter two addresses part of the first objective of the research study.

Chapter Three presents the literature review of traditional financial based PMSs and modern multidimensional PMSs in manufacturing environments. Limitations of financial performance measures, pros and cons of multidimensional PMSs and pre-requisites of an integrated PMS are presented. This chapter demonstrates the need to develop a robust, multidimensional PMS for JIT manufacturing environments and introduces a restructured extended balanced scorecard concept. Chapter three addresses part of the first objective of this research study.

Chapter Four presents a literature review on quantitative PMSs in JIT environments, addressing the final part of the first objective. The chapter also summarises the findings of informal interviews/discussions and plant visits to appreciate key variables and drivers of JIT and their resultant impact on enterprise performance. This addresses the second objective of this study. Chapter four then presents the conceptual performance measurement model developed for this study by linking the integrated framework of JIT practices and the extended BSC tool to measurable performance. Chapter four finally addresses the third objective of this research study.

Chapter Five outlines the research methodology adopted for this study and explains the practical approach taken for data collection. This chapter also presents reasons for choosing the case study approach for testing, validation and application of performance measurement model. Chapter five provides suitable research methodologies and data collection methods used to achieve all seven objectives of this research study.

Chapter Six presents the performance measurement model implementation procedure. It describes the eight-step procedure used to identify key JIT drivers and KPIs and an application of simulation and modelling using ProModel simulation software to determine the impact of those drivers on operational performance. Chapter six further presents the method to assess the impact of key JIT techniques on enterprise performance using an analytic hierarchy process tool and illustrates the survey instrument used for data collection. Chapter six addresses the fourth objective of the research study.

Chapter Seven reports the testing and validation of the conceptual performance measurement model by applying it to one of the JIT enabled assembly lines in the case manufacturing company (Denso Manufacturing (UK) Ltd.). The chapter also presents performance measurement mathematical models developed by linking key JIT variables to operational performance and the multidimensional PMS developed to measure overall performance of the case manufacturing company. Chapter seven addresses the fifth objective of the research study.

Chapter Eight describes the application of the proposed multidimensional performance measurement model to a small and medium scale, non-automotive manufacturing environment (Risane Ltd. involved in packaging). This chapter addresses the sixth objective of the research study.

Chapter Nine summarises the research process and presents key research outcomes. It presents the conclusions derived from the overall research findings, contribution to knowledge and details recommendations to improve JIT implementation and performance measurement in a manufacturing environment. Typical areas for further research are highlighted.

Figure 1.2 outlines the structure of the thesis.

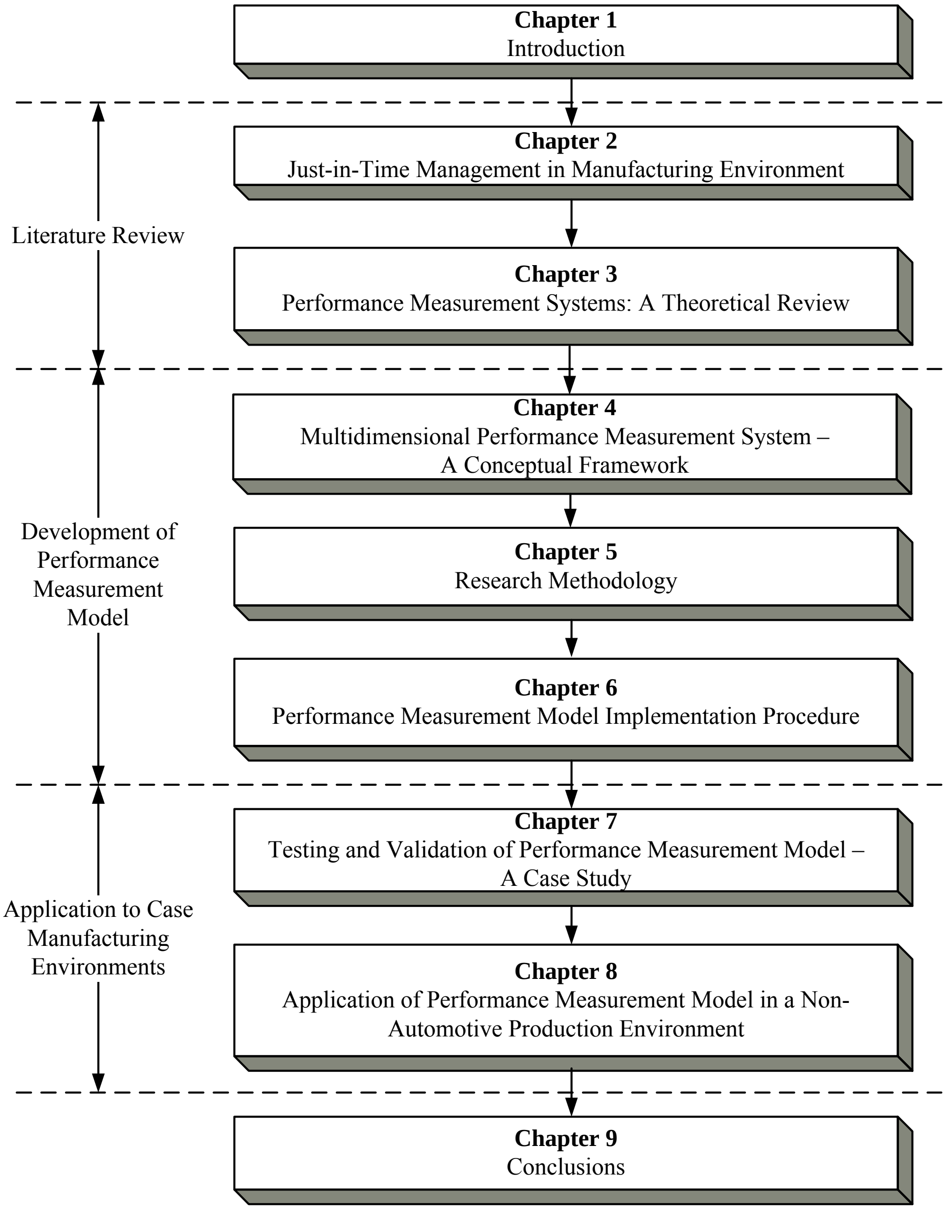

Chapter 1
Introduction
Chapter 2
Just-in-Time Management in Manufacturing Environment
Chapter 3
Performance Measurement Systems: A Theoretical Review
Chapter 4
Multidimensional Performance Measurement System – A Conceptual Framework
Chapter 5
Research Methodology
Chapter 6
Performance Measurement Model Implementation Procedure
Chapter 7
Testing and Validation of Performance Measurement Model – A Case Study
Chapter 8
Application of Performance Measurement Model in a Non-Automotive Production Environment
Chapter 9
Conclusions
Literature Review
Development of Performance Measurement Model
Application to Case Manufacturing Environments

Figure 1.2: Thesis Outline

1.7 SUMMARY

Chapter One of this thesis has presented an overview of the PhD research project. Emerging key issues in performance measurement in JIT enabled manufacturing environments have been reviewed and the need for a robust and multidimensional PMS has been discussed. This chapter also described the research aim and objectives and the research approach designed to achieve those objectives. The scope and limitations of the research and thesis outline have also been presented.

CHAPTER 2: JUST-IN-TIME MANAGEMENT IN MANUFACTURING ENVIRONMENTS

2.1 INTRODUCTION

Just-in-Time (JIT) philosophy of manufacturing management has received widespread attention over the last few decades and still plays a prominent role in the modern manufacturing era. JIT is also known as ‘Toyota Production System’ (TPS) and under the label ‘lean manufacturing’, the adoption of JIT become more widespread (Swamidass, 2007). One of the main priorities of JIT production is to understand JIT philosophy and its elements. This chapter, therefore, presents the history and definitions of JIT philosophy. It further describes JIT goals, i.e. pull production implementation, waste elimination and continuous improvement, and its practice in the UK. The JIT techniques that are identified from the literature review of a sample of 50 key research papers are discussed in detail. This chapter reviews the literature on pre-requisites of JIT implementation and Western and far Eastern socio-cultural impact on JIT performance. This chapter finally summarises benefits that can be gained from its implementation.

2.2 JUST-IN-TIME PHILOSOPHY

Abrahamson (1996 and 1997) described management philosophies such as JIT, Total Quality Management (TQM), quality circles, business process re-engineering, management by objectives, job enrichment, empowerment and downsizing as management ‘fashions’. Before Ford, most automobile plants fashion by master craftsmen and after Ford, the span of worker control was condensed, production was rationalised, efficiency soared and the world was put on wheels (Krafcik, 1988). Krafcik (1988) further argued that many of Ford’s principles are still valid and form the basis of Toyota Production System (TPS), which is later called just-in-time (JIT) manufacturing. JIT manufacturing has received widespread attention and has been widely reported on over the last few decades. The first article on JIT manufacturing was published in late 1970s (Keller and Kazazi, 1993). The JIT concept was founded in 1937 by Kiichiro Toyoda, whose basic thought was “just make what is needed in time, but not make too much” (Toyoda, 1987). The basic idea of JIT was brought in to high level of sophistication by Taiichi Ohno at the Toyota Motor Company in Japan and the JIT approach was first called Toyota Production System (Sohal, *et al.*, 1988). Krafcik (1988) compared characteristics of craftsmen, pure Fordism, recent Fordism and TPS and the comparison is given in Table 2.1.

Table 2.1: Comparison of Four Production System Characteristics (Adapted from Krafcik, 1988)

Characteristics	**Production System**			
	Craftsmen (1900 – Present)	**Pure Fordism (1920s)**	**Recent Fordism (1960s – Present)**	**TPS (1950s – Present)**
Work standardization	Low	High, by managers	High, by managers	High, by managers
Span of control	Wide	Narrow	Narrow	Moderate
Inventories	Large	Moderate	Large	Small
Buffers	Large	Small	Large	Small
Repair areas	Integral	Small	Large	Very small
Teamwork	Moderate	Low	Low	High

Close examination of above table reveals more similarities in pure Fordism and TPS (Krafcik, 1988). Massachusetts Institute of Technology's (MIT) International Motor Vehicle Program (IMVP) has been a world leader in the study of the competitive manufacturing practice such as TPS performed at global automobile industry. In *The Machine that Changed the World*, which presents the results of IMVP program, Womack *et al.* (1990) claimed that lean production would replace mass production of the twenty first century. Womack and Jones (1996) presentation on lean as a new, different and better concept simply covers up IMVP's failure to construct an explicandum, which tightly specifies the conversion advantage of the Japanese automobile industry (Williams, *et al.,* 1992). Oliver and Wilkinson, (1993) defined lean production as "a package of interrelated and mutually supportive set of manufacturing practices capable of delivering Japanese levels of manufacturing performance anywhere in the world, if implemented correctly". Fullerton (2003) identified JIT, TQM and cellular manufacturing as lean manufacturing strategies and Shah and Ward (2003) mentioned that lean production is a multi-dimensional approach that integrates a wide variety of management practices such as JIT, quality systems, cellular manufacturing and supplier management.

Some authors argue that JIT is a philosophy of production management and others claim it is only a concept (Keller and Kazazi, 1993). According to Keller and Kazazi (1993), one of the major problems in the literature is the lack of consensus concerning the interpretation and meaning of JIT implementation. The interpretation and definition of JIT has varied based on the authors' background and the different collection features (Ramarapu, *et al.*, 1995).

JIT manufacturing is a philosophy of operations management based on planned elimination of all waste for the purpose of cost reduction and continuous improvement of quality, productivity and customer satisfaction. Ohno (1982) defines JIT as:

> "Having the right part at precisely the right time, and in the right quantity, to go into assembly."

Schonberger (1982a) defines JIT as:

> "Produce and deliver finished goods just-in-time to be sold, sub assemblies just-in-time to be assembled into finished goods, fabricated parts just-in-time to go into the sub assemblies and purchased materials just-in-time to be transformed into fabricated parts."

Chakravorty and Atwater (1995) claims:

> "The core of JIT philosophy is continuous improvement through the elimination of waste."

APICS (1992) provides a broad definition of JIT manufacturing as:

> "A philosophy that encompasses the successful execution of all manufacturing activities required to produce a final product, from design engineering to delivery and including all stages of conversion from raw material onwards. The primary elements include having only the required inventory when needed; to improve quality to zero defects; to reduce lead time by reducing setup times, queue lengths and lot sizes; to incrementally revise the operations themselves; and to accomplish these things at a minimum cost."

Voss and Robinson (1987) developed comprehensive definition to JIT concept as:

> "A production methodology which aims to improve overall productivity through the elimination of waste and which leads to improved quality. In the manufacturing/assembly process JIT provides for the cost-effective production and delivery of only the necessary quality parts, in the right quantity, at the right time and place, while using a minimum of facilities, equipment, materials and human resources. JIT is dependent on the balance between the stability of the users' scheduled requirements and the suppliers' manufacturing flexibility. It is accomplished through the application of specific techniques which require total employee involvement."

More recently, Heizer and Render (2004) defined JIT as:

> "A philosophy of continuous and forced problem solving that supports lean production, driven by the 'pull' of the customer's order."

JIT involves a series of operating concepts and techniques that identifies operational problems systematically, finds solutions and corrects problems so that defects are never sent to the next process. The main objective of JIT is to supply the right materials at the right time in the right amount at each step of the production process in the most economical manner. It covers all activities of the production system, from the design of the product through production to delivery to the customer (White and Ruch, 1990).

Most of the Japanese companies traversed a productivity and quality improvement path, which encompassed TQM philosophy (Vuppalapati, *et al.*, 1995). Quality concepts are promulgated by American quality gurus such as Edwards Deming, Joseph Juran and Philip Crosby, who aggressively seek to improve product quality by eliminating causes of product defects and make quality an all-encompassing organisational philosophy (Charantimath, 2006). Vuppalapati, *et al.*, (1995) mentioned that JIT was integrated by Japanese companies into an already developed framework of TQM philosophy. According to Vuppalapati, *et al.* (1995), these strategies were deciphered by the Western countries in a reverse sequence, first JIT and then TQM. Empirical study of Powell (1995) found success of TQM critically depends on executive commitment, open organisation and employee empowerment, and less upon benchmarking, training, flexible manufacturing, process improvement and improved measurement.

Ahmed *et al.* (1996) mentioned, JIT production methods, TQM, manufacturing cells, flexible manufacturing systems, concurrent engineering, computer networking with suppliers and customers and benchmarking as operations strategies that are commonly used to enhance organisational performance. Best practice is one of the paradigms in manufacturing strategy and recent best practice literature has included JIT manufacturing, which has evolved into lean production (Voss, 1995). In contrast, Hayes and Pisano (1994) argued that managers tend to view JIT, TQM and lean production as solutions to specific problems and therefore, they are not manufacturing strategies. However, the empirical study of Ahmed *et al.* (1996) found that companies using any operations strategy have higher performance than those not using them. Data further suggest a consistently progressive relationship between the number of operations strategies and firm performance.

Many studies have suggested that JIT, TQM and Human Resource Management (HRM) are inter-related and internally consistent practices. Flynn, *et al.* (1995) divided relevant JIT practices into three groups: unique JIT practices (i.e. kanban, lot size reduction practices, JIT scheduling activities and setup time reduction practices), unique TQM practices (i.e. statistical process control, product design and customer focus) and infrastructure practices (i.e. information feedback, plant environment, management support, supplier relationship and workforce management). They proposed that TQM practices would improve JIT performance through process variance reduction and reduced rework time and that JIT practices would improve quality through problem exposure and improved process feedback. TQM practices are considered as pre-requisite for effective use of JIT. Fullerton (2003) observed that JIT firms use significantly more TQM tools to evaluate their performance than non-JIT firms.

The research study of Swamidass (2007) confirmed that in industries using JIT/TPS practices, top performing firms have greater success with inventory reduction than bottom performers and concluded that in the JIT era, inventory is associated with overall firm performance. Laugen *et al.* (2005) found that high and low performing organisations differ in terms of implementation “width” and “depth” of action programmes. Moreover, Laugen *et al.* (2005) identified that high performing organisations implement more concepts compared to low performers and more committed to continue implementing the programmes even if the results are long term. The authors further found the combination of process focus, pull production, equipment productivity and environmental capability has a significant positive effect on performance.

While many Japanese manufacturers achieve expected benefits from JIT implementation, most of the Western manufacturers have been unable to achieve the same level of success. Several scholarly journals in the last decade have published a number of articles focusing on the implementation of JIT techniques and their impact on performance in both JIT and non-JIT manufacturing plants (Sarkar and Fitzsimmons, 1989, Brox and Fader, 2002 and Fullerton, 2003). However, most of the empirical studies examining the relationship between JIT drivers and performance were unable to examine the extent to which they are generic (Huson and Nanda, 1995, White *et al.*, 1999, Callen *et al.* 2000, Fullerton *et al.*, 2003 and Laugen *et al.,* 2005).

2.3 KEY PRINCIPLES OF JIT

According to the Swamidass (2007), organisations experienced various benefits by implementing JIT based on twin foundations of waste reduction and continuous improvement. Womack and Jones, 1996, Brox and Fader, 1997, Voss and Blackmon, 1998 and Standard and Davis, 2001 identified the philosophy underlying JIT is 'continuous improvement' by implementing 'pull production' and 'eliminating all kind of wastes'. Accordingly, JIT is a production management system and a simple philosophy applied through three principles (Figure 2.1).

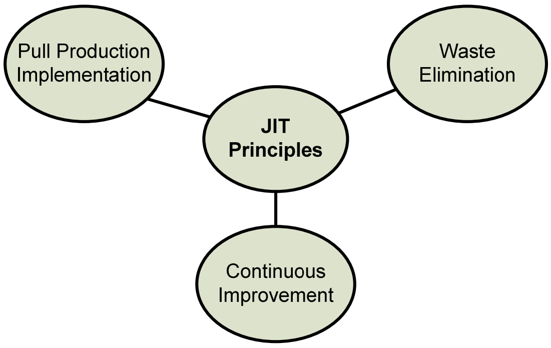


Figure 2.1: JIT Principles

2.3.1 Pull Production

Traditional push manufacturing systems pushed parts from one process to the next or to the market regardless of demand, and production was usually driven by forecast (Brox and Fader, 1997). This approach was used to maintain buffer stocks to avoid workers becoming idle when the preceding production process broke down. Push systems work well in environments where there is a high customer demand and in effect where there is a need to hold buffer stocks to cover customer demands, distributing system demands, and the supplier demands (Standard and Davis, 2001). Pull systems on the other hand, signal the replacement of parts, as they are needed (Funk, 1995). The chain starts from the customers and travels down towards the material suppliers. This is different from the push system, which consists of the different production processes having different production schedules. Each process produces the parts in accordance to its schedule and supplies or pushes its products to the following process. Laugen *et al.* (2005) found companies that have achieved a high degree of performance improvement in flexibility-speed-cost have implemented pull production with process focus, equipment productivity and environmental compatibility. Standard and Davis (2001) compared pull and push systems and listed characteristics of pull systems as follows:

- consumption-based replenishment control systems
- not zero inventory systems
- have finite buffers, in a serial production routing, while push systems have infinite buffer capacity
- control work in progress and throughput as observed production parameter
- not order driven; but consumption driven. Push systems, on the other hand, can be driven either by orders or forecasts
- closed queuing network and incoming material does not enter the system until outgoing material has exited

Standard and Davis (2001) argued that some managers are reluctant to implement pull systems because adopting pull production control takes managers to look beyond the efficiency of a single process or department and make decisions that are more profitable for the operation overall. One of the greatest strengths of pull production control is its robustness. It is able to identify where bottlenecks exist in an operation as a result of inventory accumulation at that point.

2.3.2 Eliminate Waste (Muda)

JIT in another perspective is a philosophy that encourages an organisation to remove all types of waste, which are associated with time and materials. In particular, this relates to the reduction or elimination of lead-time and inventory in all parts of the information processing and physical systems (Mazany, 1995). Waste is anything that does not add value to a product. It includes all inefficiencies in a system as well as causes of these inefficiencies and also called as ‘muda’ (Womack and Jones, 1996). This is a fundamental concept of lean manufacturing and one of the most efficient ways of improving performance and profitability of a company. The starting point of continuous improvement is to identify waste. Taiichi Ohno (1988) identified seven types of wastes: over-production, waiting, transportation, processing, storage, motion and making defective products. Womack and Jones (1996), similar to Ohno, outlined seven types of waste (Table 2.2).

Table 2.2: Seven Types of Waste (Adapted from Womack and Jones, 1996)

Waste / Muda	Definition
Defects	Mistakes which require rectification
Over production	Production of items no one wants
Unnecessary processing	Processing steps which are not actually needed
Unnecessary motion	Movement of employees and goods without any purpose
Delays	Waiting time due to shortage, maintenance, instruction, material, etc.
Excess inventory	Inventories and remaining goods pile up
Rejections	Goods which do not meet the customer needs

All aforementioned types of waste lead to production inefficiencies, loss of money and ultimately customer dissatisfaction. Chu and Shih (1992) developed a framework for JIT production systems with an objective of waste elimination and associated innovative concepts/technologies (Figure 2.2).

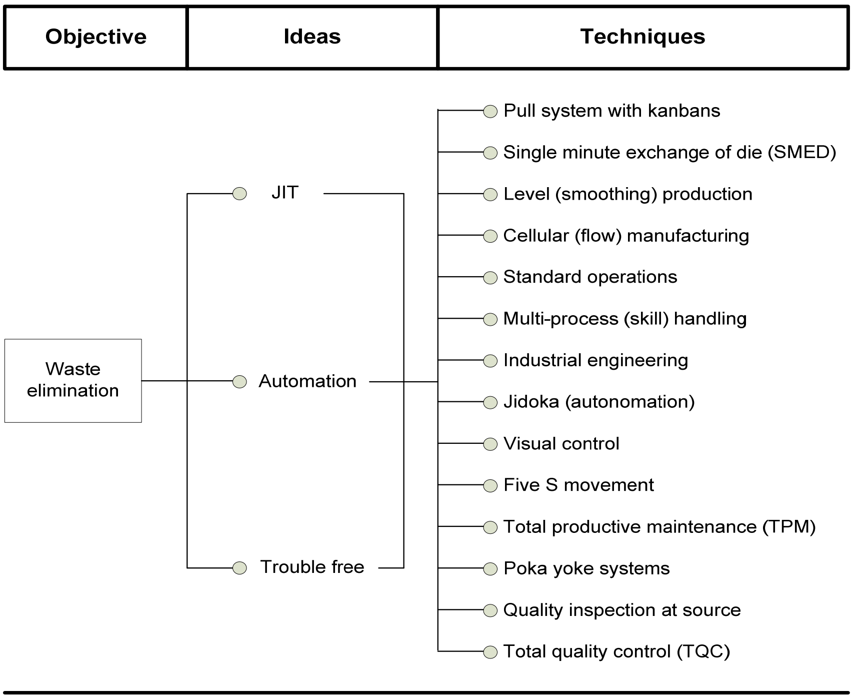

Objective
Ideas
Techniques
Waste elimination
JIT
Automation
Trouble free
Pull system with kanbans
Single minute exchange of die (SMED)
Level (smoothing) production
Cellular (flow) manufacturing
Standard operations
Multi-process (skill) handling
Industrial engineering
Jidoka (autonomation)
Visual control
Five S movement
Total productive maintenance (TPM)
Poka yoke systems
Quality inspection at source
Total quality control (TQC)

Figure 2.2: Framework of JIT Production Systems (Adapted from Chu and Shih, 1992)

Brox and Fader (2002) found that cost savings are generated primarily through scrap reduction and production process improvement. In addition, defect reduction and decline in product returns reduce the need for resources-intensive customer service. Therefore, systematic elimination of waste is a cornerstone of JIT manufacturing.

2.3.3 Continuous Improvement (CI)

JIT implementation in another context is not a one-off effort; it embodies the ethics of continuous improvement (CI), which needs to be supported by staff at all levels in the production team (Voss and Robinson, 1987, Chakravorty and Atwater, 1995 and Fernando and Luis, 2002). Kaizen is another name for CI, and it is a philosophy of never ending improvement and continually striving to be better through learning and problem solving (Ramarapu *et al.,* 1995). Experts such as W. E. Deming and M. Juran introduced various tools that help elevate Kaizen to new heights in Japan in late 1950s (Charantimath, 2006). The essence of CI is that workers not only produce, but they also improve on their production process. A well planned program of Kaizen can be broken into three segments: management oriented kaizen, group oriented kaizen and individual oriented kaizen (Charantimath, 2006). The Japanese management generally believes that a manager should spend at least 50% of his time on improvement activities. Group oriented Kaizen is represented by small group activities such as quality circles. The suggestion system is an integral part of individual oriented Kaizen. There are two approaches that can help companies with CI: (1) Plan-Do-Check-Action (PDCA) cycle and (2) Benchmarking (Bond, 1999).

1. *PDCA Cycle*

Dr. Edward Deming was the first American quality expert to teach Japanese managers methodically about quality and propounded the plan-do-check-act cycle (Charantimath, 2006). PDCA cycles (Figure 2.3) start with planning the improvement process by looking at what can go wrong and providing solutions for those problems.

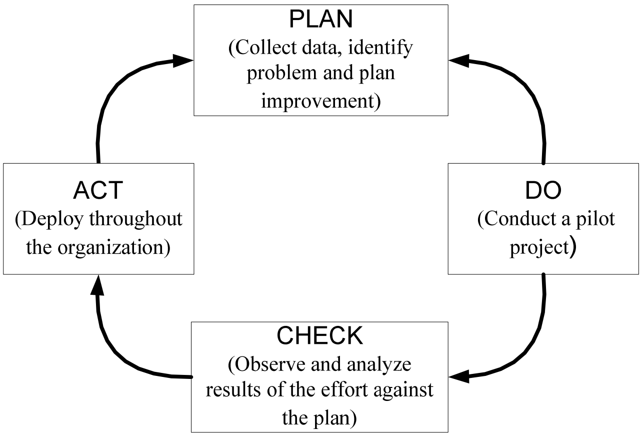

PLAN
(Collect data, identify problem and plan improvement)
DO
(Conduct a pilot project)
CHECK
(Observe and analyze results of the effort against the plan)
ACT
(Deploy throughout the organization)

Figure 2.3: PDCA Cycle

PDCA is a process through which standards are set only to be challenged, revised, and replaced by better standards (Charantimath, 2006). The process of stabilisation is often called as SDCA (standardise-do-check-action). Moreover, Hoshin Kanry is a strategic decision making tool that uses a PDCA cycle to create business objectives, assign measurable milestones and assess progress against milestones. Hoshin Kanry is commonly known as policy deployment.

2. *Benchmarking*

In manufacturing industry, the process of gathering information about other companies is called industrial espionage or industrial intelligence, and in the quality world, it is called benchmarking (Charantimath, 2006). Benchmarking involves studying business practices of other companies for the purposes of comparison. The result of this process becomes the cornerstone of the CI. Standard benchmarking terms include strategic benchmarking, performance benchmarking, process benchmarking, functional benchmarking, internal benchmarking, external benchmarking and international benchmarking.

2.4 JIT PRACTICE IN THE UNITED KINGDOM

Following successful implementation in Japan, JIT began to receive increasing attention in the West during the 1980s. In the 1970s, Japanese companies started to invest in UK manufacturing industry (Oliver and Wilkinson, 1993) and UK manufacturers were expected to gain the knowledge of Japanese technology and style of management through those investments. Other reasons for overseas investments are the need to be close to local markets and in touch with local needs and demands, economic friction between Japan and its export-destination countries, very tight labour markets and relatively high wages, and high Yen crisis in late 1990s (Oliver and Wilkinson, 1993). Interest in Japanese practice has been motivated by the publication of *The Machine that Change the World,* which revealed a 2:1 superiority in productivity and quality between Japanese and Western car assembly plants (Womack *et al.*, 1990). Voss and Robinson (1987) stated that while the UK has shown both a high level of awareness and understanding, only 10% of businesses studied had "major" JIT programs. They also found that 57% of a sample of 123 companies was either implementing or intended to implement some aspects of JIT. Voss and Robinson also reported that core JIT techniques such as "kanban", "cellular manufacturing", "statistical process control" and "zero-defects" had the lowest rating for actual and planned implementation in the UK. They observed that, "where manufacturing practitioners were attempting to implement JIT, most of them selected just a subset of JIT techniques suggesting that companies focused on easy to implement techniques rather than those giving the greatest benefits". These findings were confirmed by the study of Clode (1993), where he concluded that although many companies claim to have instituted a JIT policy, few have plans for full implementation and most have implemented only parts of the JIT philosophy. Voss and Robinson (1987) concluded that some UK companies had successfully implemented aspects of JIT practices.

According to the survey of Gathang (cited in Keller and Kazazi, 1993), companies were utilising some JIT techniques, but had failed to adopt JIT totally. He further noted that it might be the result of a misunderstanding of JIT by management due to the variety of definitions available. Sceptics question whether JIT can be transplanted effectively in the West because of substantive differences between Western and Japanese cultures. Other factors such as relationships with suppliers and clients, workers attitudes, management styles, business behaviour and the economical and political status of the country have a great influence on effective implementation. Literature suggests a change in corporate culture, organisation structures, employee involvement, worker flexibility, education and training in Western companies will ensure higher performance and productivity (Walleigh, 1986, Im and Lee, 1989 and Nakamura *et al.*, 1998).

Both manufacturing firms and retailers have reduced their inventories through lean operations (Swamidass, 2007). However, Chen *et al.*, (2005 cited in Swamidass, 2007) report that while the median for raw materials, finished goods and total inventory days drop, the mean actually rise between 1981 and 2000 in USA. According to Swamidass (2007), "inventory is a function of many variables and takes considerable skill to reduce inventories consistently".

Billesbach *et al.* (1991) and Procter (1994) used official statistical data to prove the impact of JIT on three categories of inventory levels (i.e. materials and fuel, work in progress, and finished goods inventory ratios) of manufacturing in the UK. Figure 2.4 is the most up-to-date graph for the trend of aforementioned inventory ratios between 1970 and 2005. The figure shows that since the 1980s, there has been a steady decline in all inventory ratios. Procter (1994) speculated that constant or increasing stock levels up to 1982 might be taken as evidence that JIT had not been introduced and the decline beyond 1982 might be due to the introduction of JIT. Procter (1994) also argued that whatever factors were driving the decline between the early 1980s and 1990s have lost their force and that the benefits in terms of reduced inventory offered by JIT manufacturing have been exhausted. This is perhaps confirmed by the work in progress and finished inventory ratio figures, which have been varying considerably since 1995. However, falling inventory levels might also be ascribed to concepts other than JIT, such as lean manufacturing, quick response manufacturing.

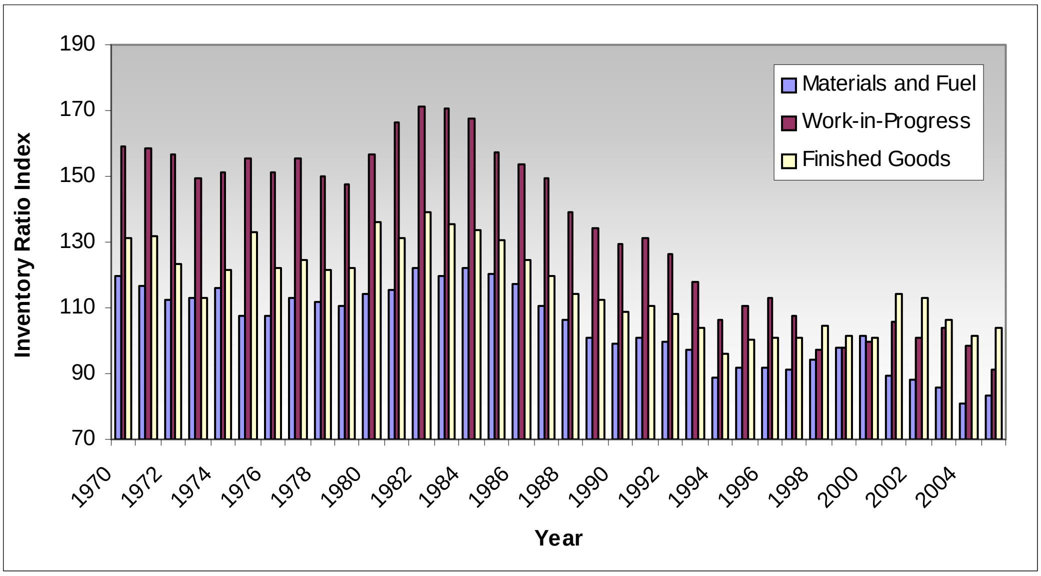


Figure 2.4: Indices of Ratios of Manufacturers' Inventories to Production in UK, 1970 – 2005 (Reference Year 2003 = 100) (National Statistics, 2006)

The above findings are in agreement with the output of the UK manufacturing industry during 1970 – 2005. As shown in Figure 2.5, there has been steady growth in manufacturing output since 1982, which might be due to the introduction of JIT philosophy.

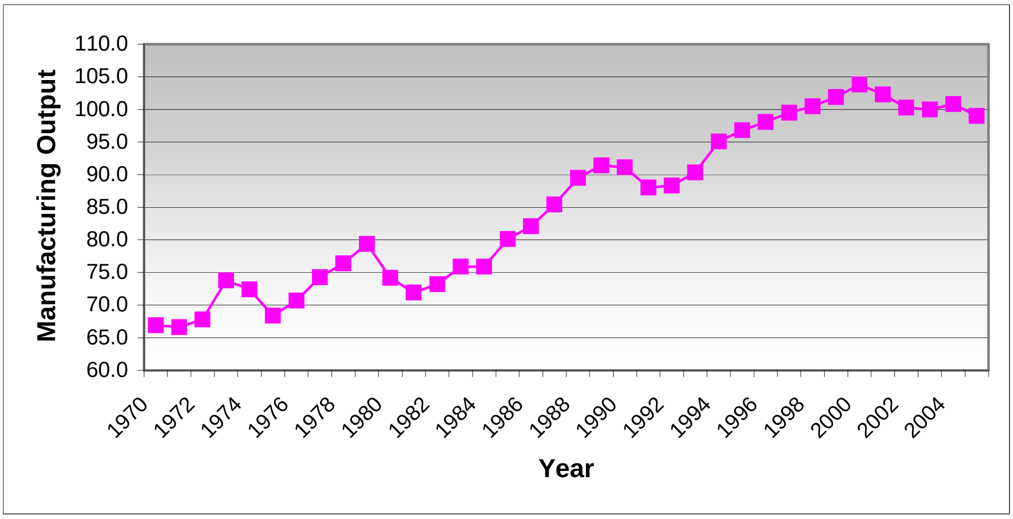


Figure 2.5: Output of Manufacturing Industry in UK, 1970 – 2005 (Reference Year 2003 = 100) (National Statistics, 2006)

Billesbach *et al.* (1991) emphasised that there is strong evidence that the implementation process in both the UK and US companies is not as efficient and effective as it could be. Further, empirical studies that examine the JIT techniques and their impact on plant performance have reported mixed results.

Selection and implementation of suitable JIT tools and techniques are therefore, paramount to achieving the goals of JIT philosophy (refer to Section 2.3). Hence, there is a need to reconsider JIT techniques and continuous improvement processes in manufacturing environments in order to maintain sustainable competitive advantage and survival in the 21st century.

2.5 ELEMENTS OF JIT

JIT is used as an umbrella term to refer to a package of techniques (Oliver and Wilkinson, 1993). Past researchers cited an array of techniques that can be included under the JIT umbrella. This research study is analysed only a sample of 50 key research papers among hundreds of papers written on JIT techniques. A review of the 50 key research papers that discussed JIT techniques and especially their impact on the production performance in manufacturing environments is presented in Table 2.3. The techniques that were reported at least three times among the selected key research papers were considered for this analysis. The JIT techniques have been sorted in descending order of frequency of citation in the selected literature. It helped to identify most and least frequently cited JIT techniques in key literature.

A total of twenty (20) JIT techniques were extracted from the literature and listed in Table 2.3. Given the ambiguity surrounding the terminology used by the different authors, best judgement has been used in grouping the JIT techniques analysed and presented in the table (refer to Sections 2.5.1 to 2.5.20 for definitions and detailed descriptions). For example, terms such as 'cellular manufacturing' and 'machine integration' are classified under 'group technology', and 'uniform work load' under 'level schedules' (Keller and Kazazi, 1993 and White and Prybutoc, 2001). Therefore, some of the variables are not mutually exclusive (Ramarapu *et al.*, 1995).

Table 2.3: Literature Summary of JIT Techniques

JIT Techniques	Sources (Reference shown below)																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Pull system (Kanban)	X	X			X		X	X	X	X	X	X			X		X	X	X	X					X
Multifunction employee	X	X			X		X	X	X	X	X	X				X	X	X	X	X				X	X
Group technology	X			X	X		X	X	X	X	X	X				X			X	X	X	X		X	X
Quality control activities	X	X		X	X		X	X	X		X	X				X		X	X	X				X	
Setup time elimination plans	X	X			X		X	X	X	X	X	X				X	X	X		X	X			X	
TPM	X				X		X	X	X		X	X				X				X				X	X
Quality circles	X				X		X	X	X	X	X												X		X
Level schedules	X		X	X	X		X	X	X		X			X	X									X	X
Focused factory	X	X			X		X	X	X										X	X	X				
Employee training	X	X		X	X		X	X	X	X		X				X		X							
Integrated product & process design							X	X	X			X	X			X		X		X				X	
Line balancing	X				X	X	X	X	X						X	X			X	X					X
JIT purchasing		X										X	X							X	X				X
Supplier integration	X	X		X	X		X	X	X		X		X			X									
Workplace organization plan		X									X	X						X						X	X
Effective comminication		X								X		X						X							
Inventory transportation system	X				X		X	X	X																
Innovation and investment plans																X				X					
Value analysis																X									
Other control techniques																				X					

References (Refer to References & Bibliography for further details)

[1] (Ahmad *et al.*, 2004) [2] (Ahmad *et al.*, 2003) [3] (Aigbego and Monden, 1997) [4] (Alles *et al.*, 2000) [5] (Brox and Fader, 1996, 1997, 2002) [6] (Bukchin, 1998) [7] (Callen *et al.*, 2000)
[8] (Callen *et al.,* 2001) [9] (Callen *et.al*, 2002) [10] (Cheng, 1990) [11] (Crowford and Cox, 1991) [12] (Cua, *et al.*, 2001) [13] (Dong *et al.*, 2001) [14] (Drexl and Kimms, 2001)
[15] (Estrada *et al.*, 1997) [16] (Fawcett and Myers, 2001) [17] (Fernando and Luis, 2002) [18] (Flynn, *et al.,* 1995) [19] (Fullerton and McWatters, 2001) [20] (Fullerton *et al.*, 2003)
[21] (Funk, 1995) [22] (Gravel *et al.*, 2000) [23] (Gray, 1993) [24] (Hall, 1987) [25] (Im and Lee, 1989)

Contd...

Contd .....

JIT Techniques	Sources (Reference shown below)																									
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	Total
Pull system (Kanban)		X	X	X	X	X	X	X	X	X		X		X	X		X	X		X	X	X	X	X		34
Multifunction employee		X					X	X		X		X		X			X	X	X	X	X	X	X			29
Group technology	X	X	X	X						X		X						X	X	X	X	X	X			28
Quality control activities		X					X	X		X		X		X	X	X	X	X		X	X	X	X			28
Setup time elimination plans		X	X	X			X	X							X		X	X	X	X	X	X	X			28
TPM		X	X	X			X	X		X		X			X	X	X	X	X	X	X	X	X			27
Quality circles	X	X								X				X	X	X	X	X		X	X	X	X			21
Level schedules	X	X	X	X			X					X						X							X	20
Focused factory	X	X								X	X							X		X	X	X	X			18
Employee training	X	X										X		X	X				X							17
Integrated product & process design		X					X	X		X				X	X		X	X								17
Line balancing		X																X		X	X	X	X			17
JIT purchasing		X		X			X										X	X	X X	X	X	X	X			16
Supplier integration		X	X				X	X						X					X							16
Workplace organization plan		X					X	X						X	X		X									12
Effective comminication	X	X					X							X	X				X							10
Inventory transportation system		X					X																			7
Innovation and investment plans										X		X	X													5
Value analysis							X							X												3
Other control techniques		X												X												3

References (Refer to References & Bibliography for further details)

[26] (Mazany, 1995) [27] (McLachlin, 1997) [28] (Nakamura *et al.*, 1998) [29] (Norris, 1992) [30] (Pheng, 1992) [31] (Pheng and Chuan, 2001) [32] (Prasad, 1995a, b) [33] (Sakakibara, *et al.*, 1997) [34] (Savsar, 1996) [35] (Shah and Ward, 2003) [36] (Skinner, 1974) [37] (Spencer and Guide, 1995) [38] Swamidass and Nair (2004) [39] (The Society of Management Accountants in Canada, 1993) [40] (Voss, 1984) [41] (Voss and Blackmon, 1998) [42] (Voss and Robinson, 1987) [43] (Vuppalapati, *et al.*, 1995) [44] (Wafa and Yasin, 1998) [45] (White and Ruch, 1990) [46] (White, 1993) [47] (White, *et al.*, 1999) [48] (White and Prybutok, 2001) [49] (Yuvuz and Satir, 1995) [50] (Zeramdini *et al.*, 2000)

According to the above review, kanban and pull system, multifunction employee, group technology, quality control activities, setup time elimination plans, TPM, quality circles and level schedules are the most frequently addressed JIT techniques. Those techniques are cited more than 20 times among the selected 50 research papers. Techniques such as focused factory, employee training, integrated product and process design, line balancing, JIT purchasing, supplier integration, work place organisation plans, effective communication and inventory transportation systems are moderately reviewed whereas innovation and investment plans, value added analysis and other control techniques are less frequently reported in the past literature. JIT techniques that are cited less than five times are categorised under least frequently cited techniques. Aforementioned categorisation was motivated by author's desire to keep the three groups very distinct from each other.

Value analysis and innovation and investment plans are emerging JIT practices that do not currently represent key JIT techniques, but may develop into that direction. Swamidass and Nair (2004 cited in Swamidass, 2007) report that JIT innovations emerge as a strong performance enhancing tool at the shop floor level, as well as at the business level. Despite the apparent lack of convergence of innovation and investment plans, value added analysis concept and other control techniques, they are classed as extremely essential aspects of JIT manufacturing. A review of these techniques now follows.

2.5.1 Pull System - Kanban

The term "kanban" is a Japanese word originating from a type of card used in signalling for supplies in Japanese production plants. It involves a scheduling strategy aimed to achieve organised operations by means of a pull system. White and Ruch (1990) stated that "the kanban system is often presented in the literature as being synonymous with JIT, however it should be clearly understood that kanban represents only the production and inventory control system". Voss and Robinson (1987) and Flynn *et al.* (1995) indicated that the use of kanban is not necessarily critical for improved performance. Flynn *et al.* (1995) further mentioned that "strong management support for the use of JIT practices can serve as a surrogate for kanban; conversely, in the absence of strong management support for JIT, the use of a kanban can help compensate". Monden (1994) presented simple formulas to determine the number of kanbans for the various JIT systems. Subsequently, several researchers such as Fallon and Browne (1988), Savsar (1996), Gupta and Al-Turki (1998) and Fernando and Luis (2002) used simulation and modelling to formulate mathematical models in order to calculate the number of kanbans or to investigate the impact of kanban on manufacturing performance in various manufacturing conditions. However, to most companies, kanban is a visual signalling system rather than production control system.

2.5.2 Multifunction Employee

The most salient feature of the lean/JIT organisation is the extensive use of multifunctional teams and the aim is to have employees who are able to perform more than one task in the team (Ramarapu *et al.,* 1995). It is generally believed that less multifunctional employees may act as a barrier to JIT implementation. Multifunctional ability can be achieved through extended cross training of employees on several different machines and in various functions (White and Ruch, 1990 and White *et al.*, 1999). It avoids labour idleness, creates flexibility for adaptation to demand changes and improves productivity (Voss and Robinson, 1987 and White and Ruch, 1990). Multifunction employee supports group technology, total quality control and TPM (White and Ruch, 1990). According to Voss and Robinson (1987) and White *et al.* (1999), multifunction employee is one of the most frequently used JIT techniques in the manufacturing industry and has been in practice for some time in production environments. Clode (1993) found that there is a high possibility for flexible practices to exist in the UK due to the informal nature of British Trade Union agreements.

2.5.3 Group Technology

Group technology examines products/parts and groups similar items to simplify design and manufacturing processes. White and Ruch (1990) state that "it includes activities such as sequencing similar parts or families of parts through the same machine; creating manufacturing cells to process one or several part families; coding of parts at the design stage for retrieval of previous designs and part standardisation;

and coding of raw materials, parts and components for purchasing in order to obtain statistics and other information not traditionally available". Group technology may also involve changes of physical facilities, i.e. cellular arrangements in the improvement effort (McIlhattan, 1987 and White *et al.*, 1999).

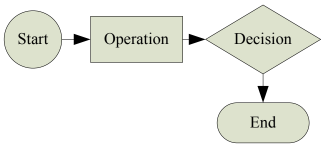
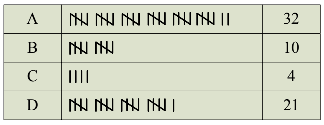
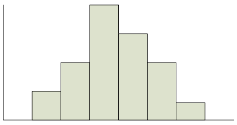
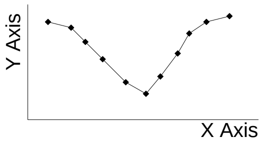
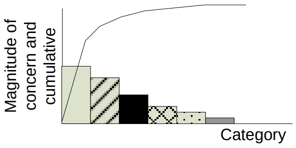
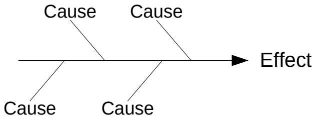
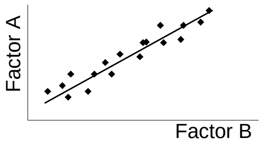
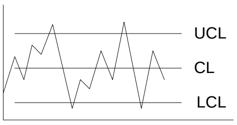
Moreover, group technology consists of breaking up two or more machines and merging them into an integrated machine. Akashi motorcycle plant in Japan had followed the group technology concept to physically merge the punch press and welding stages in the production of motorcycle frames and improved plant productivity and product quality (Schonberger, 1982b). Gravel *et al.* (2000) presented an interactive tool for designing manufacturing cells for an assembly shop and developed three diagrams illustrating (1) functional layout (2) hybrid cellular layout and (3) shared machines in hybrid shop. Group technology can be used to arrange physical layout of production process in order to minimise setup time, lead-time, inventory levels and non-value added activities and maximise quality and productivity.

2.5.4 Quality Control Activities (QC)

Another important step in JIT implementation is the adoption of quality control activities (Keller and Kazazi, 1993). White and Ruch (1990) stated that quality must be established as the first priority of the manufacturer's business objectives and all other objectives are driven by the quality objective. Quality control activities (QC) requires the cooperation of people and functions by focusing on quality at the source of the problem. The idea of "poke yoke" helps to identify areas where errors are likely to occur and introduce fail-safe devices to prevent the error. This is also described as "jidoka", "autonomation" or "automation with human touch". According to White *et al.* (1999) QC is one of the most frequently implemented JIT practices in large manufacturing organisations.

Implementation of statistical quality control (SPC) methods for defect prevention is an integral part of the total quality control program (White *et al.*, 1999). Table 2.4 shows eight basic SPC tools, which can be used in defect prevention exercises (Oakland, 2003).

Table 2.4: Basic Tools of SPC (Adapted from Oakland, 2003)

	SPC Basic Tools	**Diagram**	**Question to be Addressed**
1	Process Flowcharts		**What is done?** It is a pictorial representation describing a process being studied or even used to plan stages of a project.
2	Check Sheets	 A 32 B 10 C 4 D 21	**How often it is done?** Use to gather data on the number of occurrences of various issues, problems, inputs or outputs during specified time period
3	Histograms		**What does the variation look like?** Graphical representation of the nature of the distribution of data, the average and variability.
4	Graphs		**Can the variation be represented in a time series?** Visually track process variation over time.
5	Pareto Analysis		**Which are the big problems?** Based on Pareto principle, i.e. “80-20” rule, which states that a few causes are responsible for most of the effects.
6	Cause and Effect Analysis		**What causes the problem?** Graphical representation of relationship between causes and effect. Helps to identify root causes and measurable outcome.
7	Scatter Diagram		**What are the relationship between factors?** Graphical representation of positive/ negative/no relationship between two variables.
8	Control Charts		**Which variations to control and how?** Graphical representation of performance over time, which enables to detect out of control conditions.

2.5.5 Set-up Time Elimination Plans

The setting up of a machine is the preparation of the machine to manufacture a product and consists of changing the machine from a readiness to produce one product to another. Set-up time elimination plans lead to frequent lot sizes, uniform workload and effective utilisation of machines by reducing non-productive machine time, which is considered as muda (Funk, 1995 and Vuppalapathi *et al.*, 1995). Single Minute Exchange of Dies (SMED) is one methodology to systematically reduce setups from hours to nine minutes or fewer. A reduction of setup time is an important way of eliminating waste (Ramarapu *et al.,* 1995). According to the research carried out by White *et al.* (1999), set-up time elimination plan is one of the most frequently implemented JIT techniques amongst large and small and medium enterprises. White and Prybutoc (2001) reported that the setup time had the highest implementation rate in repetitive production systems compared to other systems.

2.5.6 Total Productive and Preventive Maintenance (TPM)

Total productive and preventive maintenance (TPM) applies rigorous and regularly scheduled preventive and corrective maintenance and machine replacement programs with an objective of eliminating any unplanned machine downtimes during the production process (Voss and Robinson, 1987, White and Ruch, 1990 and Norris, 1992). TPM used to eliminate wastes caused by equipments such as failures, unnecessary set-ups, adjustment times, idle times and minor stoppages. Based on the research findings, White *et al.* (1999) categorised TPM as another less frequently used JIT technique in small manufacturing organisations. Along with regular preventive maintenance, and constant cleaning and adjustment, machines last longer (Hayes, 1981).

2.5.7 Quality Circles

Quality circles started gaining recognition as part of a TQM philosophy for tackling quality-related problems (Sriparavastu and Gupta, 1997). Quality circles are a small group of employees formed for problem solving. White and Ruch (1990) pointed out that even though quality circles are often considered a subset of quality control, they go beyond the quality control concept in that they allow for employees to utilise their capabilities in solving non-quality problems. According to White and Prybutoc (2001), implementation of quality circles is more likely in repetitive production systems than intermittent systems.

Gray (1993) carried out a survey to investigate the current and past usage of quality circles in the US and concluded that there is a substantial difference between the approach and philosophy of TQM and that of quality circles. The comparison between TQM and quality circles is shown in Table 2.5. Although quality circles and TQM have some differences, most organisations have modified quality circles to fit the quality management approach.

Table 2.5: Comparison of Quality Circles to TQM (Gray, 1993)

Quality Circles	TQM
▪ Management control of the decision process	▪ Employee responsibility for decision process at the production or service level
▪ Internally focused on specific issues	▪ Continuous focus on quality and customer need
▪ Limited management involvement	▪ Total organisation management philosophy
▪ Short term orientation	▪ Long term orientation to continuous process and product quality improvement
▪ Intrinsic and extrinsic reward base	▪ Primarily intrinsic reward base

2.5.8 Level Schedules

Level scheduling is used to stabilise and smooth the production workload (uniform workload), to reduce upstream inventory swings and panic reactions to schedule demands in the manufacturing environment. JIT scheduling activities include mixed model scheduling and daily production scheduling to match demand (Flynn *et al.*, 1995). Monden (1994) identified two salient criteria for JIT assembly line level scheduling named (1) parts usage smoothing and (2) product load smoothing and Aigbedo and Monden (1997) developed two objective functions to optimise both aspects in a mixed-model assembly line. White and Ruch (1990) reported that production variation from the schedule should be ten percent or less each day and over several days of the master production schedule. Voss and

Robinson (1987) and White *et al.* (1999) indicated that level schedules are less frequently implemented in manufacturing organisations and White and Prybutoc (2001) research revealed that it has the lowest implementation rate in intermittent production systems.

2.5.9 Focused Factory

The focused factory technique is based on concepts such as simplicity, repetition, homogeneity of tasks and seeks to eliminate production inefficiencies, simplify the organisational structure and minimise the complexities involved in the manufacturing process (Skinner, 1974, White and Ruch, 1990 and White *et al.*, 1999). Skinner (1974) argued that a factory that focuses on a narrow product mix for a particular market niche would outperform the conventional plant, which attempts a broader mission. However, the fact that a factory produces multiple products does not necessarily imply that the factory is unfocused.

2.5.10 Employee Training

Training can provide employees with the skills needed to participate in the implementation of JIT techniques more efficiently and effectively. White *et al.* (1999) and Mazany (1995) mentioned that the increased interdependencies created among organisational sub areas with implementation of JIT require more open communication and decision making among employees; therefore substantial training could be required to develop the necessary employee skills, such as meeting, presentation, communication, problem solving, conflict resolution and negotiation. Billesback *et al.* (1991) found that US companies provide a greater range of training and education for their employees than do UK companies. Devaraj and Babu (2004) devised the Training Effectiveness Relationship Measurement (TERM) model and their study was mainly focused on the linkage between training effectiveness and on-the-job performance. Devaraj and Babu identified that the link between stream-specific performance and on-the-job performance is stronger than the link between generic performance and on-the-job performance. This stronger link might result because production processes always need more skill-specific capabilities than the generic capabilities.

2.5.11 Integrated Product and Process Design

Integrated product and process design aims to improve design characteristics using concepts such as design for manufacturability and reliability; inter-functional design efforts and new product quality efforts incorporating trial runs; extensive prototyping and design modifications prior to release to manufacturing (Flynn *et al.*, 1995). Chin *et al.* (2005) outlined the general inputs, outputs, controls and resources/mechanisms for the integrated product and process development task using IDEF0 (Integration Definition for Function Modelling) methodology as shown in Figure 2.6. However, they have not considered regulatory conditions and facilities available as controls and new concepts such as value engineering, dynamic simulation and multi-criteria decision making tools as mechanisms in designing an integrated manufacturing system for new product development.

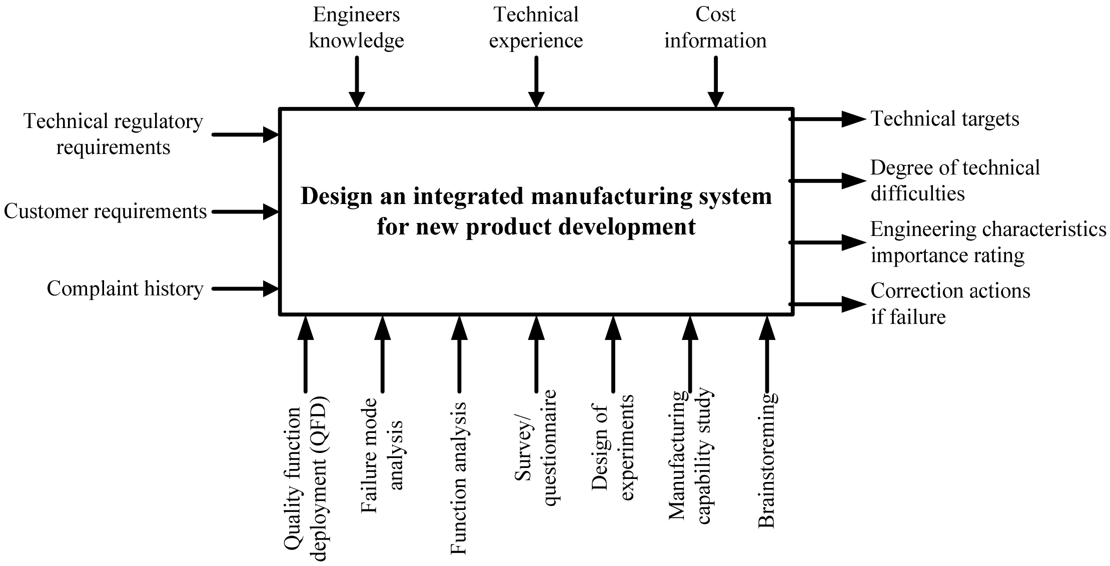

Engineers knowledge
Technical experience
Cost information
Technical regulatory requirements
Customer requirements
Complaint history
Design an integrated manufacturing system for new product development
Technical targets
Degree of technical difficulties
Engineering characteristics importance rating
Correction actions if failure
Quality function deployment (QFD)
Failure mode analysis
Function analysis
Survey/ questionnaire
Design of experiments
Manufacturing capability study
Brainstoreming

Figure 2.6: An Integrated Manufacturing System for New Product Development (Chin et al., 2005)

2.5.12 Line Balancing

Line balancing (line smoothing) is a method that balances and synchronises the production flow. According to Chakravorthy and Atwater (1995), balanced line achieves a lower cycle time, lead-time, takt time and total processing time than unbalanced lines. In an unbalanced assembly line, some sub-assembly stations tend to be heavily loaded with sub-assembly activities whereas other stations are lacking in activities with high idle times. Line smoothing can be easily achieved by identifying all sub-assembly activities at each station, taking stopwatch readings for each and every activity and distributing activities equally among stations. This technique increases flexibility and the multifunctional ability of employees. Bukchin (1998) identified that the balancing procedure is subject to constraints such as precedence, equipment, and the allocation of assembly times and tasks to stations.

2.5.13 JIT Purchasing

Just-in-time purchasing is the technique of receiving the right part in the right quantity at the right time from suppliers (White and Ruch, 1990 and Norris, 1992) and involves the procurement of quality materials meeting exact specifications via frequent, timely deliveries in small quantities (Kaynak, 2005). Kaynak (2005) research study findings suggested that just-in-time purchasing, regardless of the level of technical complexity, can improve a firm's performance in all dimensions. It can be achieved using supplier participation and partnership programs and involves suppliers in long-range mutually rewarding cost-reduction efforts, such as value analysis and the implementation of JIT practices (White *et al.*, 1999). Their survey findings reveal that the JIT purchasing is a practice that has been in operation for the shortest time compared to other practices in small manufacturing organisations. Dong *et al.* (2001) carried out an exploratory analysis to determine whether the use of JIT purchasing reduces costs for both suppliers and buyers and concluded that:

- Supply chain integration directly increases the extent of JIT purchasing
- There is no significant relationship between supply chain integration and buyer/supplier logistics cost
- The extent of JIT purchasing directly increases supplier use of JIT manufacturing
- The extent of JIT purchasing directly reduces buyer logistics costs but has no significant relationship with supplier logistics cost
- The extent of JIT manufacturing by the supplier directly reduces supplier logistics costs but has no significant impact on buyer logistics cost

2.5.14 Supplier Integration

Once JIT has been implemented in the company, it has a chain reaction on its suppliers. When orders from manufacturer fluctuate widely, suppliers are forced either to hold greater amounts of inventory or adopt JIT itself (Hall, 1989). Supplier integration encourages suppliers to deliver high quality products on a JIT basis, deliver on short notice on time in the most economical manner and to establish long-term mutually supportive relationships. The use of certified suppliers and long-term supplier relationships based on quality criteria can be used to reduce or eliminate pre-processing cycle time delays for incoming inspection (Flynn *et al.*, 1995 and Sriparavastu and Gupta, 1997). According to Laugen *et al.* (2005), supplier strategy does not currently represent best practice, but may develop into that direction. Furthermore, McLachlin (1997) suggested that supplier integration could include long term relationship with certified suppliers, encourage suppliers who can add value, little incoming inspection, help to improve suppliers' processes, active supplier audit and certification programme, suppliers' involvement with new product development and supplier selection based on quality rather than price. However Ahmed *et al.* (1991) suggest that some of the issues such as suppliers' proximity and the lead-time of the supplier, which have been traditionally considered to be important, are not major impediments to JIT implementation. Monczka and Morgan (1996) developed a framework for supplier integration in a manufacturing environment. According to their model, supplier input and participation may be sought at any point in the new product development and order fulfilment processes. Christensen *et al.* (2005) research study confirmed a positive relationship between JIT strategy and applied supplier supply chain knowledge. Although the researchers used a single narrow measure of performance (i.e. market performance), the research confirmed no relationship between applied supplier supply chain knowledge and market performance.

2.5.15 Work Place Organisation Plan

Eliminating storage facilities is one of the major objectives of JIT implementation. Materials have to be taken from storerooms and stored on factory floors. Factories should be well organised and floors, work areas and equipment should be clean and tidy. Problems become more visible when factory floors are organised and clean. 5 S is one of the latest practices used to establish and maintain a quality environment in an organisation and it includes techniques such as Organisation (*Seiri*), Neatness (*Seiton*), Cleaning (*Seiso*), Standardisation (*Seiketsu*) and Discipline (*Shitsuke*) (Gunasekaran and Lyu, 1997). However, Spencer and Guide (1995) suggested that the management of physical layout is not the primary reason for achieving flexibility benefits, although it is considered to be an important JIT technique.

2.5.16 Effective Communication

In JIT implementation, employees must be informed about projected changes through display boards, newsletters, meetings and open houses. The availability and feedback of information is certainly important in a JIT production environment when each station in a chain of manufacturing process is tightly linked with its previous and subsequent stations in order to determine production lot sizes and schedules (Cua *et al.*, 2001). More informal and formal communication links are needed between teams as production process complexity increases (Funk, 1995). Information and communication systems such as electronic data interchange (EDI), automated material handling equipments, hand-held data entry device, optical scanning, expert systems, barcodes, and robotics become critical in providing support for JIT (Spencer *et al.,* 1994 and Stank and Crum, 1997). Inaccurate or distorted demand for information created in the supply chain is described as bullwhip effect and the results are excessive inventories, ineffective transportation use, misused manufacturing capacities and lost revenue.

2.5.17 Fast Inventory Transportation System

Transportation of inventory is another source of waste that does not add any value to the product. It is therefore essential to reduce unnecessary motion of inventory in the manufacturing process. Fast inventory transportation system can be achieved using conveyors, rollers, cranes, hoists and auto guided vehicle systems, using standardised containers to transport component and forwarding incoming materials straight to the point of use. Fast inventory transportation systems reduce total cycle time and improve customer service by providing flexibility in meeting customer demands.

Callen *et al.* (2000) found that fast inventory transportation systems such as automated material handling systems are commonly implemented in the USA. According to Ramarapu *et al.* (1995), automating transport is fine, but eliminating the need for transport is far better. However, this JIT technique appears to have received less research attention.

2.5.18 Innovation and Investment Plans

Time-based competition is one of the recent trends and includes developing new products and services faster than the competition, reaching the market first and meeting customer orders most quickly (Reid and Sanders, 2005). Cua *et al.* (2001) found that manufacturing plants that invest in process technology are more likely to use manufacturing as a source of competitive advantage and excel on all performance dimensions. However, their survey shows that the general emphasis is on improvement and investment in new and advanced process technologies rather than equipment design and layout. Companies must constantly think about the next generation of technologies, which can be used to achieve the aim and objectives of JIT philosophy. Adams *et al.* (2006) proposed a framework for innovation management with seven categories, specified in terms of the requisite organisational capabilities to make and manage change. They further identified a series of measurement areas for each category as shown in Table 2.6.

Table 2.6: Innovation Management Measurement Areas (Adams *et al.*, 2006)

Innovation Management Model Category	Measurement Areas
▪ Inputs	▪ People, Physical and financial resources, Tools
▪ Knowledge management	▪ Idea generation, Knowledge repository, Information flows
▪ Innovation strategy	▪ Strategic orientation, Strategic leadership
▪ Organisation and culture	▪ Culture, Structure
▪ Portfolio management	▪ Risk/return balance, Optimisation tool use
▪ Project management	▪ Project efficiency, Tools, Communication, Collaboration
▪ Commercialisation	▪ Market research, Market testing, Marketing and sales

2.5.19 Value Added Analysis

JIT is a management philosophy with an aim of elimination of non-value added activities. Value added analysis is a holistic approach to eliminate all wastes from the whole supply chain using few resources and shortening the total manufacturing lead-time to enhance the value for the end customer. In value analysis, value is defined as Eq: 2.1 (Kermode, *et al.* 2000):

$$Value = \frac{Function\ cost}{Actual\ cost} \quad \text{...} \quad \textbf{Eq: 2.1}$$

Value analysis reveals and clarifies the product functions and then a creative effort improves the product as shown in Figure 2.7 (Kermode, *et al.* 2000).

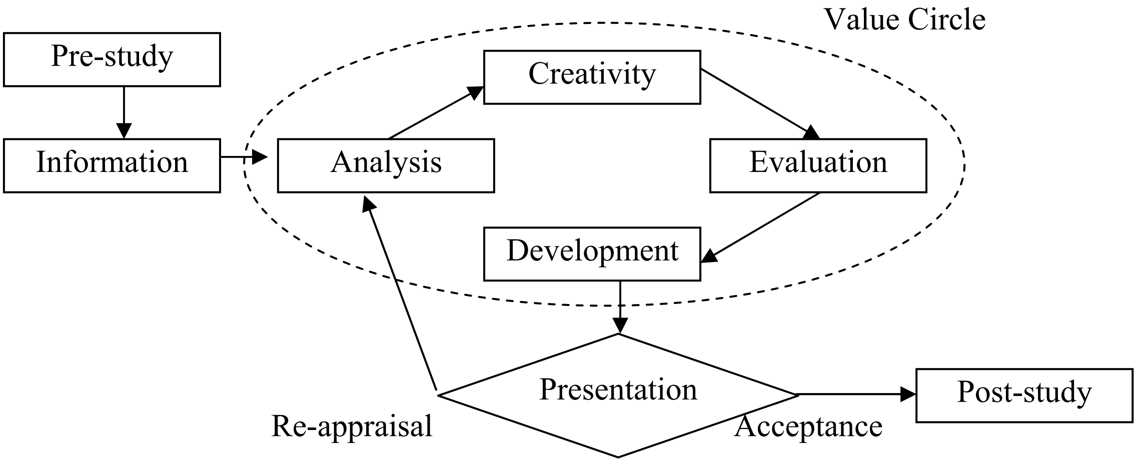


Figure 2.7: Interactive Value Analysis Job Plan (Kermode *et al.*, 2000)

The model outlines eight core steps of value analysis job plan. The purpose of each phase is as follows:

- *Pre-study phase*: Plan and prepare for the value analysis workshop
- *Information*: Gather complete, accurate information about the product
- *Analysis*: Gain a complete understanding of the product functions and identify areas for improvement
- *Creation*: Generate novel solutions for the targeted problem areas
- *Evaluation*: Select the most promising ideas for further development
- *Development*: Carry out embodiment design of the proposal for improvement
- *Presentation*: Gain the acceptance of management for the proposed changes
- *Implementation*: Implement the changes accepted during the presentation phase

Value added analysis is another recent trend, but less frequently investigated JIT technique in modern management research.

2.5.20 Other Control Techniques

Control techniques that are not covered under the previous techniques are discussed under other control techniques. Some examples include compensation systems, individual and organisation performance evaluation systems, accounting systems, capital appreciation systems, supplier selection procedures and bidding techniques (The Society of Management Accountants of Canada, 1993). Narrow job descriptions, incentives, piecework and compensation systems that are used in craft production are not appropriate for JIT. Pay for knowledge compensation plan is more suitable in JIT environment, where job descriptions are broad and employees are trained to perform multi tasks. On the other hand, traditional financial accounting systems no longer support performance measurement in JIT enabled manufacturing environments (Sandanayake and Oduoza, 2007). This drawback is further discussed in Chapter 3.

The 20 JIT techniques discussed above will be further classified into three inter-related and internally consistent categories in Chapter 4

2.6 PRE-REQUISITES OF JIT IMPLEMENTATION

Much research has been carried out to identify conditions that are critical to JIT success. While a fair number of Western firms have been successful with JIT implementation, other firms that could benefit appear to be addressing only a few features rather than the overall philosophy and system (McLachlin, 1997). Funk (1995) suggested that JIT manufacturing might not be equally applicable to all manufacturing industries. According to Billesback *et al.* (1991), UK companies tend to implement JIT using their own staff where as US companies outsource to specialists in the initial implementation stages. According to Oliver and Wilkinson, (1993), the successful implementation of JIT is seen primarily as a technical problem, requiring enhanced responsiveness and particularly precise coordination of the resources involved in the production process.

Most managers and entrepreneurs believe that JIT is the solution to all of their problems, which is not true in most situations (Hall, 1989). Further to Hall (1989), in fact, JIT creates more problems than it solves, if it is inappropriately applied. In the analysis of the underlying causes for JIT success, Crawford and Cox (1991) proposed 12 requirements for successful implementation of JIT philosophy. Crawford *et al.* (1988) classified problems associated with JIT implementation into two broad categories; people and technical problems. Here, people problem were categorised into cultural resistance to change, lack of resources, lack of top management understanding and commitment, improper PMS and inadequate communication systems. Technical problems were classified as inability to meet schedule, poor quality, lack of vendor support, poor forecasting, data inaccuracy and machinery breakdown.

JIT implementation depends on how critical is the need for change, how healthy is the organisation and the resources required for change. According to Galbraith (1977), the success of implementation of management practices such as JIT frequently depends upon organizational characteristics. The size of the organisation and type of manufacturing process employed affects the number of JIT techniques adopted by the organisation. The type of planning and production control system also affects the JIT adoption process (White and Ruch, 1990). The size of plant and its capacity, choice of equipments, plant layout, production process, production scheduling system, inventory control system, employee behaviour and organisational structure also have great influence on JIT implementation. The model developed by Funk (1995) hypothesised the relationship between logistical complexity, the importance of JIT manufacturing and the most appropriate organisational structure for implementation of JIT manufacturing systems (Figure 2.8).

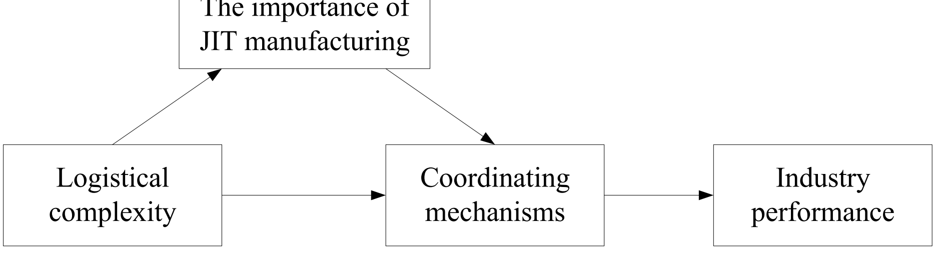


Figure 2.8: Relationship between JIT, Logistical Complexity, Organisation Structure and Performance (Funk, 1995)

Wafa and Yasin (1998) believed that JIT concepts are difficult to implement because of the necessity of fundamental organisational changes. Based on the results of the field study, they have identified variables affecting JIT implementation and hindering problems and benefits. These variables are clustered in to four categories: management, workers, process and suppliers, and their proposed framework is presented in Figure 2.9.

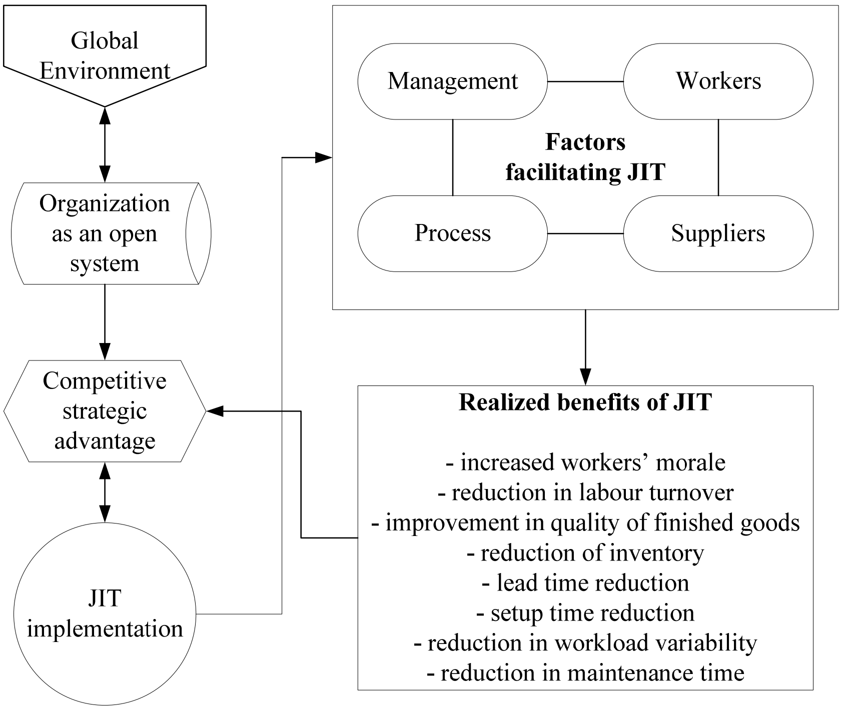

Global Environment
Organization as an open system
Competitive strategic advantage
JIT implementation
Management
Workers
Factors facilitating JIT
Process
Suppliers
Realized benefits of JIT
- increased workers' morale
- reduction in labour turnover
- improvement in quality of finished goods
- reduction of inventory
- lead time reduction
- setup time reduction
- reduction in workload variability
- reduction in maintenance time

Figure 2.9: A Conceptual Framework for Successful JIT Implementation (Adapted from Wafa and Yasin, 1998)

Traditional intermittent operating systems such as project or batch processes are capable of producing a high variety of products where as repetitive operating systems like line or continuous processes are lacking in the manufacture of high variety products (Reid and Sanders, 2005). Figure 2.10 shows types of production processes. White and Prybutoc (2001) revealed that repetitive production systems appear to be more successful in their utilisation of JIT practices than intermittent production systems.

Implementation of JIT practices may depend upon the type of production. JIT works well when the product being sold is ordered well in advance and there is a substantial lead-time between ordering and delivery (Hall, 1989). Traditionally it was believed that JIT manufacturing requires high volume production with constant demand from customers. According to recent literature, JIT is also used in low volume, high variety products manufacturing. When there are fewer product substitutes and more loyal customers, there is a greater chance for JIT being successful (e.g.: automobile and aerospace industry).

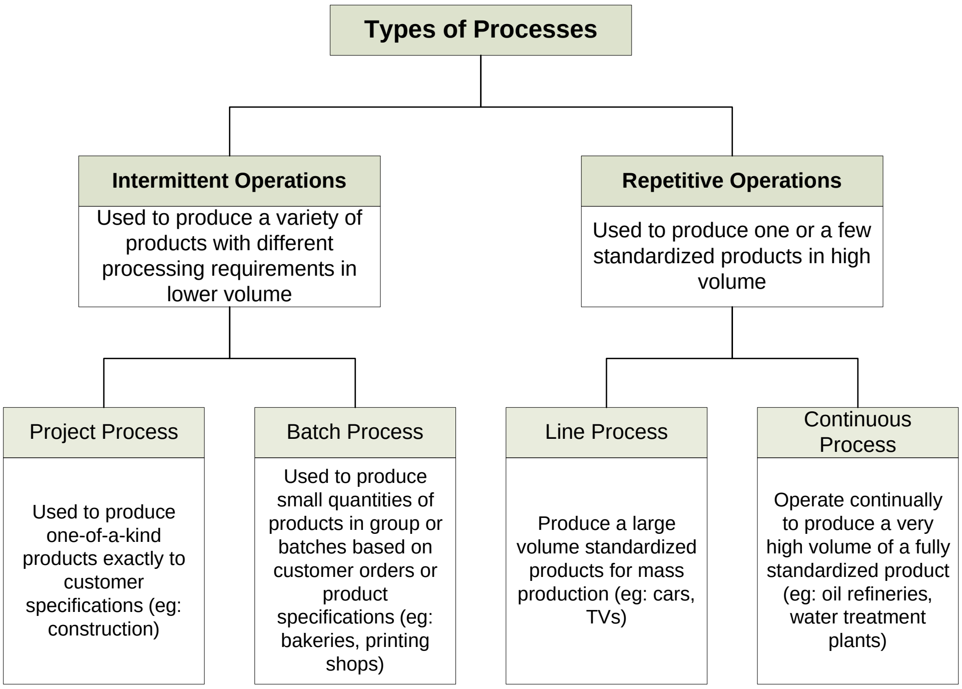

Types of Processes
Intermittent Operations
Used to produce a variety of products with different processing requirements in lower volume
Repetitive Operations
Used to produce one or a few standardized products in high volume
Project Process
Used to produce one-of-a-kind products exactly to customer specifications (eg: construction)
Batch Process
Used to produce small quantities of products in group or batches based on customer orders or product specifications (eg: bakeries, printing shops)
Line Process
Produce a large volume standardized products for mass production (eg: cars, TVs)
Continuous Process
Operate continually to produce a very high volume of a fully standardized product (eg: oil refineries, water treatment plants)

Figure 2.10: Types of Production Processes (Adapted from Reid and Sanders, 2005)

One JIT technique for facilitating relatively lot-less production is the Kanban system (Schonberger, 1982b). Further to Schonberger (1982b), some repetitive manufacturers have been able to achieve lot-less final assembly either by dedicated assembly lines each making only a single model or running mixed models down a single line. White and Ruch (1990) mentioned that the focused factory technique may include minimisation of the complexity involved in a high variety of products or processes.

Hall (1989) argued that the higher the intensity of competition the lower the likelihood that JIT would work. Since competition implies changes in demand for some of the competitors as a result of the actions of the other rivals, it is more difficult to forecast demand accurately. Hall further argued that, in a highly competitive market, it is difficult to fulfil the sudden increase in demand due to zero inventory concept. Therefore the trade-off between inventory and ability to fulfil demand is inevitable under JIT environment. Hall (1989) highlighted three precautions that managers can take in order to avoid unfortunate situations:

- a buffer or slack variable, which will allow the firm to minimise its inventory costs and help avoid stock shortages, should be built into JIT
- understand that JIT is not panacea for all management problems, but a management tool directed at lowering cost
- make sure that once JIT is in place, it remains flexible and changeable

JIT will probably be easier to implement by new entrants, because they will not have to overcome problems such as organisational culture, which is proved to be very difficult. It is apparent that characteristics of employees may have positive or negative impact on JIT implementation and performance.

2.7 WESTERN AND FAR EASTERN SOCIO-CULTURAL IMPACT ON JIT PERFORMANCE

Sriparavastu and Gupta, (1997) argued that, with no concept of quality and no consideration for customers' satisfaction, US firms not only lost their competitive edge but also even lost their domestic markets to the formidable quality conscious products of the Japanese after World War II. Toyota started to implement JIT in early 1970s and by the early 1980s, JIT became a very popular manufacturing innovation in Western and Asian countries. However, the idea of JIT actually originated with the mechanism used in American supermarkets to replenish shelves as customers deplete inventory (Joo and Wilhelm, 1993). In early 1900s, Fords inventory of finished and completed cars was non-existent, because the demand of their products was higher than their capacity to produce. In 1929, Toyoda had been visiting Ford's plant at River Rough, which might have inspired him (Svensson, 2000). Some authors suggested that JIT is not a new system, but is an old production philosophy, with the same principles which originated in the American automobile industry in the early 1900s (Keller and Kazazi, 1993).

The Japanese JIT concept has been described and discussed by several authors, however, there is often considerable misunderstanding about the concept (Keller and

Kazazi, 1993). Though many Western manufacturers use JIT techniques in their plants, most are still confused regarding the philosophy. Thus it is interesting to study the reasons for the misunderstanding of the concept. Part of the evidence is provided by the experience of Japanese takeovers of plants in the West as well as by Japanese transplant operations in which Japanese manufacturing management proved to be successful under Western conditions (McLachlin, 1997).

JIT philosophy is deeply rooted to Japanese traditions and culture and the Japanese society which is considered to be homogeneous and group oriented compared to Western society, which is heterogeneous and individual oriented (Hall, 1989 and Kim and Takeda, 1996). Spear and Bowan (1999) contended that one central tenet of the corporate culture is responsible for JIT and Toyota's continuous success and that tenet is "all work processes are controlled, scientific experimented, constantly modified and improved by the people who do the work". According to Ramarapu *et al.* (1995), for JIT implementation to be successful in the USA, a Japanese approach to worker-orientation appears critical. However, Oliver *et al.* (1996) argued that although there are signs that Japanese style, team based work organisation is diffusing to the West, especially in the UK and the USA, the link between group oriented organisation and performance is not clear. The authors further observed that team based work is much more conditional on local context than some researchers have suggested.

Pheng and Chuan (2001a) reported, "unlike in Japan, the extent to which the application of JIT methods in the West will depend upon the hegemony of management over labour". Bates *et al.* (1999) stated, "Japanese people have greater loyalty to their employer than their counter parts in the UK". Japanese managers treat all workers equally, allocate daily job responsibilities, evaluate their performance, and provide potential lifetime employment (Kim and Takeda, 1996). The authors described this relationship as "rentai" (joint responsibility) and "wa" (harmony), which are key features in Japanese culture. Kim and Takeda (1996) described these as essential ingredients needed to obtain true benefits from JIT implementation. These relationships encourage workers to work hard, identify defects, reduce waste and costs, enhance innovation and investments, increase profits and ultimately achieve customer satisfaction. In this scenario, Japanese manufacturers have to employ lots of workers in their customer oriented manufacturing environments to produce items to match customer orders. In contrast, Western manufacturers consider this as overstaffing. However, a major problem that is already starting to become evident in many Japanese companies is the shortage of young workers and the relatively large number of older employees (Katayama and Bennett, 1996).

Speed is another major concern in Japanese culture; hence, manufacturing industry is always trying to reduce process time and lead-time of production processes. However, one of the most apparent effects relating to today's JIT production has been the increase in traffic brought about by the pressure for smaller, and thereby more frequent deliveries of materials to factories (Katayama and Bennett, 1996). Traditional Western management practices have been built around the principles of division of labour, standardisation, simplification and specialisation. Breaking down the traditional adversarial barriers that exists between Western labour and management would further increase labour effectiveness.

However, Katayama and Bennett's study (1996) on the Japanese perspective of lean (JIT) production, argued that the recent recession, coupled with the threat from imports, has cast doubt on whether lean production will be the most appropriate system in changing competitive world. According to Katayama and Bennett (1996), a particular weakness of lean (JIT) production is its inability to accommodate the variations or reductions in demand for finished products.

2.8 BENEFITS OF JIT PRODUCTION SYSTEM

Fullerton and McWatters (2001) summarised benefits in to five categories: quality benefits, time-based benefits, employee flexibility, accounting simplification and firm profitability. The increase in performance is usually attributable to a decrease in inventory levels, smoother production flow, lower storage cost and ultimately a decrease in average cost per unit (Hall, 1989). Callen *et al.* (2000) reported that JIT plants have significantly less WIP than non-JIT plants. JIT plants also store fewer finished products and have lower variable and total costs than the non-JIT equivalent. Callen and co-workers further found that JIT plants are significantly more profitable than non-JIT plants, but are neither successful at minimising WIP and costs nor maximising profits.

According to Kazazi and Keller (1994), little research has been reported on the quantitative tangible and intangible benefits of JIT implementation. Brown and Inman (1993) compared Manoochehri's (Manoochehri, 1988, cited in Brown and Inman, 1993) theoretical benefits of JIT with reported benefits from surveys and case studies and found that these two groups share the concepts of inventory reduction, improved quality and shorter lead times.

Green *et al.* (1991), Clode (1993), Flynn *et al.* (1995), Huson and Nanda (1995), Pandya and Boyd (1995), Clinton and Hsu (1997), McLachlin (1997), Sakakibara *et al.* (1997), Wafa and Yasin (1998), Callen *et al.* (2000), Fullerton and McWatters (2001), White and Prybutoc (2001), and Ahmad *et al.*, (2004) presented potential benefits and performance improvements achieved through JIT implementation. The summary of main benefits of JIT is listed below:

- reduced process time, setup time and lead time
- reduced raw material, WIP and finished goods inventory levels and lot size
- improved machinery and reduced machine breakdowns and downtimes
- minimised space requirement
- improved flow of products
- lowered production costs
- simplified production processes
- improved quality
- improved flexibility, multifunctional ability, motivation and problem solving capability of employees
- increased productivity and performance
- improved consistency of production scheduling
- increased emphasis on supplier integration

Kazazi and Keller (1994) found that the degree of benefits derived from JIT could vary from company to company, because of different skill levels, organisation structure, management ability, financial resources and other factors. However, organisations can achieve benefits and performance excellence by accepting JIT as an organisational philosophy and implementing JIT practices in an effective manner.

2.9 SUMMARY

Since the industrial revolution, the manufacturing industry has looked for ways to improve its processes to achieve better performance. The JIT philosophy has been employed to respond to the performance related problems in manufacturing environments. However, misunderstanding of the philosophy still remains critical and implementation issues remain unclear. There is empirical evidence to suggest that implementation of JIT can improve the performance of manufacturing companies. The empirical studies that examined the impact of JIT practices on plant performance have reported mixed results. Swamidass (2007) argued that the mixed findings may be due to the fact that researchers have treated all firms in an industry as homogeneous entities. A major characteristic to JIT implementation is that there are no universally accepted JIT techniques, as they seem to vary from culture to culture and also from industry to industry. These are the significant problems, which need prompt attention.

This chapter has explored and documented the JIT philosophy, goals and elements. The pre-requisites of JIT implementation, socio-cultural impact on implementation and benefits that can be gained from implementation have also been described. The review has identified 20 JIT techniques from the theories and concepts presented in the manufacturing literature. According to the review, kanban and pull system, setup time elimination plans, level schedules, group technology, quality control activities, quality circles, TPM, and multifunction employee are the most frequently addressed JIT techniques whereas inventory transport systems, innovation and investment plans, value added analysis and other control techniques are least frequently reported in past literature. Techniques such as line balancing, JIT purchasing, focused factory, integrated product and process design, work place organisation plans, effective communication, supplier integration and employee training are moderately investigated in past literature. Chapter 2 has further reviewed the aforementioned 20 JIT techniques and their implementation issues in detail.

A review of literature on existing performance measurement systems and their suitability or insufficiency in JIT production performance appraisal is presented in the next chapter.

CHAPTER 3: PERFORMANCE MEASUREMENT SYSTEMS: A THEORETICAL REVIEW

3.1 INTRODUCTION

Performance measurement forms an integral part of management control systems and it is used to gauge the performance of companies, departments, plants, cells and individuals. This chapter explores performance measurement systems (PMSs) used in the manufacturing industry and reviews the literature in the areas of: (1) financial PMSs and (2) multidimensional PMSs applied in production environments. A review of the aforementioned themes provides the background and appreciation of how performance measurement is carried out in manufacturing organisations. This chapter also makes a case for robust multidimensional PMS such as the balanced scorecard suitable for application in a JIT enabled manufacturing environment.

3.2 PERFORMANCE MEASUREMENT

Performance measurement is critical to the economic well being of manufacturing companies (Dixon *et al.*, 1990). Suwignjo *et al.* (2000) argued that many researchers prefer to propose the criteria for design of performance measurement systems rather than provide generalised frameworks for performance measurement. According to Neely *et al.* (1995), performance measurement is a topic often discussed but rarely defined. However, in the last decade, a growing number of authors defined, discussed and pointed out the crucial role played by performance measurement in modern manufacturing firms. Neely *et al.* (1995) therefore defined,

> "Performance measurement as the process of quantifying the efficiency and effectiveness of an action"
>
> "Performance measure as a metric used to quantify the efficiency and/or effectiveness of an action"
>
> "Performance measurement system (PMS) as the set of metrics used to quantify both the efficiency and effectiveness" (Neely et al., 1995)

Procurement Executive Association (1998) defined performance measurement as;

> "A process of assessing progress towards achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of a program of activity compared to its intended purpose)."

According to Kerssens-van Drongelen and Bilderbeek (1999) performance measurement is;

> "An acquisition and analysis of information about the actual attainment of company objectives and plans, and about factors that may influence this attainment."

Moullins (2002) described performance measurement as;

> "Evaluating how well organisations are managed and the value they deliver for customers and other stakeholders."

Moreover, Bititci, *et al.*, (1997) defined performance management as;

> "A closed loop control system which deploys policy and strategy, and obtains feedback from various levels in order to manage the performance of the system."

Bititci, *et al.*, (1997), Procurement Executive Association (1998) and Kerssens-van Drongelen and Bilderbeek (1999) defined performance measurement as attainment of goals and objectives, while Neely *et al.*, (1995) and Moullins (2002) described it as a process of quantifying efficiency and effectiveness of actions. However, the ultimate aim of quantification is to attain the organisational goals (Kulatunga *et al.*, 2007). Although, Moullins (2002) and Pratt (2005) presume that the survival of an organisation largely depends on stakeholder satisfaction, Bocci (2004) and Neely (2005) argue that considering mainly stakeholder satisfaction would ignore the other aspects of performance measurement, and hence limit its applicability.

Within the context of this study on performance measurement in JIT enabled manufacturing environments, the importance of both organisational goals and JIT processes were evident. Accordingly, performance measurement can be defined as a process of quantifying both efficiency and effectiveness of JIT processes and techniques in order to achieve predetermined goals and objectives.

JIT practices have direct and indirect impact on financial and non-financial performance measures. Upton (1998) suggested that JIT firms make greater use of non-financial measures than non-JIT firms. Hence, it is essential to integrate financial measures and operational measures in multidimensional PMS in a JIT enabled manufacturing environment. Figure 3.1 depicts the relationships between JIT practices, and operational and financial measures.

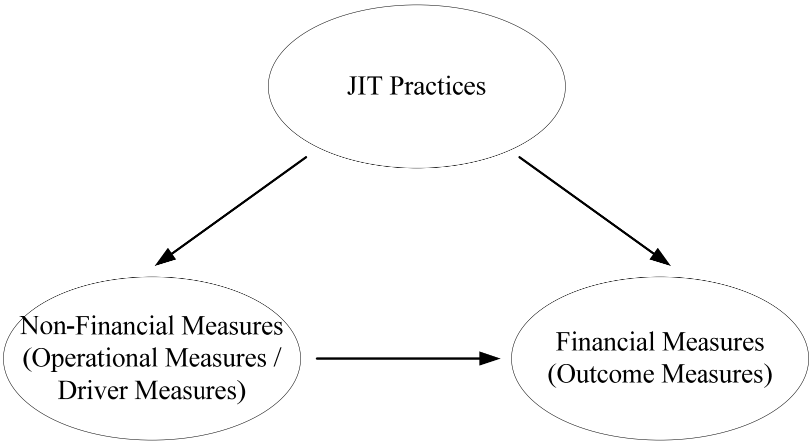

JIT Practices
Non-Financial Measures (Operational Measures / Driver Measures)
Financial Measures (Outcome Measures)

Figure 3.1: Relationships between JIT Practices and Operational and Financial Measures (Adapted from Ahmad *et al.,* 2004)

To foster the shift to lean manufacturing strategies such as JIT, TQM and cellular manufacturing; a firm's MAS may require significant changes (Fullerton, 2003). JIT's success is dependent upon a PMS that effectively measures and reports both financial and operational performance of the enterprise.

PMS provides systematic feedback on organisational, functional and individual performance of a company. Some of the major concerns of performance measurement include “What to measure?”, “Which measures are used?”, “How to measure?” and “How to interpret results?” (Sandanayake and Oduoza, 2005 and 2007). There are no universally accepted PMSs describing generic performance measures applicable to a production environment. Firms tend to use empirical measures to appraise system performance. Halachmi (2005) argues that when the tasks of performance measurement are considered, it would be impossible to do performance measurement correctly. However, Kulatunga *et al.*, (2007) argued that "the solution is not to avoid the use of performance measurement as there are well established positive influences, but to design and materialise a system which is user friendly, and which negates the negative impact by providing positive impacts". Neely *et al.* (1995) stated that there should be a technique for managers to reduce the number of possible measures to a meaningful set. Dixon *et al.* (1990) in their study outlined four fundamental reasons for performance measurement, which must be updated in order to support manufacturing practice improvement. Those reasons are:

- dissatisfaction with financial measurement systems is growing
- measurement approaches must support ever-increasing excellence
- managerial effectiveness is achieved by integrating strategies, actions and measures
- inability of existing PMSs to focus managerial attention to overhead cost and the deployment of overhead personnel

Neely (2005) carried out citation/co-citation analysis of work in the field of performance measurement to explore developments in the field globally. Every publication that contained the phrase "performance measurement" in its title, key word and abstracts were identified using ISI Web of Science database. Neely found that the most frequently cited authors were Rob Kaplan (398 citations) and Andy Neely (153 citations) from 1,352 papers published in 546 different journals.

Although there are some success stories about the implementation of multidimensional PMSs in organisations (Kaplan and Norton, 1993 and Neely *et al.*, 2001), there is also a growing body of literature addressing the factors, which influence the failure of PMSs (Bourne *et al.*, 2003). Many academics and industry practitioners believe that financial performance measures are inadequate for the present manufacturing environment due to its complex nature (Dixon *et al.,* 1990, Kaplan and Norton, 1993 and Neely *et al.*, 2001). Upton (1998) found evidence to suggest that JIT firms were implementing non-financial measures specifically related to JIT philosophy. Swenson and Cassidy's (1993) accounting literature emphasise the importance of PMSs and how they can enhance JIT performance. Most of the manufacturing companies use ad-hoc performance measures to assess performance based on the manager's experience and tacit knowledge, instead of complete and well-structured integrated PMSs (Sandanayake and Oduoza, 2005).

Recent developments in management accounting systems (MAS) such as contemporary and strategic MAS, which led to the introduction of a 'balanced scorecard approach' as a performance measurement tool, broaden the scope of management accounting information (Kaplan, 1984 and Kaplan and Norton, 1992). This is because the approach incorporates both qualitative and quantitative, financial and non-financial information on performance indicators including operating income, revenue growth, cost controls, product defects, yield, manufacturing lead time, time to market, market share, customer response time and satisfaction, product reliability, quantity of defective products shipped to customers, and ratio of good output to total output (Mia, 2000). Hence, the present day literature defines performance measurement as the use of a set of multidimensional performance measures, which integrate both financial and non-financial measures (Kaplan and Norton, 1992, 1996a, 1996b, Swenson and Cassidy, 1993, Ghalayini and Noble, 1996 and Ghalayini *et al.*, 1997). The financial performance measures are discussed in the next section.

3.3 FINANCIAL PERFORMANCE MEASURES

From the nineteenth century to the 1920s, there was a huge boom in innovation of financial and management accounting techniques. Accounting is the process of identifying, measuring and communicating economic information to make relevant judgements and decisions by users of the information. Literature concerning performance measurement can be divided into two main phases (Ghalayini and Noble, 1996). The phase from late 1880s to 1980 emphasised on financial measures and the second phase started in the late 1980s as a result of changes in the world market. Traditional accounting systems are classified in to two groups, according to the users of the information:

- financial accounting systems (external users)
- management accounting systems (internal users)

Kaplan (1984) mentioned that "virtually all the practices employed by firms today had been developed by 1925". Kaplan argued that despite considerable changes in the nature of organisations and the dimensions of competition after 1920s, there has been little innovation including discounted cash flow and residual income in the cost accounting and management control systems. Kaplan further stated that the standardisation of internal and external reporting to regulatory bodies is a reason for slow innovation in MAS. Hence, until late 1980s, performance measures based on MAS played a vital role in financial performance measurement. These financial measures focused on profits, productivity, return on investment, standard cost variance analysis, turnover, current ratio and liquidity ratio. Performance measurement is a critical aspect of management accounting systems within a JIT environment (Upton, 1998). However, the use of efficiency variances may encourage buffer stocks rather than demand and also, price variance may lead to purchase of low quality materials (Upton, 1998).

Various studies have considered productivity and profitability as the major indicators in financial performance measures. Productivity may be simply defined as the ratio of output to inputs. It is concerned with the efficient utilisation of resources (inputs) in producing goods and/or services (output) (Sumanth, 1984). The most important characteristics of productivity measures are its ability to reveal factors contributing to changes of productivity, to detect factor substitutions, to determine relative contribution of various inputs and outputs and to distinguish price effects from changes in physical productivity (Misterek *et al.*, 1992). However, Bond (1999) categorised process time and cost of waste as determinants of productivity, which are non-financial operational performance measures. Mistry (2005) found that, though JIT has been widely implemented, interest in documenting its impact on financial performance and productivity was generated during last few decades. For example, Inman and Mehra (1993) established the link between JIT benefits and bottom line financial measures. Olsen (2004, cited in Swamidass, 2007) is stated that "lean/JIT firms tend to have better return on equity", since lean/JIT is associated with low inventories. However, according to Fullerton and McWatters, (2002), the use of financial performance measures under the present competitive market conditions appears unsustainable due to various reasons. The limitations of financial performance measures are discussed in detail in the next section.

3.4 LIMITATIONS OF FINANCIAL PERFORMANCE MEASURES

Traditionally, productivity has mainly been measured from the financial perspective. Therefore traditional MAS were highly criticised due to their dysfunctional behaviour (Ridgway, 1956). Clinton and Hsu (1997), Sanger (1998) and Kagioglou *et al.* (2001) argued that organisations, which rely on financial measures alone can identify their past performance, but not what contributed to achieve that performance. Skinner (1986) stated that, "productivity ignores quality, reliable delivery, short lead times, customer service, rapid product introduction, flexible capacity, and efficient capital deployment in today's competitive market". Further he argued that managers who are under relentless pressure to maximise productivity resist innovation. Martin (1997) argued that "orienting PMSs towards financial and cost management measures has had disastrous consequences for the long-term efficiency and profitability of a firm, since the focus is to reduce the cost of inputs rather than maximise the quality and volume of throughput".

Financial reports are based on past financial data and presented monthly, quarterly or annually. These financial reports have a fixed format and customary way of interpreting data. According to the Cross and Lynch (1989), one major complaint of manufacturing managers is that the basic measures such as profitability consider too late for mid-course corrections and remedial actions. Therefore, financial measures are inflexible in performance measurement and hence, termed as lagging indicators (Ghalayini and Noble, 1996). Lessner (1989) stated that PMS used to evaluate managers, served as a communication vehicle for top management to make decisions on issues that are critical to the growth of the organisation. These financial reports are used for middle and top management decision-making and are often confidential in nature. As a result, employees are not able to obtain a comprehensive picture of the performance level of the company. Financial performance measures are not incorporated in the company strategy in designing the PMS (Ghalayini and Noble, 1996). The main focus of financial measures is to minimise costs, increase labour efficiency, enhance machine utilisation, increase profitability, and shareholders value. Financial measures present only a desired result or goals and do not go far enough toward communicating the means and approach to achieving the goals (Lessner, 1989).

The financial performance measures neglect individual performance leading to employee frustration. Moreover, financial measures ignore shop floor level practices and other operational performances of the factory such as lead-time, takt time, setup time, quality, waste, on-time delivery and worker skill flexibility. Ghalayini and Noble (1996) agreed that it is important to realise that when a company is making a profit it does not necessarily imply that its operations, management, and control systems are efficient. Misterek *et al.* (1992) emphasised that productivity measures might not be good indicators of competitiveness. Kaplan and Norton (1992) argued that the traditional financial accounting measures like return on investment and earnings-per-share can give misleading signals for continuous improvement and innovation activities in today's competitive manufacturing environments. Actions taken by managers such as introduction of new technology, employee training to improve competitiveness in the long term may lower the productivity in the short term. Firms, which fail to improve their products, will experience a decrease in revenue and productivity. This will result in loss of customers in the long run and competitors will capture the niche market.

One of the main aims of any company is to retain and satisfy existing customers, attract new customers and enhance customer relationship over time. But financial performance measures fail to take into account the requirements and perspectives of internal and external customers (Cross and Lynch, 1989). Moreover, manufacturing philosophies such as JIT, TQM and lean manufacturing are emphasised on eliminating non-value added activities or wastes by value analysis. But, financial measures do not capture the environmental consequences in modern production situations.

Abdel-Maksoud *et al.*, (2005) mentioned that surveys of UK manufacturers revealed high emphasis on non-financial measures, focussing specially on quality and market issues. Although many research studies have been written about overall performance measurement, there is limited literature concerned detailed non-financial performance measures at operational level (Abdel-Maksoud *et al.*, 2005). Moreover, Abdel-Maksoud *et al.*, (2005) survey revealed that the adoption of Japanese inspired production philosophies such as JIT, TQM and TPM are likely to be associated with considerable interest in non-financial performance measures. However, financial PMS especially in a production environment tends to ignore performance in terms of business innovation and growth, customer and employee satisfaction, suppliers efficiency, sustainable production and internal business process perspectives, which are key drivers of financial performance. In particular, the quantitative non-financial/operational measures such as takt time, defects rate, inventory levels, productivity and on-time delivery and qualitative non-financial measures such as customer satisfaction, worker skill flexibility, supplier relationship, employee morale and innovation have commonly been ignored in financial PMSs. Therefore, according to Swamidass (2007), "one compelling view of a valid firm performance measure is that it should be multidimensional".

3.5 MULTIDIMENSIONAL PERFORMANCE MEASUREMENT SYSTEMS

The introduction of new manufacturing technologies and management philosophies such as JIT, TQM, concurrent engineering, lean manufacturing, flexible manufacturing systems, world class manufacturing, computer integrated manufacturing shows that financial performance measures are no longer suitable for performance measurement especially in production related settings (Dixon *et al.,* 1990, Neely *et al.,* 2001, Fullerton, 2003 and Sandanayake and Oduoza, 2007). The JIT philosophies are creating manufacturing environments that require a new and innovative JIT performance measures appropriate for cost management systems (McIlhattan 1987)

Multidimensional PMSs enable the managers to make decisions based on facts rather than on assumptions and faith (Parker, 2000). Dixon *et al.* (1990) argued that the main advantage in separating integrated PMS from traditional accounting systems is that it concentrates on measurement for continual improvement for strategic advantage rather than measurement against past or budgeted financial performance. Rangone (1996) outlined two major problems in the selection and implementation of performance measures as:

- the selection of a proper set of measures that are capable of assessing and controlling all critical factors

- the integration of those several measures, expressed in heterogeneous units, into a single evaluation of the overall performance of a manufacturing department (Rangone, 1996)

Dixon *et al.* (1990) introduced a three-phase model for changing performance measures and discussed the "Three Phases of Change" that companies are likely to pass through after reaching the level of frustration with financial performance measures:

- *Tinkering with the cost accounting systems:* Companies focus their attention on inadequacies of costing systems and spend inordinate resources to "fix" the cost accounting systems
- *Cutting the Gordian Knot:* When companies find that great amounts of tinkering leave them with inadequate performance measurement, they decide that cutting the knot between accounting and performance measurement is much more effective than trying to untie it.
- *Embracing change in strategies, actions and measures:* Once performance measurement is unbound from accounting, organisations can focus on making adaptive, pre-emptive change a matter of course (Dixon *et al.*, 1990)

The relationship between strategies, actions and measures is well documented by Dixon *et al.* (1990). Bititci *et al.* (1997) agreed that performance management is the process by which the company manages its performance in line with its corporate and functional strategies and objectives. Bond (1999) identified four levels of process management (i.e. maintaining process status quo, process improvement, process re-engineering and achieving process stability) and suggested that each of these phases has its own characteristics, which should be taken into account when determining performance metrics and approaches.

Rockart (1979) defined Critical Success Factors (CSFs) as the few key areas where "things must go right" for the business to flourish. Maisel (1992) identified five generic CSFs as customer responsiveness, profitability, quality, innovation and flexibility, while, Hendricks (1994) identified five CSFs important to many JIT firms as customer delivery, quality, flexibility, productivity and financial performance. Dixon *et al.* (1990) outlined five characteristics of good PMS:

- be mutually supportive and consistent with the business's operating goals, objectives, CSFs, and program
- convey information through as few and as simple a set of measures as possible
- reveal how effectively customers' needs and expectations are satisfied
- provide set of measurement for each organisational component that allows all members of the organisation to understand how their decision and activities affect the entire business
- support organisational learning and continuous improvement (Dixon *et al.,* 1990)

Although some researchers have introduced performance measurement development and application criteria for manufacturing industry, Halachmi (2002) argued that sometimes cost of introducing and implementing PMS could exceed the potential benefits of it. Bond (1999) developed a seven step control cycle for process stabilisation. Similarly, Medori and Steeple (2000) developed an integrated performance measurement framework structure revolving around a six-stage plan (Figure 3.2). But the researchers have not considered company vision, mission, core competencies and strategy in designing PMS.

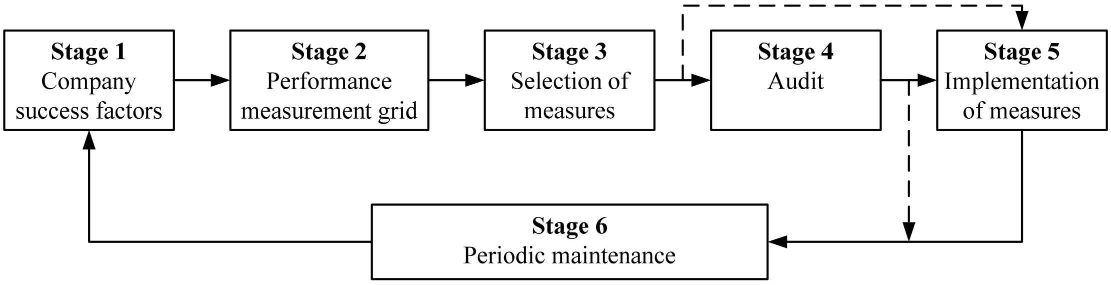


Figure 3.2: The Basic Design Requirements of the Integrated Performance Measurement Framework (Medori and Steeple, 2000)

Longernecker and Fink (2001) found that lower benefits were gained by the organisations which lacked the utilisation of PMS and feedback loops for improvement of performance. Ridgway (1956) considered single and multiple criteria for analysing the impact of performance measurements upon job performance. Single criteria occur when only one quantity is measured and observed, such as total output or profit while, multiple criteria occur when several quantities are measured simultaneously, such as output, quality, cost, safety and waste. More recently, the following well-known, better-structured and commonly cited integrated PMSs in the present day manufacturing environments have been introduced:

- SMART system (Cross and Lynch, 1989)
- Performance measurement questionnaire (PMQ) (Dixon *et al.*, 1990)
- Performance measurement matrix for time-based competition (Azzone and Masella, 1991)
- Performance prism (Neely *et al.*, 2001)
- Integrated dynamic performance measurement system (Ghalayini *et al.*, 1997)
- Integrated performance measurement system (Bititci *et al.*, 1997)
- EFQM framework (EFQM, 2004)
- Balanced scorecard (BSC) (Kaplan and Norton, 1992)

3.5.1 SMART System

At Wang Laboratories, the Experimental Process Improvement Challenge (EPIC) found that JIT work cell approach has reduced throughput time, and improved quality and worker morale (Cross and Lynch, 1989). After the implementation of EPIC, managers realised that they were not getting information to make critical business decisions by relying on financial performance measures. As a result, the research group developed the Strategic Management Analysis and Reporting Technique (SMART), with objectives to integrate both financial and non-financial reporting:

- to link manufacturing to the strategic goals for the company
- to concentrate the measurement system design on satisfying customer needs
- to develop a system to foster constant evolution (Dixon *et al.*, 1990)

Figure 3.3 shows a four level SMART performance pyramid of objectives and measures with an effective link between the corporate vision and strategies and the operations. The second level defines the objectives of each business in both market and financial terms. The third level describes more tangible operating objectives and priorities in each business operating system in terms of customer satisfaction, flexibility and productivity. At the foundation level (i.e. departmental level), the objectives are converted into four specific operational pillars such as quality, delivery, process time and cost. These operational measures are the keys to achieving higher-level results, corrective actions and continuous improvement at the departmental level.

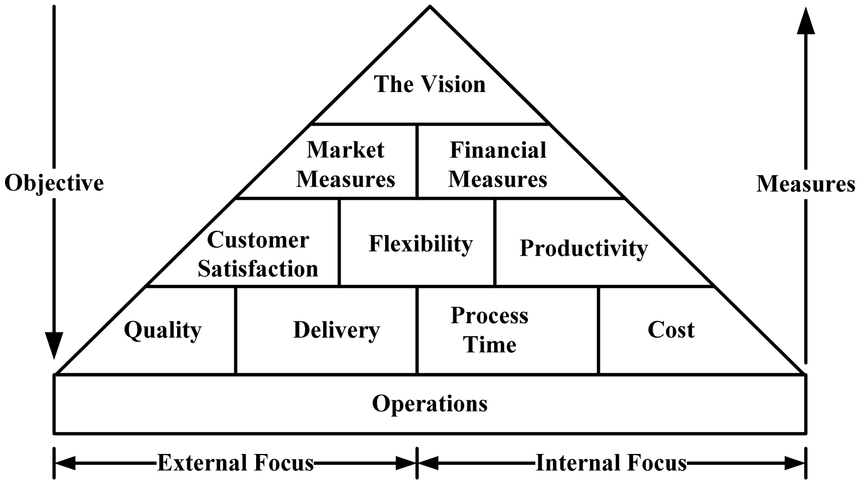


Figure 3.3: The SMART Performance Pyramid (Cross and Lynch, 1989)

Though the main strength of the SMART system is its attempt to integrate corporate objectives with operational performance indicators, there are weaknesses of the system. SMART system does not provide any mechanism to identify key performance indicators (KPIs). Another notable omission of the SMART system is the human related measures such as employees, suppliers and environmental and social groups. SMART system neither provides a proper mechanism to measure current performance of the business nor specific targets for performance levels. Hence, it does not directly support cross industry comparisons, benchmarking and the concept of continuous improvement.

3.5.2 Performance Measurement Questionnaire (PMQ)

Dixon *et al.* (1990) developed the PMQ to evaluate the importance of improvement and to identify the effect of current performance measures on improvement. The information collected is then used to challenge the status quo and also as a basis for amending the existing performance measures (Bourne *et al.*, 2003). The PMQ tool can also be applied to perform a reality check on the performance measurement in practice rather than the one on paper (Tsang, 1999). PMQ consists of four parts:

- *Part I*: Requests for general data to be used to classify the respondents
- *Part II*: Focuses on competitive priorities and PMSs. This section labelled as "Improvement Areas" and consists of 24 items related to product, process, human resource, information, finance and environment (Figure 3.4)
- *Part III*: Focuses on importance of performance factors and emphasis on measurement of those factors. This includes 39 performance factors, which covers financial, quality, time and process performance and stability, customer satisfaction, employee performance, supplier performance, safety factors, innovation and environmental performance (Figure 3.4)
- *Part IV*: Asks respondents to record their own performance and presents general comments

Long-Run Importance of Improvement	**Improvement Areas**	**Effect of Current Performance Measures on Improvement**
None > > > Great		Inhibit > > > Support
1 2 3 4 5 6 7	Quality	1 2 3 4 5 6 7
1 2 3 4 5 6 7	Labour efficiency	1 2 3 4 5 6 7
1 2 3 4 5 6 7	Machine efficiency	1 2 3 4 5 6 7

Relative Importance to the Company	**Performance Factors**	**Emphasis of Measurement**
Very unimportant > Very Important		No Emphasis > Major Emphasis
1 2 3 4 5 6 7	Inventory turnover	1 2 3 4 5 6 7
1 2 3 4 5 6 7	Conformance to Specification	1 2 3 4 5 6 7
1 2 3 4 5 6 7	Cost of quality	1 2 3 4 5 6 7

Figure 3.4: Performance Measurement Questionnaire (Dixon *et al.*, 1990)

The results are analysed to identify alignment, congruence, consensus and confusion. PMQ helps to identify both the need for and the demand for a change among managers and to ascertain the overall commitment to the mission. The mismatch between left and right hand side scores notifies the time for new measures to be introduced and old measures to be removed from the measurement system. It helps to identify the effect of current performance measures on improvement. Similar to the SMART system, PMQ does not provide target performance levels. In addition, the content of improvement areas and performance factors vary from industry to industry and hence, PMQ is unsupportive in inter-industry performance comparisons and benchmarking.

3.5.3 Performance Measurement Matrix for Time-Based Competition

According to Azzone and Masella (1991), time-based competitors focus on shrinking the elapsed time between customer decision to buy and product delivery to the customer. The researchers therefore proposed a detailed and specific measurement framework for time-based competitors (Figure 3.5), consistent with the strategic objectives of a company and its organisational structure.

	Internal Configuration		External Configuration
R & D	Engineering Time	Number of changes in project, Average time between two subsequent innovations	Development time for new product
Operations	Throughput time	Adherence to due date, Incoming quality, Distance travelled, Value added time/total time, Scheduled attainment	Outgoing quality, Manufacturing cost
Sales and Marketing	Order processing lead time	Complexity of procedure, Size of batches of information	Cycle time, Bid time

Figure 3.5: Matrix for Time-Based Competitors (Azzone and Masella, 1991)

Their model reflects the use of time as a way to increase the value of products through actions on effectiveness (external configuration) and the role of time as a source of efficiency (internal configuration). This is a simple, detailed and specific performance measurement model. Performance indicators are mainly focused on time and time measurements. This is most suitable for time-based competitors and encourages continuous improvement and innovation. However, it does not include time factors related to the customer, employee and other stakeholders as dimensions and hence it gives an unbalanced performance model. Similar to most other PMSs, it does not directly support cross industry comparisons and benchmarking.

3.5.4 Performance Prism

The performance prism (Figure 3.6) is a measurement framework designed to assist performance measurement selection using five inter-related facets:

- Stakeholder satisfaction – Who are the stakeholders and what do they want and need?
- Strategies – What are the strategies we require to ensure the wants and needs of our stakeholders are satisfied?
- Processes – What are the processes we have to put in order to allow our strategies to be delivered?
- Capabilities – What are the capabilities we require to operate our processes?
- Stakeholder contribution – Include stakeholder's contribution to the organisation (Neely *et al.*, 2001)

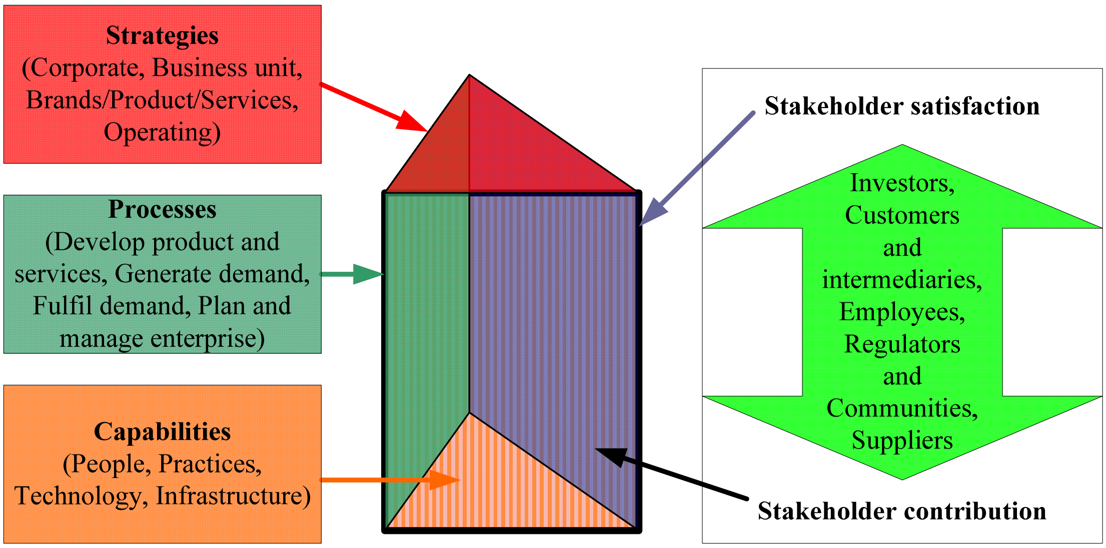

Strategies
(Corporate, Business unit, Brands/Product/Services, Operating)
Processes
(Develop product and services, Generate demand, Fulfil demand, Plan and manage enterprise)
Capabilities
(People, Practices, Technology, Infrastructure)
Stakeholder satisfaction
Investors, Customers and intermediaries, Employees, Regulators and Communities, Suppliers
Stakeholder contribution

Figure 3.6: The Performance Prism (Adopted from Neely *et al.*, 2001)

Neely *et al.* (2001) found that all the other PMSs such as the PMQ, BSC and integrated dynamic performance measurement systems have failed to recognise the reciprocal relationship between stakeholders and organisation. Neely and co-workers further argued that those PMSs are focused on stakeholder satisfaction but not stakeholder contribution. In contrast, Kaplan and Norton (1996a) concentrated on employee satisfaction as well as their contribution to business plan development and process improvement by teaming and empowerment. Therefore, one of the critical and unique features of the performance prism is stakeholder contribution. The performance prism provides a broader view of stakeholders, but makes reference only to customers and shareholders. However, the performance prism is a highly flexible measurement tool though it provides little guidance on appropriate measures selection. Performance measures vary from organisation to organisation and hence the performance prism does not support benchmarking and is less concerned with innovation and continuous improvement.

3.5.5 Integrated Dynamic Performance Measurement System

Figure 3.7 shows an integrated dynamic performance measurement system developed by Ghalayini *et al.* (1997) by integrating three functional areas namely management, process improvement teams and factory shop floor in conjunction with the Missouri Plant of Square D. The system used PMQ, the half-life concept and the modified value focused cycle time as key tools to measure and improve performance in an integrated manner. This framework builds on several different concepts to develop a system, which has an explicit process for maintenance and for ensuring fast and accurate feedback (Hudson *et al.*, 2001).

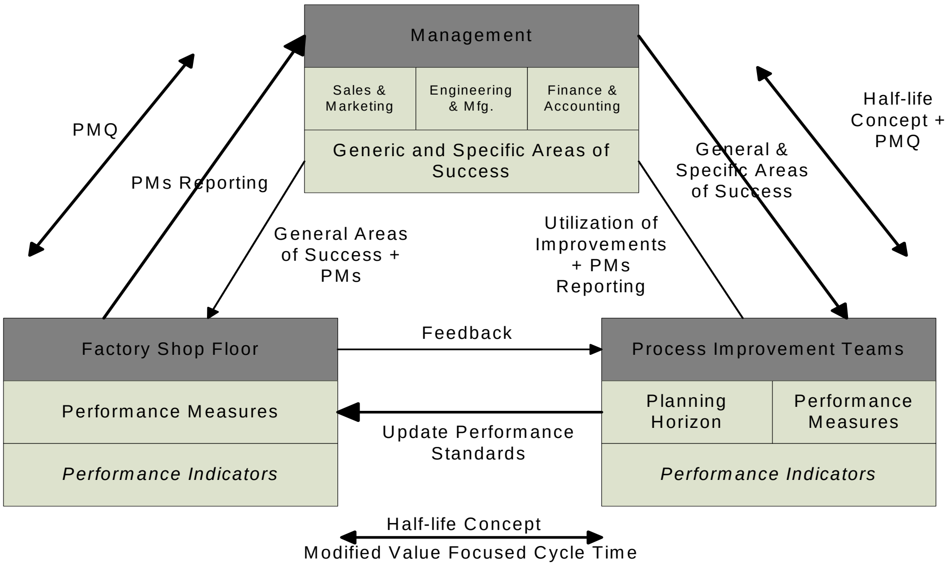


Figure 3.7: Integrated Dynamic Performance Measurement System (Ghalayini *et al.*, 1997)

The system was developed to overcome limitations of the existing PMSs and incorporate continuous improvement. It provides tools to identify different areas of success, performance measures and indicators. The system consists of a small number of critical performance measures, which save time, money and effort. However, performance indicators used in process improvement teams and factory shop floor are for internal reporting only. Performance is not reported to management, since management focus is on the overall and the aggregated effect of performance indicators. Performance indicators vary from industry to industry and hence do not support benchmarking. Moreover, external parties and their influences have not been integrated in to the PMS.

3.5.6 Integrated Performance Measurement System

Bititci *et al.* (1997) developed an integrated performance measurement model consisting four levels: corporate, business units, business processes and activities (Figure 3.8). Bititci and his colleagues introduced five key factors at each level of the structure: stakeholders, control criteria, external measures, improvement objectives, and internal measures.

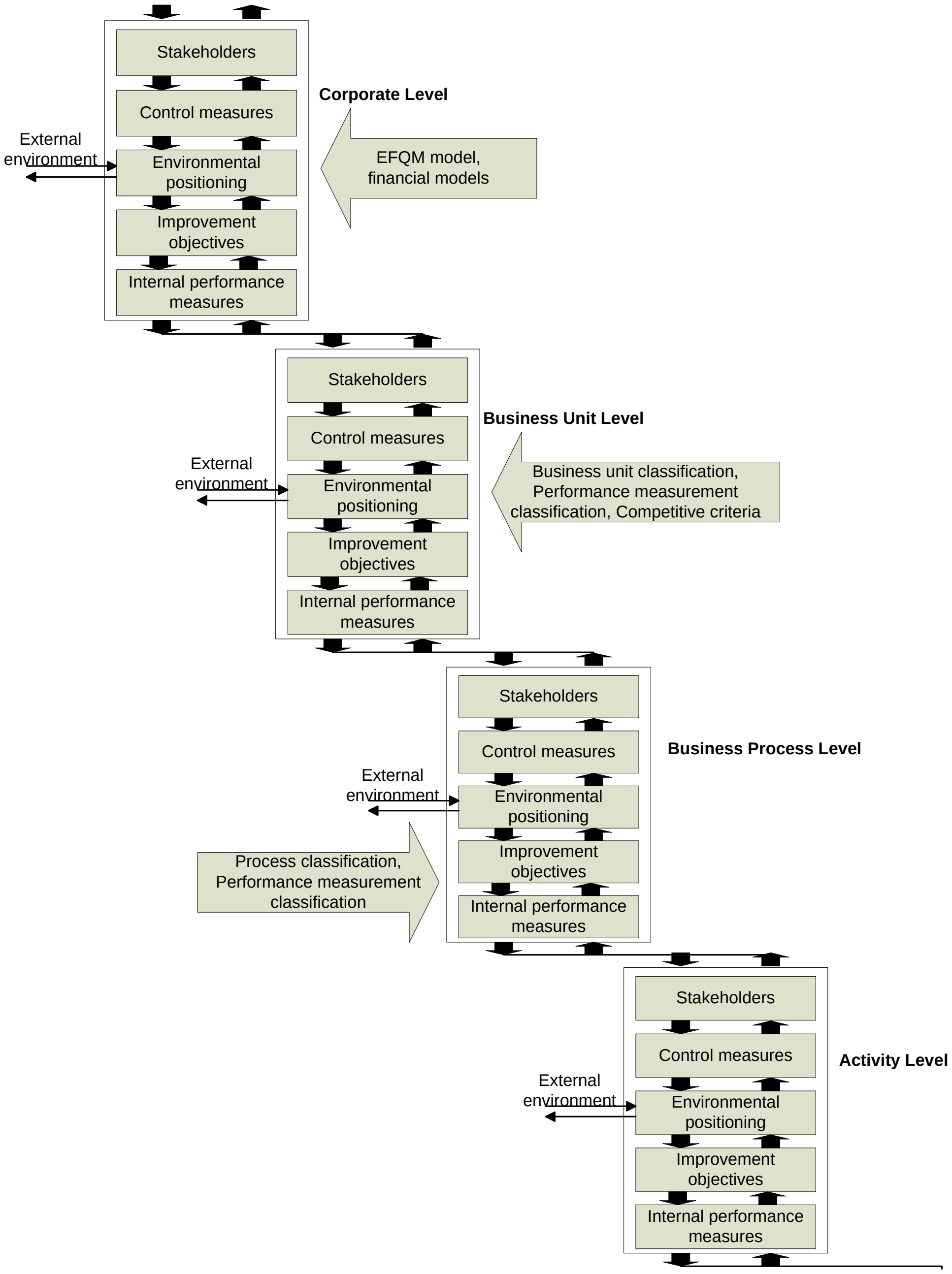

Stakeholders
Control measures
Environmental positioning
Improvement objectives
Internal performance measures
External environment
Corporate Level
EFQM model, financial models
Business Unit Level
Business unit classification, Performance measurement classification, Competitive criteria
Business Process Level
Process classification, Performance measurement classification
Activity Level

Figure 3.8: Integrated Performance Measurement Model (Bititci *et al.,* 1997)

Hudson *et al.* (2001) argued that though this model covers many criteria required for a comprehensive PMS, it fails to provide a structured process that specifies objectives and timeliness for development and implementation. This model does not attempt to structure these measures in a logical manner to understand and manage the relationships between measures (Suwignjo *et al.*, 2000 and Bititci *et al.*, 2001). Moreover, it does not provide a proper mechanism to identify KPIs. Hence, this model does not directly support for cross industry comparisons or benchmarking. However, this system can help to stimulate continuous improvement.

3.5.7 EFQM Framework

The European Foundation for Quality Management (EFQM) was founded in the late 1980's by 14 major European companies. In 1992, this foundation introduced the EFQM Business Excellence Model, which has since been applied by many manufacturing organisations. The main objectives of this tool are twofold: (1) Participation in the European Quality Awards competition and (2) Internal quality assessment, improvement and benchmarking. The EFQM framework is a self-performance-assessment tool based on TQM and continuous improvement using nine criteria. This framework comprises five enabler domains and four results domains, including 32 sub criteria (Figure 3.9). Enablers show actions to improve performance and results show achievements of the organisation.

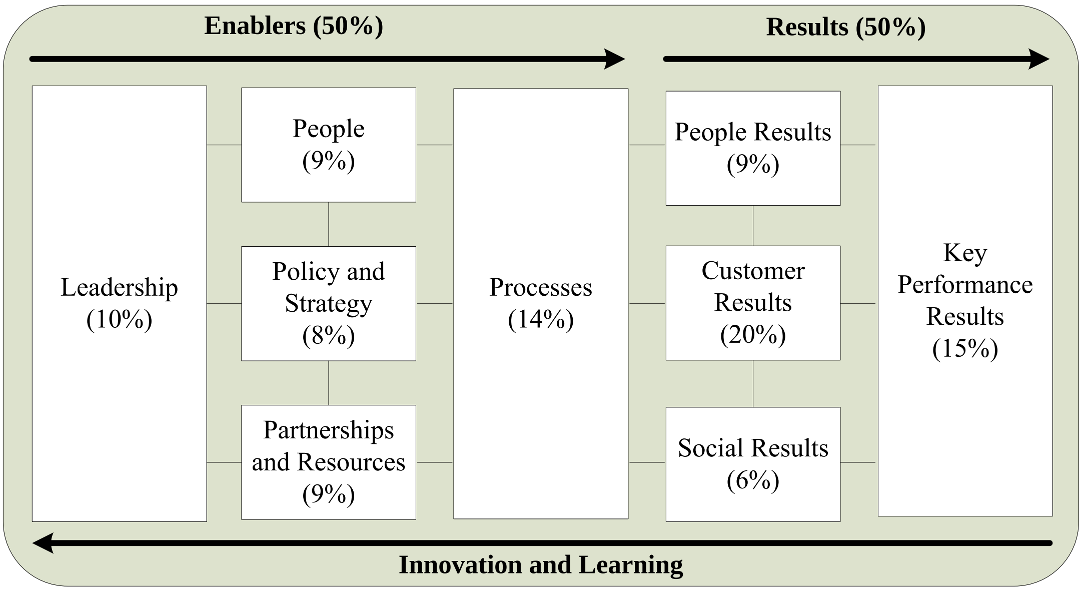


Figure 3.9: EFQM Excellence Model (EFQM, 2004)

This model is designed to achieve customer satisfaction, employee satisfaction, minimum social impact and better financial and other key performance results through well-defined organisational strategy and processes, people management and resource management guided by the organisation's leadership. The EFQM provides two evaluation tools:

1. Pathfinder Card – A Self-Assessment tool for identifying opportunities for improvement
2. RADAR Scoring Matrix – Consists of four elements called:
    - Determine the **R**esults
    - Develop an integrated set of **A**pproaches to deliver the required results
    - **D**eploy the approaches in a systematic way
    - **A**ssess and **R**eview the approaches and implement improvements where needed

One of the major weaknesses of this model is the difficulty in implementation due to its fixed template and complex measurement criteria. The EFQM model does not involve specific target performance levels. Further, it provides less emphasis on financial performance. However, this model supports cross-industry comparisons and benchmarking. Measurement outcomes describe the current performance of the business and encourage continuous improvement.

3.5.8 Balanced Scorecard (BSC)

In 1992, Professor Robert S. Kaplan and David P. Norton devised a successful mechanism, incorporating all measures that drive performance called the Balanced Scorecard (BSC). The BSC provides a comprehensive framework that translates a company's strategic objectives into a coherent set of performance measures with four different perspectives (Figure 3.10).

> *"The BSC includes financial measures that tell the results of actions already taken. And it complements the financial measures with operational measures on customer satisfaction, internal processes and the organisation's innovation and improvement activities - operational measures that are the drivers of future financial performance (Kaplan and Norton, 1992)".*

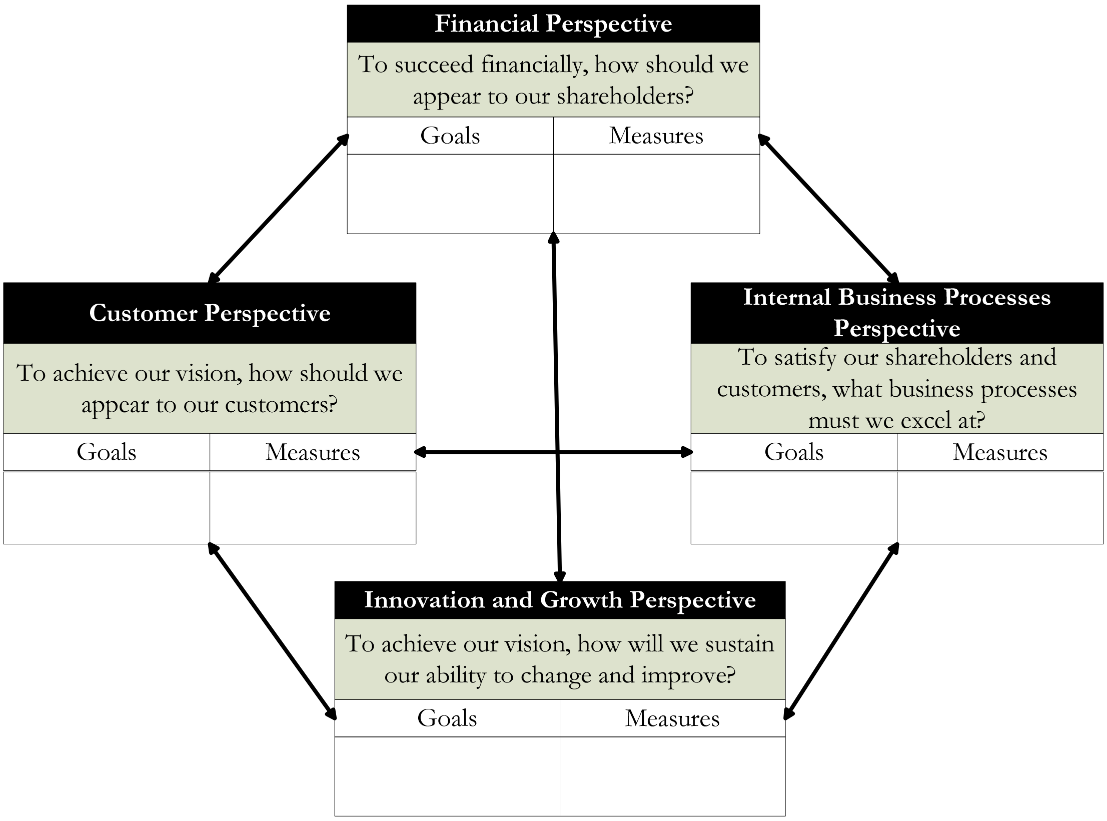

Financial Perspective
To succeed financially, how should we appear to our shareholders?
Goals
Measures
Customer Perspective
To achieve our vision, how should we appear to our customers?
Goals
Measures
Internal Business Processes Perspective
To satisfy our shareholders and customers, what business processes must we excel at?
Goals
Measures
Innovation and Growth Perspective
To achieve our vision, how will we sustain our ability to change and improve?
Goals
Measures

Figure 3.10: The BSC Framework (Kaplan and Norton, 1992)

According to Sanger (1998), BSC is used to measure performance and develop strategies by analysing results across a range of activities. Amaratunga *et al.*, (2002), further stated that BSC is not just a PMS, but is a management system that focuses the efforts of people throughout the organisation, towards achieving strategic objectives. BSC is therefore a multidimensional approach to performance measurement and management control that is linked specifically to organisational strategy (Dabhilkar and Bengtsson, 2004). The traditional BSC consists of four perspectives, i.e. financial, customer, internal business processes and innovation and growth:

1. *Financial Perspective* – This perspective assesses performance in terms of growth, profitability and risk from the stakeholders' point of view. It is a baseline in BSC and includes CSFs such as profitability and productivity and measures for profitability, operating income, return-on-capital-employed, cash flow, fixed and variable costs.
2. *Customer Perspective* – Since value creation begins with the customer, PMS should view products and services from the perspective of the customer

(Maisel, 1992), expressing the needs of the customers. Typical customer related performance measures are market share, customer satisfaction index, customer retention, acquisition and turnover and CSF is customer satisfaction.

3. *Internal Business Processes Perspective* – The internal business processes perspective identifies in house processes in which the organisation must excel. This parameter captures key internal processes (for instance procurement, production and order fulfillment) that should be monitored to ensure satisfactory outcome. This includes CSFs such as process capability and efficiency and measures such as throughput time, product and process quality, defect rate, machine breakdown and on- time delivery.
4. *Innovation and Growth Perspective* – Kaplan and Norton (1992) emphasised that a company's ability to innovate, improve and learn directly ties up to the company's value. This perspective includes measures that support innovativeness and organisational growth such as innovation rate, time to market a new product, revenue from new product, and research and development cost. It also focuses on employee training and infrastructure that the plant must build, to create long-term growth and continuous improvement.

The BSC reflects the balance between short-term and long-term objectives, financial and non-financial measures, lagging and leading indicators, external and internal perspectives and objective and subjective measures (Hepworth, 1998 and Sedara *et al.*, 2001). However, Ridgway (1956) was the first to discuss the need for a "balanced" set of performance measures in his review on dysfunctional consequences of single measures of performance. Dabhilkar and Bengtsson (2004) outlined three reasons for exploring the use of BSC in manufacturing:

- high rate of diffusion of the concept
- few empirical studies that explore and illustrate in detail how BSC is implemented and used
- significant need for further research on the concept of a scorecard

Kaplan and Norton (1996b) defined strategy as 'a set of hypotheses about cause and effect' and argued that a BSC should contain outcome measures and that the performance drivers should be linked together in cause-and-effect relationships.

Bassioni *et al.*, (2004) stated that "innovation and learning develop new processes and technologies that decrease costs and increase efficiencies in the internal business perspective, which in turn provides more value to the customer and therefore satisfies them, and will finally reap improved financial results". Kaplan and Norton (1996b) introduced four critical management processes for innovative companies who are using the scorecard as a strategic management system to manage their long-term strategic objectives with short-term actions as shown in Figure 3.11.

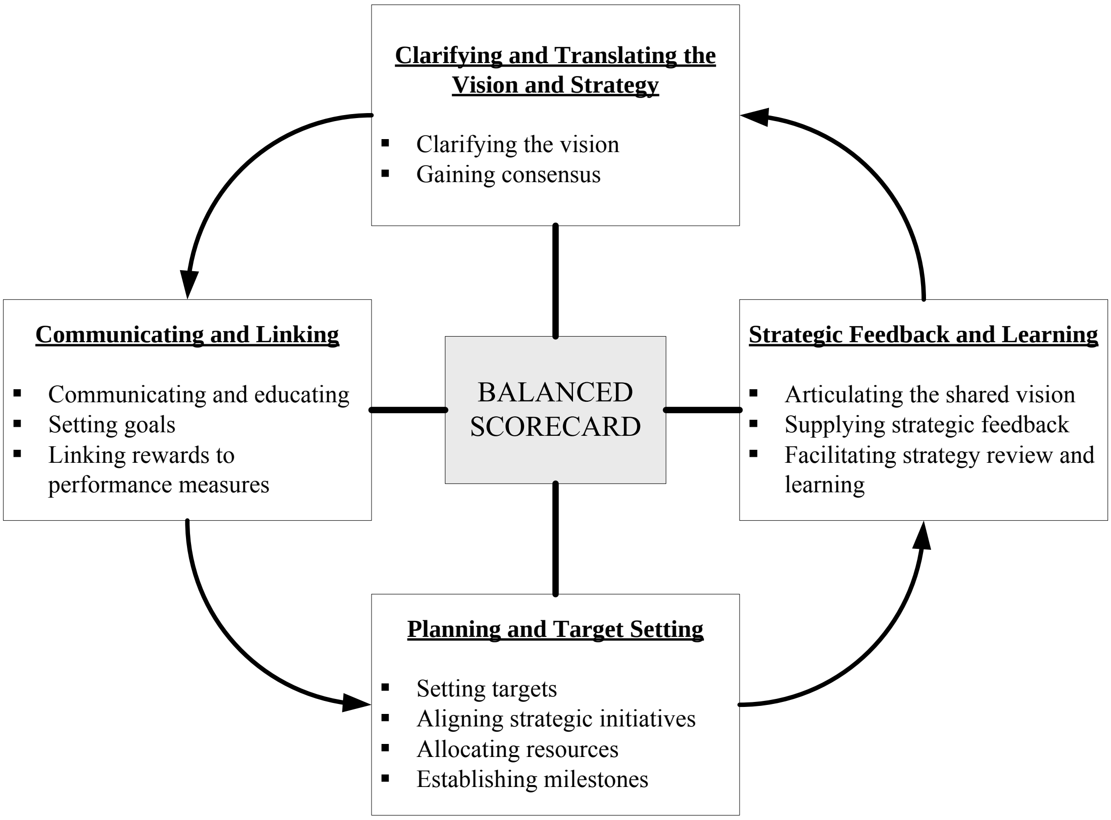

Clarifying and Translating the Vision and Strategy
▪ Clarifying the vision
▪ Gaining consensus
Communicating and Linking
▪ Communicating and educating
▪ Setting goals
▪ Linking rewards to performance measures
BALANCED SCORECARD
Strategic Feedback and Learning
▪ Articulating the shared vision
▪ Supplying strategic feedback
▪ Facilitating strategy review and learning
Planning and Target Setting
▪ Setting targets
▪ Aligning strategic initiatives
▪ Allocating resources
▪ Establishing milestones

Figure 3.11: The BSC as a Strategic Framework for Action (Kaplan and Norton, 1996b)

Kaplan and Norton (2000) developed a strategy map, which is a logical and comprehensive architecture to describe, implement and manage organisation strategies. Figure 3.12 is a sample strategy map and it specifies the critical elements and their linkages for an organisation's strategy. Kaplan and Norton's (2000, p.4) strategy map depicts "objectives for revenue growth, targeted customer markets in which profitable growth will occur; value propositions that will lead to customers doing more business and at high margins; the key role of innovation and excellence in products, services and processes; and the investment required in people and systems to generate and sustain the projected growth".

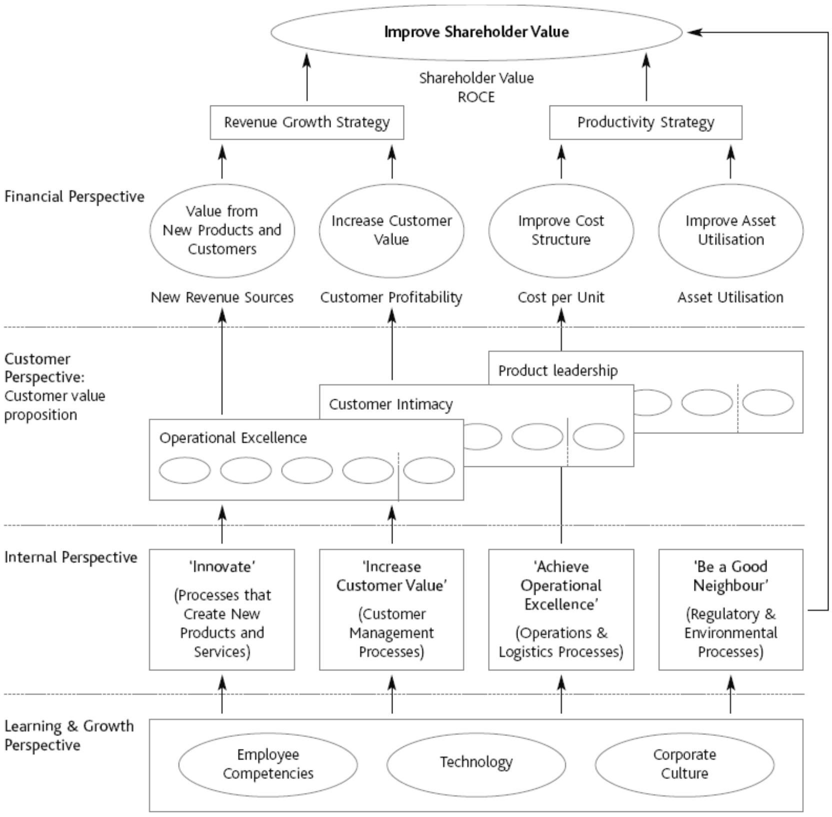

Improve Shareholder Value
Shareholder Value
ROCE
Revenue Growth Strategy
Productivity Strategy
Financial Perspective
Value from New Products and Customers
Increase Customer Value
Improve Cost Structure
Improve Asset Utilisation
New Revenue Sources
Customer Profitability
Cost per Unit
Asset Utilisation
Customer Perspective: Customer value proposition
Product leadership
Customer Intimacy
Operational Excellence
Internal Perspective
'Innovate' (Processes that Create New Products and Services)
'Increase Customer Value' (Customer Management Processes)
'Achieve Operational Excellence' (Operations & Logistics Processes)
'Be a Good Neighbour' (Regulatory & Environmental Processes)
Learning & Growth Perspective
Employee Competencies
Technology
Corporate Culture

Figure 3.12: Sample Strategy Map (Kaplan and Norton, 2000)

Clinton and Hsu (1997) developed metrics linking manufacturing control activities to management control metrics via the BSC for JIT production environments, and only three out of twenty seven metrics are categorised as financial measures. These are inventory costs, cash flow, return on investment and percent of revenue from investment. Similarly, three measures (i.e. time spent outside primary work area, average number of jobs the worker is trained to perform and number of new products) were categorised under innovation and growth while number of customer complaints and enterprise market share gave an indication of customer satisfaction. The other nineteen measures are classed under internal business processes.

The BSC pays little attention towards rewards, recognition and final feedback to relevant stakeholders and is primarily designed for senior managers to get an overall view of performance. This tool therefore is not intended for the factory floor level. However, Dabhilkar and Bengtsson (2004) conducted a study at “Sapa Heat Transfer”, a Swedish manufacturer and designed scorecards for the company, functional and operational levels, which are revised every year by the management and supervisory team. Another manufacturer called SKF, successfully adopted plant, production line and continuous improvement team level scorecards comprising both strategic objectives and measures from financial, customer and process perspectives (Dabhilkar and Bengtsson, 2004). Abdel-Maksoud *et al.*, (2005) found that at shop-floor level, much of the performance measurement and reporting is non-financial.

However, the BSC concept does not provide any mechanism to identify KPIs, specific target levels and proper method to measure current performance of the business. BSC performance indicators are thought to be unique to every organisation and do not support inter-industry comparisons and benchmarking. Bond (1999) stated that a notable omission of BSC is direct personnel measures. According to Abdel-Maksoud, (2005), 'human resources' do not readily map onto the Kaplan and Norton BSC. CIMA (1993, cited in Abdel-Maksoud, 2005) suggested that ideas for improving JIT processes and performance for customers must increasingly come from front-line workers. Moreover, BSC neglects external factors such as suppliers, environmental and social perspectives which are major perspectives in JIT enabled manufacturing environments.

3.6 COMPARISON OF MULTIDIMENSIONAL PMSS

Table 3.1 compares the strengths and weaknesses of the aforementioned eight multidimensional PMSs. All PMSs have integrated both financial and operational measures. Most of those systems, excluding the EFQM framework, provide broad and non-perspective templates, where managers can develop their own measures to measure performance. The lack of a mechanism to identify KPI is a common weakness of all aforementioned PMSs, except EFQM framework. Hence, all PMSs (except EFQM framework) do not support inte-organisation comparisons and benchmarking.

Having considered the research context, aim and objectives with strengths and weaknesses of the above PMSs (refer to Table 3.1), Kaplan and Norton's BSC is selected for further study. By focusing not only on financial performance but also on drivers of it, such as customer satisfaction, efficiency of internal business processes, and innovation and growth, the BSC provides a more comprehensive view of business performance. The BSC is a flexible, simple and easy to use concept, which in turn helps organisations to act in their best long-term interests. Section 3.7 addresses some weaknesses in the traditional BSC concept.

Table 3.1: Strengths and Weaknesses of Multidimensional PMSs

Multidimensional PMS	Strengths	Weaknesses
SMART System	▪ Integrate corporate objectives with operational performance indicators.	▪ No proper mechanism to identify key performance indicators. ▪ No specific targets for performance levels. ▪ Does not support the concept of continuous improvement. ▪ No proper mechanism to measure current performance of the business ▪ External factors such as suppliers, environmental and social groups are not addressed ▪ Does not directly support cross industry comparisons or benchmarking
Performance Measurement Questionnaire (PMQ)	▪ Provide mechanism to evaluate the importance of improvement and improvement areas. ▪ Help to identify the effect of current performance measures on improvement	▪ No specific targets for performance levels. ▪ Content of improvement areas and performance factors are vary from industry to industry ▪ So does not directly support cross industry comparisons or benchmarking
Performance Measurement Matrix for Time-Based Competition	▪ Aiming at shrinking the elapsed time between customer decision to buy and product delivery ▪ Simple, detailed and specific performance measurement framework ▪ Encourage continuous improvement and innovation	▪ Most suitable for time-based competitors ▪ Performance indicators are mainly focus on time and time measurement ▪ Does not include customer and human resources dimensions ▪ Does not directly support cross industry comparisons or benchmarking
Performance Prism	▪ Highly flexible ▪ Recognise reciprocal relationship between stakeholders and organization. i.e. Stakeholder satisfaction and stakeholder contribution	▪ Provide little guidance on how to select appropriate measures ▪ Performance measures are vary from organization to organization and non-supportive for benchmarking ▪ Less concern on innovation and continuous improvement.
Integrated Dynamic Performance Measurement System	▪ Relates strategic areas of success and appropriate measures ▪ Provide tools to identify different areas of success, performance measures and performance indicators ▪ Works as a continuous improvement tool ▪ Provide a small number of critical performance measures which save time, money and effort	▪ Performance indicators are vary from industry to industry ▪ Performance indicators are using for internal reporting only ▪ Does not directly support cross industry comparisons or benchmarking ▪ External parties and their influence is not integrated to the performance measurement system
Integrated Performance Measurement Model	▪ Enable strategic objective identification ▪ Performance measure under 4 levels: Corporate, Business unit, Business process and Activities ▪ Stimulate continuous improvement	▪ No proper mechanism to identify key performance indicators (KPIs). ▪ Does not directly support cross industry comparisons or benchmarking
EFQM Framework	▪ Self assessment tool based on TQM and emphasis on nine criteria ▪ Criteria and performance indicators used are same for any organization to enable benchmarking. ▪ Outcome describes the current performance of the business. ▪ Encourage continuous improvement	▪ No specific targets for performance levels. ▪ Fixed and complex measurement criteria. ▪ Less emphasis on financial performance.
Balanced Scorecard	▪ Translates a company's strategic objectives into a coherent set of performance measures with four different perspectives ▪ Flexible, simple and easy to use. ▪ Able to extend BSC within organization through cascading specially designed scorecards at the functional level and operational level, which are linked into company BSC. ▪ Encourage continuous improvement	▪ Performance indicators are unique to every organization. ▪ Primarily designed for top management decision-making. ▪ No specific targets for performance levels. ▪ No proper mechanism to measure current performance of the business ▪ External factors such as suppliers, environmental and social groups are not addressed ▪ Does not directly support cross industry comparisons or benchmarking

3.7 NEW PERSPECTIVES ON THE TRADITIONAL BALANCED SCORECARD

A decade ago, Hepworth (1998) argued that the BSC is more acceptable within the US management culture than the more conservative British equivalent and questioned, “Why the BSC concept remains unused in the UK?” There is no evidence in literature on the reasons for this lack of implementation within the UK. 2GC (2001) compared the BSC and the EFQM models and found that BSC is a tool to do the right things whereas the EFQM model is designed as a diagnostic tool to do things right. According to Punniyamoorthy and Murali (2008), for an organisation to be successful, they must be willing to adopt any processes and accept any benchmarking standards which would help them in not only doing things right but also in doing the right thing. Further, 2GC research group pointed out that the BSC information is not directly useful for cross industry comparisons or other benchmarking activities. According to the Kanji and Sa (2001), BSC is only a conceptual model, which is not easy to convert into a measurement model.

Furthermore, few researchers introduced new perspectives to the traditional BSC. Lohman *et al.* (2004) developed a cluster method for the performance matrix selection and it resembles the BSC, but extended with clusters for sustainability and people (Figure 3.13). The study developed BSC tailored to the needs of the European Operations Department of Nike (sportswear manufacturer). The researchers have categorised employees under people cluster, but have not considered suppliers, socio-cultural groups and innovation in their model.

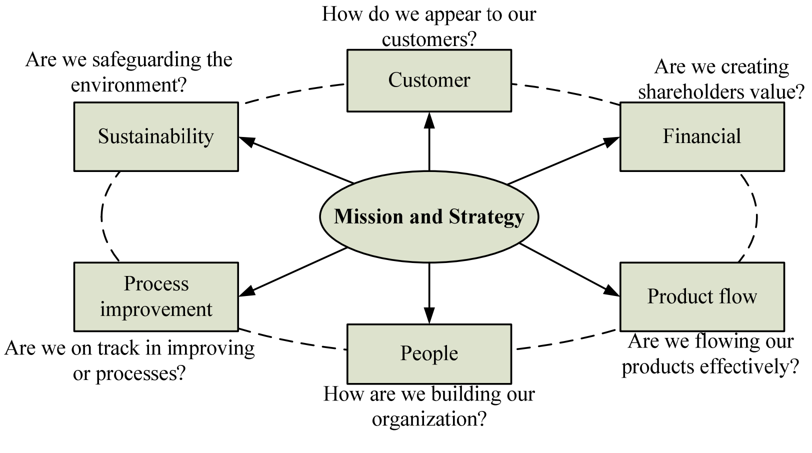

How do we appear to our customers?
Customer
Are we safeguarding the environment?
Sustainability
Are we creating shareholders value?
Financial
Mission and Strategy
Process improvement
Are we on track in improving or processes?
Product flow
Are we flowing our products effectively?
People
How are we building our organization?

Figure 3.13: BSC with New Clusters for ‘Nike’ Operations (Lohman *et al.*, 2004)

Furthermore, Searcy (2004) introduced a BSC for lean enterprise with new categories. In his BSC framework, the four perspectives of traditional BSC are retained, but the internal business processes perspective is subdivided into three subcategories: operating performance, safety and product quality. However, Searcy has also not considered suppliers, socio-environmental groups and innovation perspectives in the BSC framework.

Lohman *et al.* (2004) and Searcy (2004) introduced the abovementioned new perspectives to the traditional BSC based on the operations of the case study companies. Moreover, both studies ignored suppliers, socio-environmental groups and innovation perspectives in their organisation specific scorecards. The development of an extended BSC to address these gaps therefore became another task of this study.

3.8 DEVELOPMENT OF AN EXTENDED BALANCED SCORECARD CONCEPT

Currently, JIT enabled manufacturing enterprises are involved in complex supply chains and focused on human resource management and socio-cultural and environmental activities. Traditional BSC failed to highlight employee and supplier contributions and not considering regulators, local community, environmental bodies and pressure groups. Hepworth (1998) and Ahn (2005) suggested that additional perspectives should be included if applicable and necessary. Lee *et al.* (2008) also mentioned that “depending on the sector in which a business operates and on the strategy chosen, the number of perspectives can be enlarged, or one perspective can be replaced by the other”. Thus, the traditional BSC would need to be expanded to incorporate other perspectives such as “supplier”, “employee” and “external socio-environmental groups” in order to represent new trends in the JIT enabled manufacturing industry (Sandanayake and Oduoza, 2007). Considering the strengths and weaknesses of the BSC frameworks discussed in Section 3.7, Figure 3.14 introduces an extended BSC and depicts the relevant KPIs in BSC perspectives.

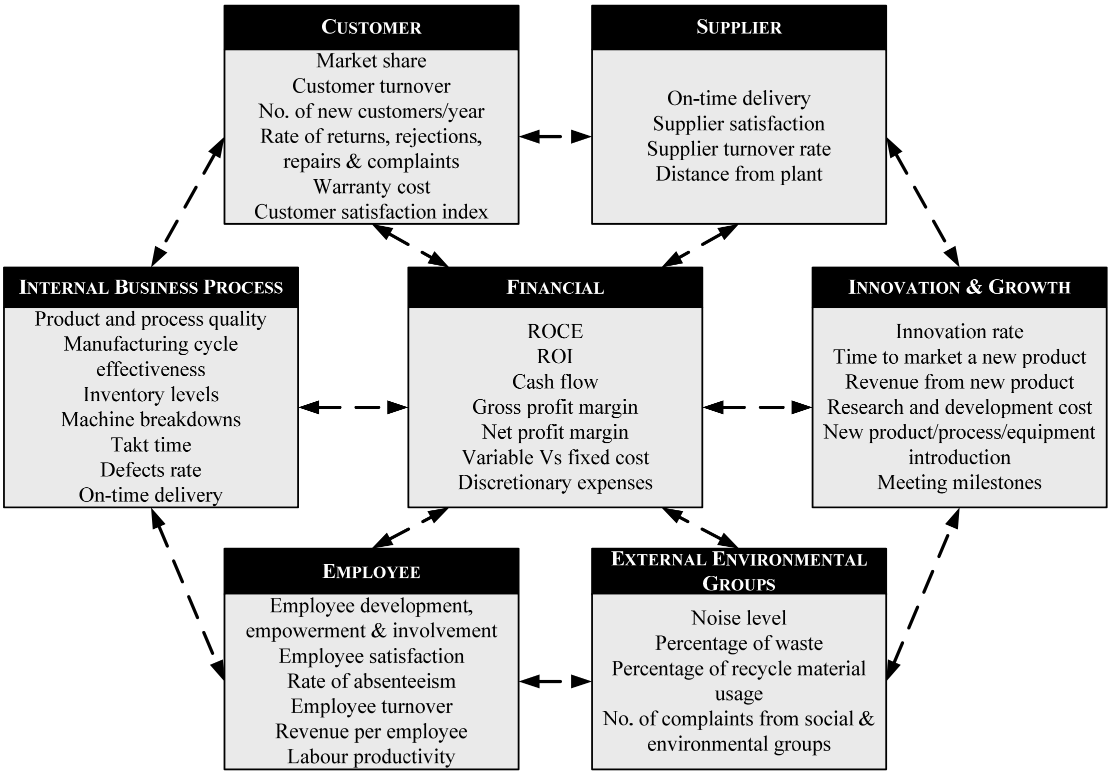


Figure 3.14: Extended Balanced Scorecard Concept (Extended BSC)

3.8.1 Employee Perspective

"To satisfy our employees and improve their performance, how should we inculcate organisational citizenship?"

Employee relationships and teamwork play a vital role in the present day JIT enabled manufacturing environment. In order to achieve flexible manufacturing, workers should be able to move to different plants, workstations or functions according to the demand of production in the present production environment. Japanese managers treat all workers equally, allocate daily job responsibilities, evaluate their performance, and provide potential lifetime employment (Kim and Takeda, 1996). The employee relationships inculcate organisational citizenship and encourage behaviours such as punctuality, teamwork, effective quality circles, multifunction ability, problem solving, volunteering and innovations. Obviously, cultivating or training the individual worker to become a multifunctional employee is an important part of achieving flexibility and employee satisfaction. Thus, the employee perspective plays a vital role in a good PMS and should include CSFs such as competency and satisfaction and performance measures such as employee satisfaction, employee turnover, revenue per employee and labour productivity.

3.8.2 Supplier Perspective

"To achieve target production, what operating parameters do we want suppliers to adhere to?"

Supplier relations and collaboration are relatively new areas that come under JIT manufacturing and supply chain management and supplier relationship management in the modern manufacturing era. The major objective of supplier integration is to improve flow and coordination between an enterprise and its suppliers. Nakamura *et al.* (1998) identified that Japanese business practices tend to emphasise long-term business relationships with suppliers. The number of suppliers in the present manufacturing environment is typically much smaller than in traditional systems and the aim is to increase accountability for quality, delivery and service problems, develop stable and repetitive delivery schedules and eliminate paperwork (Reid and Sanders, 2005). Upton (1998) found that JIT firms use supplier quality and on-time delivery measures to a greater extent than non-JIT firms. It is essential to evaluate supplier performance and satisfaction and give feedback and necessary advice to suppliers regularly in order to uphold their performance. Supplier responsiveness is a CSF and on-time delivery, quality rejects, supplier satisfaction, supplier turnover are common supplier related performance measures.

3.8.3 External Socio-Environmental Groups Perspective

"To meet with external requirements such as legislations, how will we use our ability and resources to comply?"

Two current popular paradigms are lean thinking and sustainable manufacturing. Lean manufacturing is the systematic elimination of all kinds of production wastes such as over-production, waiting, transportation, inventory, motion, over-processing and defects. Sustainable manufacturing involves transformation of materials using renewable resources without emission of greenhouse gases or generation of waste. Every company has internal customers (employees), near external customers

(customers and suppliers) and far external customers (social, legal, technological, economic, environmental and political). This perspective concentrates on the far external customers or stakeholders. For example, social and environmental groups might be concerned about air emissions or other releases from manufacturing plants, while political and legal groups are concerned with issues such as labour conditions. On the other hand, technological and economical groups may be keen on the use of renewable energy sources and resources. The external stakeholder's perspective should therefore play a vital role in performance measurement in JIT enabled production environment. This perspective includes CSF such as sustainability and measures such as noise levels, percentage of waste, usage of renewable resources and recycled material and number of complaints from social and environmental groups.

Addition of these three new dimensions to the traditional BSC will form a comprehensive multidimensional PMS suitable for the present day manufacturing environment.

3.9 PRE-REQUISITES OF AN INTEGRATED PERFORMANCE MEASUREMENT SYSTEM

In designing a successful PMS, the organisation must consider the needs of the various stakeholders as stated in the company strategic plan. The company strategy is determined based on company vision, mission and core competencies and is driven by the critical success factors (CSFs). BSC is a performance management system that can be used by any organisation to align the vision and mission with all functional requirements (Punniyamoorthi and Murali, 2008). According to the research carried out by Dixon *et al.* (1990), Bititci *et al.* (1997), Bassioni *et al.* (2004) and Luu *et al.* (2008), performance measures have direct relationships with the CSFs of the company and also performance indicators may affect CSFs (refer to Section 3.5). The CSFs are the forces driving the performance measurement and management process, and key performance indicators (KPIs) are measures of CSFs. The degree of specification and frequency of usage of operational measures are high at production cell level, whereas the degree of specification and frequency of usage of financial measures are high at company level. Therefore, an integrated PMS should facilitate the production of a high quality product at the right time in the right quantity in the most economical and productive manner. Figure 3.15 shows the pre-requisites of a PMS in a typical production environment.

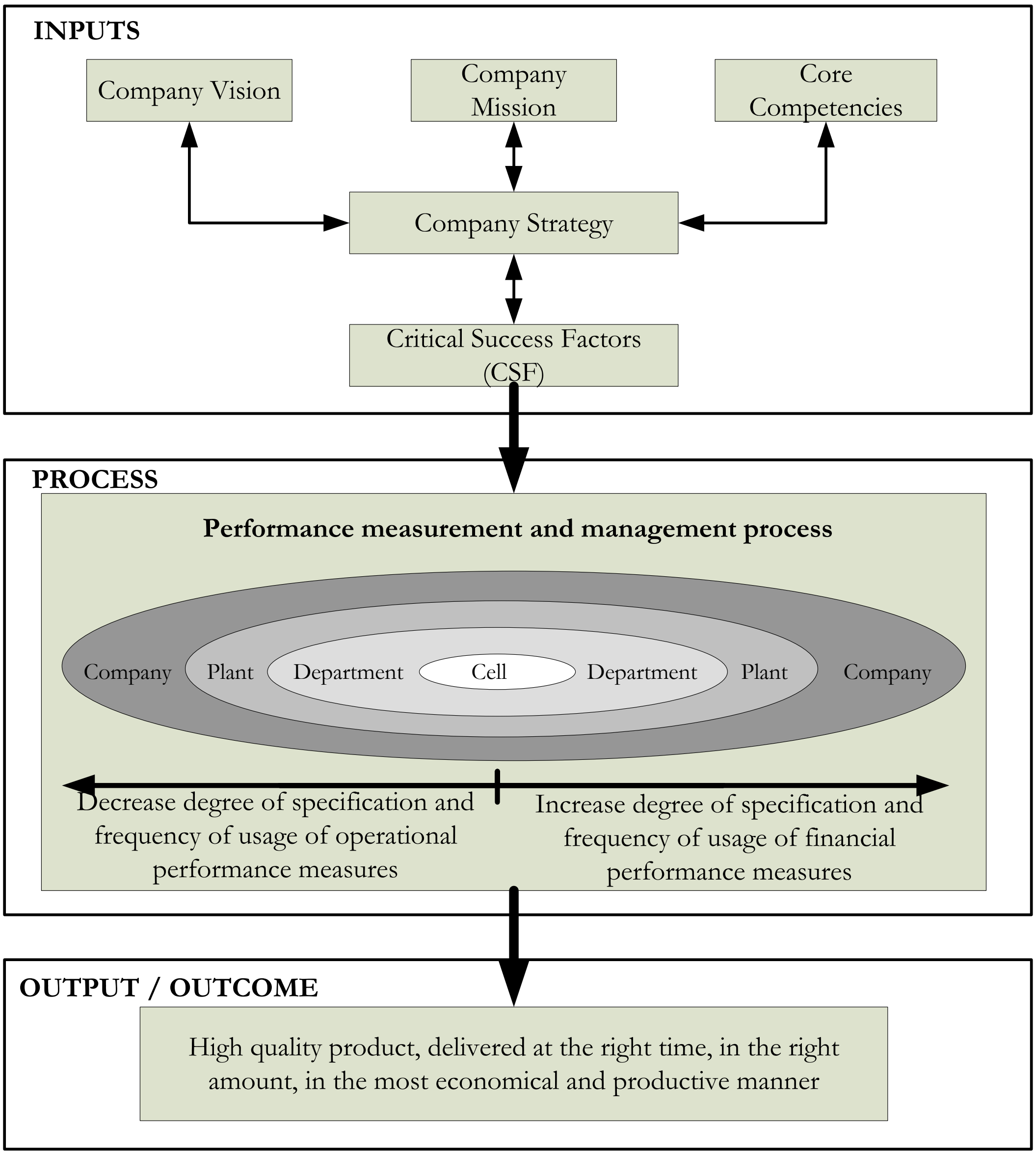

INPUTS
Company Vision
Company Mission
Core Competencies
Company Strategy
Critical Success Factors (CSF)
PROCESS
Performance measurement and management process
Company
Plant
Department
Cell
Department
Plant
Company
Decrease degree of specification and frequency of usage of operational performance measures
Increase degree of specification and frequency of usage of financial performance measures
OUTPUT / OUTCOME
High quality product, delivered at the right time, in the right amount, in the most economical and productive manner

Figure 3.15: Pre-requisites of PMS in a Typical Production Environment

In a typical manufacturing environment, the unique, TQM related and human/strategic oriented JIT techniques (refer to Section 4.3) are implemented at cell, department, plant and company levels. For example, techniques such as line balancing, setup time elimination plans, level schedules, group technology, quality control activities, TPM and multifunction employee are implemented at cell level. Techniques such as pull system, focused factory, inventory transportation systems, quality circles, value analysis, integrated product and process design, workplace organisation plans, effective communication are implemented at department or plant levels. Moreover, techniques such as JIT purchasing, supplier integration, employee training, innovation and investment plans, and other control techniques are implemented at plant or company levels. Different JIT techniques, therefore, affect the performance of different levels of the organisation structure. Thus, it is essential to assess the impact of JIT techniques on:

- operational performance at the cell level
- organisational competitive priorities at the departmental, plant and company levels

The conceptual model developed in Section 4.4 and the performance measurement model implementation procedure introduced in Section 6.3 will provide necessary tools to quantify the impact of JIT drivers on operational performance. The model and implementation procedure also provide a criterion to assess the influence of JIT drivers on organisational competitive priorities using the extended BSC tool.

3.10 SUMMARY

This chapter has presented an overview of PMSs in a production environment. It also has reviewed the financial and operational PMSs and highlights the drawbacks of financial PMSs. The chapter has compared the strengths and weaknesses of well-known and better structured multidimensional PMS.

From the literature review carried out in this chapter, the following conclusions can be drawn:

- Financial performance measures are no longer adequate for performance measurement in the present day manufacturing scenarios since they are based on past financial data and appear inflexible in performance measurement. Financial measures are considered as lagging indicators.
- There is a need for multidimensional PMS, which integrates both financial and operational measures in order to facilitate robust decision-making.
- All aforementioned PMSs emphasise the need to integrate both outcome measures (lagging indicators) and driver measures (leading indicators).

Outcome measures without driver measures do not communicate how the outcomes are to be achieved. Driver measures without outcome measures fail to recognise whether improvements in operational measures have translated into financial performance.

- All existing models excluding the EFQM framework provide broad and non-perspective templates, where managers can develop own measures to match their business strategy and vision.
- All multidimensional PMSs (except EFQM framework) are lacking in a mechanism to identify KPIs and hence performance indicators vary from industry to industry. As a result, existing PMSs do not support inter departmental comparisons and benchmarking.
- Organisations who are wishing to implement or upgrade PMS, should consider multidimensional approach such as the extended BSC, which is capable of assessing enterprise performance not only from economic and financial standpoints but also based on customer, employee, supplier, innovation and growth, socio-environmental as well as internal business processes perspectives.

This chapter therefore has discussed the need to develop a multidimensional PMS in the present day JIT enabled manufacturing environment and introduced an extended BSC concept. Thus, Part II of Objective 1 has been addressed.

CHAPTER 4: MULTIDIMENSIONAL PERFORMANCE MEASUREMENT SYSTEM – A CONCEPTUAL MODEL

4.1. INTRODUCTION

The aim of this chapter is to develop a conceptual model for performance measurement in JIT enabled manufacturing environments. Chapter 4 reviews key literature and presents informal discussion findings that are used to develop a conceptual model for this study. The extensive set of JIT techniques are classified into three elements, unique, TQM related and human/strategic oriented JIT practices, and incorporated into an integrated framework of JIT practices. Finally, the chapter presents a conceptual performance measurement model that will guide further investigation for this research. The main purpose of developing the model is to build a relationship between operational JIT drivers and measurable performance. As a whole, Chapter 4 addresses the Objective 3 of this study.

4.2 MULTIDIMENSIONAL PMSS IN JIT ENVIRONMENTS

JIT techniques have direct and indirect impact on financial and operational performance. For example, techniques such as Kanban, JIT purchasing and supplier integration provide quick and precise information about inventory requirement at each stage of the production process and hence minimise storage requirements, overproduction, waste, running and capital cost and improve product quality, on-time delivery and process efficiency. JIT techniques such as line balancing, setup time elimination plans, level schedules, group technology, focused factory, fast inventory transportation systems improve manufacturing cycle efficiency, reduce lead time and in turn contribute to profitability. Furthermore, quality control, quality circles, value analysis, integrated product and process design, total productive and preventive maintenance, and workplace organisation plans improve quality of product and process, minimise defects, wastes and environmental impact and ultimately improve profitability and customer satisfaction. Top management commitment, employee training, multifunctional ability of employees and innovations enhance productivity and production cost savings. A well-developed multidimensional PMS therefore, must consider all JIT drivers relevant in the manufacturing environment and consider their direct and indirect impact on performance for each perspective.

A comprehensive literature review (refer to Chapters 2 and 3, and Sections 4.2.1 and 4.3) and informal interviews/discussions (refer to Section 4.2.2) have been employed to develop a conceptual performance measurement model. Literature survey and informal interviews/discussions together with research methods used for this study are presented in Sections 5.5.1 and 5.5.2.

4.2.1 Performance Measurement in JIT Environments – A Review

JIT has become somewhat of a catchphrase in last few decades with heavy overlaps to concepts such as TQM, TPM, CI, time based manufacturing and business process re-engineering (Flynn *et al.*, 1995, Mazany, 1995, Sriparavastu and Gupta, 1997 and Cua *et al.*, 2001). It also involves an external focus and cooperation with suppliers (Mazany, 1995). There have been only a few attempts at defining the components of JIT philosophy (Spencer and Guide, 1995) as it has been described as a comprehensive production and inventory control system. A few decades ago, researchers failed to incorporate quality improvement and employee involvement activities as integral parts of JIT philosophy (White and Ruch, 1990). Five year IMVP study of the motor industry also did not test the relationship between human resource practices and performance (Womack *et al.,* 1990). MacDuffie (1995) also confirmed that despite the claims that human resource (HR) practices can boost firm-level performance, few studies have been able to confirm the relationship empirically. Thus, thereafter, researchers such as Flynn *et al.* (1995), MacDuffie (1995), Karlsson and Ahlstrom (1996), Sakakibara *et al.* (1997), Sriparavastu and Gupta (1997), Cua *et al.* (2001), Fullerton *et al.* (2003) and Shah and Ward (2003) have all studied the relationship between quality improvement, human involvement and JIT activities.

Flynn *et al.* (1995) therefore proposed that the use of TQM practices would enhance JIT performance through process variance reduction and improve quality performance through problem exposure. Their study proved that there is a relationship between TQM and JIT practices and performance. MacDuffie (1995) mentioned that much of the research on the performance of manufacturing environments has emphasised on either technical system (JIT) or HR system without fully exploring the interaction of the two systems. Hence, MacDuffie (1995) developed three indices (use of buffers, work systems and human resource management) to capture systematic differences in organisational logic between mass production and flexible production (JIT) and found that each of the indices has high internal consistency, in terms of inter-correlations among the human resource bundled practice.

Vuppalapati *et al.* (1995) rejected the traditional view of treating JIT and TQM as two separate approaches and presented three different views of JIT-TQM implementation and effectiveness of each view as shown in Figure 4.1.

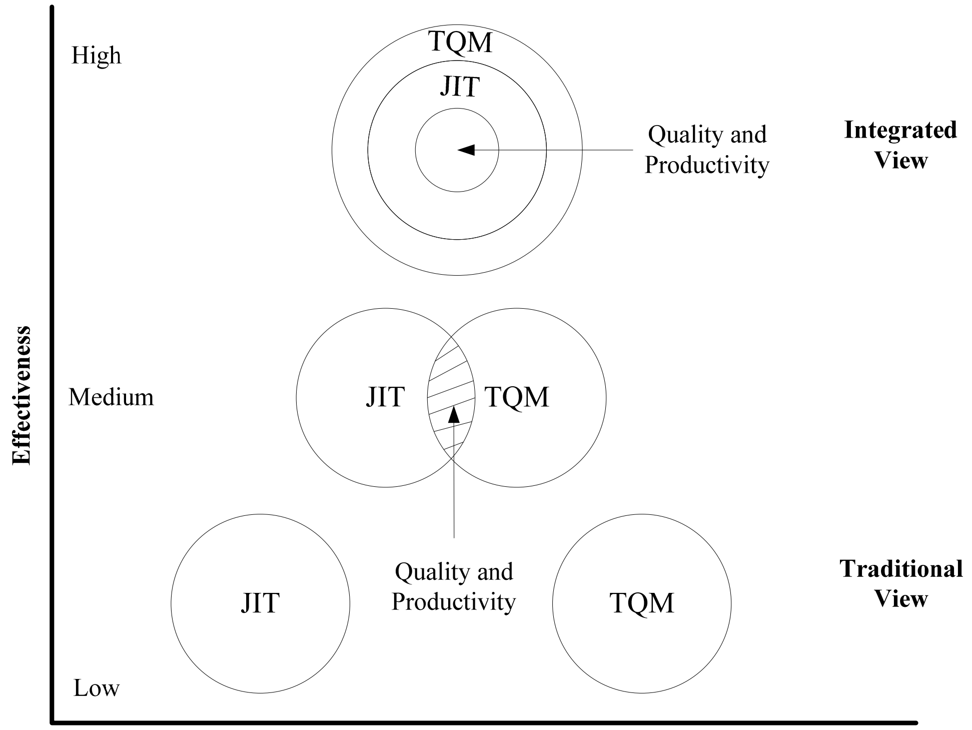


Figure 4.1: Three Views of JIT-TQM Implementation (Vuppalapati, *et al.* 1995)

Karlsson and Ahlstrom (1996) developed an operationalised model (Figure 4.2) which can be used to assess the changes taking place in an effort to introduce lean production. The model summarised various principles characterising different functional areas and the overall strategy of the lean company. However, the model did not present the link between lean factors and performance of lean organisation. Moreover, Karlsson and Ahlstrom (1996) considered JIT as one principle of lean production and used the term in a narrower way than is often considered in literature.

Further, the authors considered lot size, work in progress, order lead time and level of JIT as the determinants that are highly interrelated with JIT, without detailed justification.

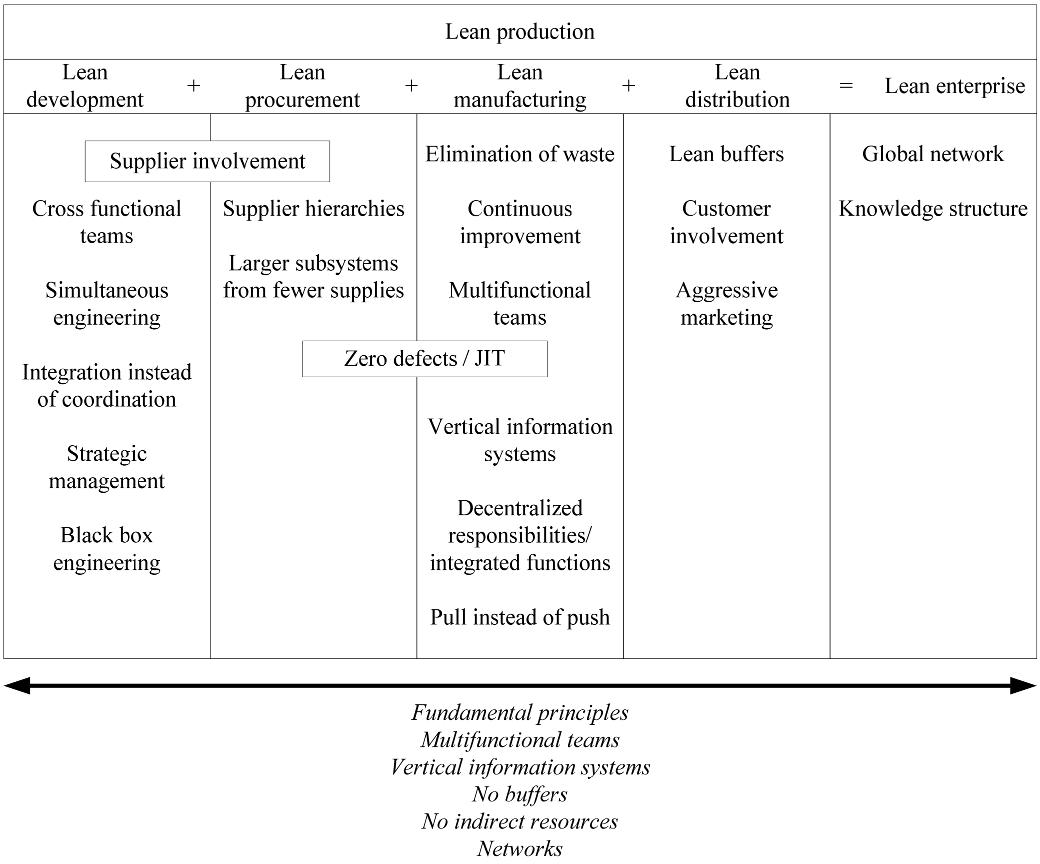


Figure 4.2: Functional Areas of Lean Production (Karlsson and Ahlstrom, 1996)

Cua *et al.* (2001) developed a theoretical model (Figure 4.3) to test the impact of basic JIT, TQM, TPM and human and strategic oriented practices on manufacturing performance. They identified some common practices that are shared by all three programs and classified those under human and strategic oriented common practices. Each JIT, TQM and TPM programs have technical and process oriented unique practices. Based on extensive empirical survey of 163 manufacturing plants they draw the following conclusions.

- a high level of manufacturing performance is expected when JIT, TQM, TPM and human and strategic oriented practices are jointly implemented
- cost efficiency and on-time delivery are positively associated with TQM, JIT and TPM

- quality is strongly associated with the implementation of TQM and human and strategic oriented practices
- flexibility does not have a significant relationship with all four practices

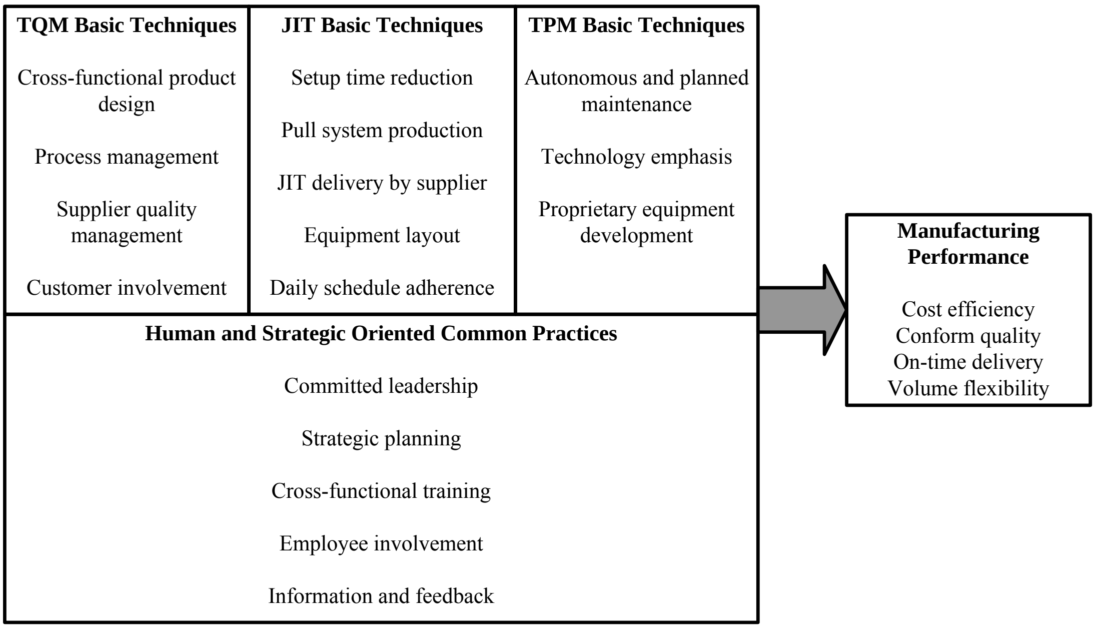


Figure 4.3: Theoretical Model of Relationship between Manufacturing Practices and Performance (Adapted from Cua *et al.*, 2001)

Sakakibara *et al.* (1997) defined JIT as an overall organisational philosophy and focused on the impact of both JIT practices and their supporting infrastructure practices on manufacturing performance. They introduced a conceptual model to investigate the relationship between JIT practices and manufacturing performance (Figure 4.4). Their results show that:

- there is a very strong relationship between JIT and infrastructure practices
- the combination of JIT management and infrastructure practice is related to manufacturing performance
- infrastructure, by itself, is sufficient to explain manufacturing performance
- manufacturing performance is related to competitive advantage

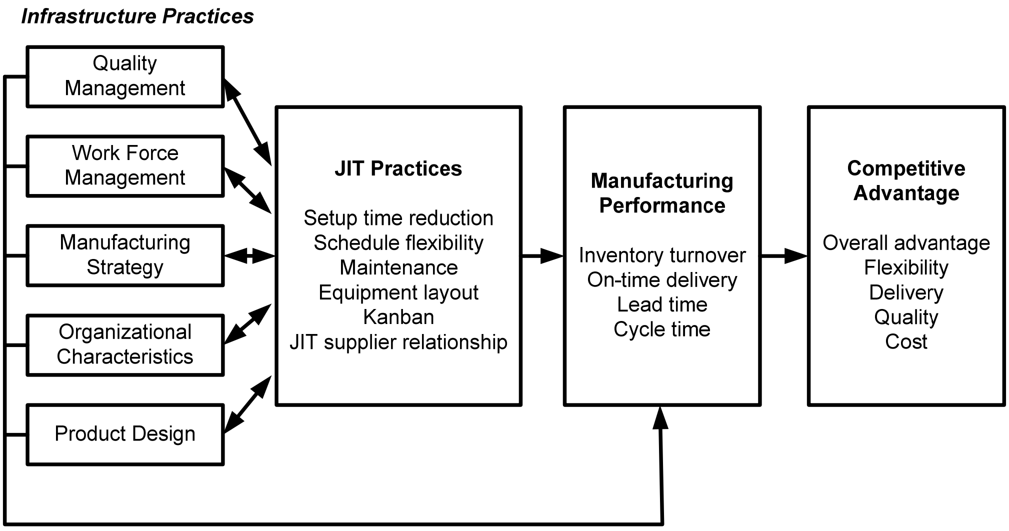


Figure 4.4: Conceptual Model to Investigate the Impact of JIT and Its Infrastructure on Manufacturing Performance (Sakakibara *et al.*, 1997)

The findings of Sakakibara *et al.* (1997) provided support for the notion that JIT is an overall organisational phenomenon rather than strictly limited to shop floor practices. However, their model is limited to a few JIT techniques and performance measures.

The study of Sriparavastu and Gupta (1997) concluded that an integration of JIT and TQM gives significantly higher performance levels than implementing either one or the other alone. Their two major conclusions were:

- Manufacturing units implementing JIT and TQM strategies observe increased quality standards when compared to manufacturing units implementing only JIT strategies; the improvement in quality standards can be attributed to TQM strategies
- Manufacturing units implementing JIT and TQM strategies have increased productivity levels when compared to units implementing only TQM strategies; the improvement in productivity level can be attributed to JIT strategies (Sriparavastu and Gupta, 1997)

McLachlin (1997) categorised JIT techniques in to three categories, i.e. management initiatives, flow elements and quality elements. The researcher further identified six management initiatives and tested whether each is necessary for JIT implementation (Figure 4.5).

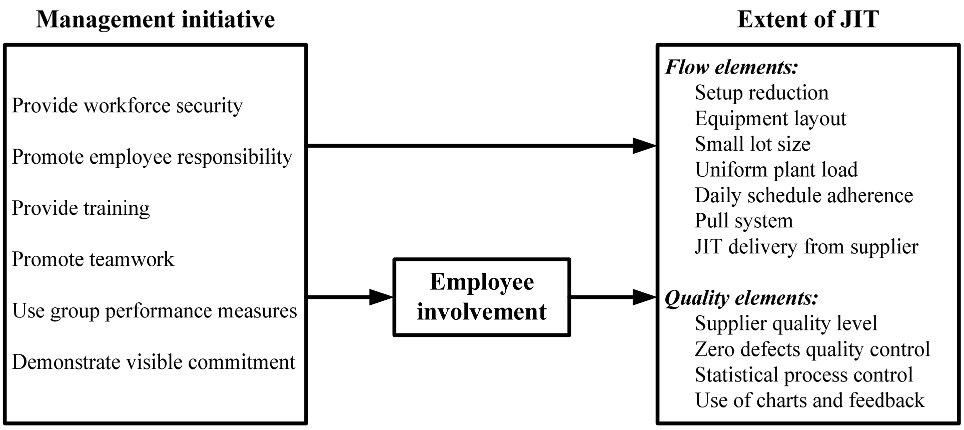
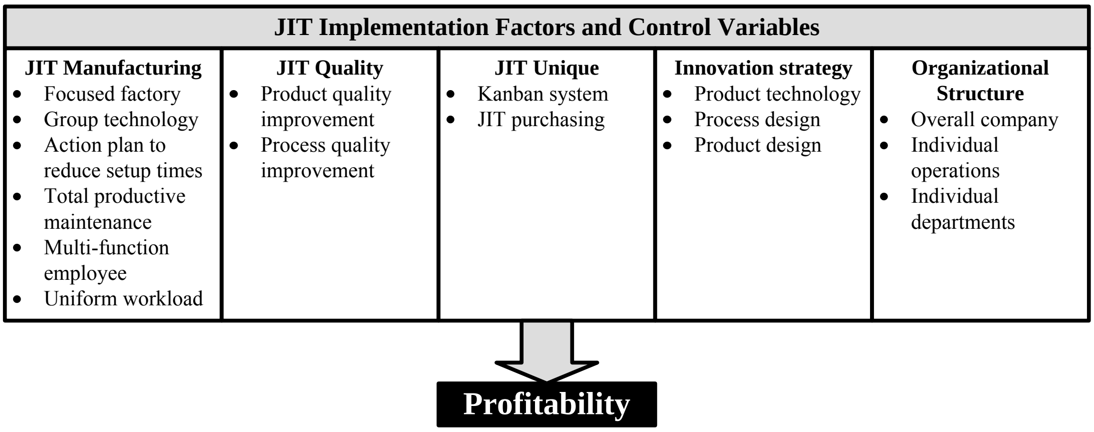


Figure 4.5: Impact of Six Management Initiatives on Extent of JIT Implementation (McLachlin, 1997)

Out of six management initiatives, four were supported as necessary conditions for JIT flow, JIT quality and employee involvement, namely, (1) promotion of employee responsibility, (2) provision of training, (3) promotion of teamwork and (4) demonstration of visible commitment (McLachlin, 1997).

Fullerton *et al.* (2003) studied the impact of five JIT implementation factors and their control variables on profitability (Figure 4.6). Three variants of profitability measures are used as the dependent variable for hypotheses testing: *return on assets*, *return on sales*, and *cash flow margin*. The Fullerton group carried out a survey among 253 US manufacturing firms to establish the relationship between measures of profitability and JIT practices.



JIT Implementation Factors and Control Variables				
JIT Manufacturing	**JIT Quality**	**JIT Unique**	**Innovation strategy**	**Organizational Structure**
• Focused factory • Group technology • Action plan to reduce setup times • Total productive maintenance • Multi-function employee • Uniform workload	• Product quality improvement • Process quality improvement	• Kanban system • JIT purchasing	• Product technology • Process design • Product design	• Overall company • Individual operations • Individual departments

Figure 4.6: Relationship between JIT Implementation Factors and Profitability (Adapted from Fullerton *et al.*, 2003)

Fullerton *et al.* (2003) developed a multiple linear regression model to link JIT measures with profitability (refer to Eq: 6.2 in Chapter 6). Their research findings indicated that:

- the firms that implement higher degrees of JIT manufacturing practices outperformed competitors who do not
- the implementation of higher degrees of JIT quality practices decreased firm profitability
- implementation of JIT unique measures demonstrated no significant relationship with profitability

However, Fullerton *et al.*'s (2003) study was limited to financial performance measures.

Moreover, Shah and Ward (2003) proposed JIT, TQM, TPM and HRM as four lean bundles of inter-related and internally consistent practices. The researchers divided JIT practices into four lean bundles using principal component analysis as shown in Figure 4.7. The results indicate that implementation of lean bundles contribute substantially to the operating performance of plants. However, Shah and Ward (2003) identified 22 lean practices from JIT/Toyota production literature.

JIT	TPM	TQM	HRM
▪ Lot size reduction ▪ JIT/ Continuous flow production ▪ Pull system ▪ Cellular manufacturing ▪ Cycle time reduction ▪ Focused factory production systems ▪ Agile manufacturing strategies ▪ Quick changeover techniques ▪ Bottleneck/constraint removal ▪ Reengineered production processes	▪ Predictive and preventive maintenance ▪ Maintenance optimisation ▪ Safety improvement programs ▪ Planning and scheduling strategies ▪ New process equipment or technologies	▪ Competitive benchmarking ▪ Quality management programs ▪ Total quality management ▪ Process capability measurement ▪ Formal continuous improvement program	▪ Self-directed work teams ▪ Flexible, cross-functional workforce

Operational Performance

Figure 4.7: Relationship between Lean Bundles and Operational Performance (Adapted from Shah and Ward, 2003)

More recently, Mistry (2005) developed a data-supported model by linking JIT-driven processes in the supply chain to profitability (Figure 4.8). Their model integrated three sets of variables, i.e. JIT-driven processes in the supply chain, mediating improvements in the production processes and the financial performance indicators. However, Mistry has not tested and validated the model.

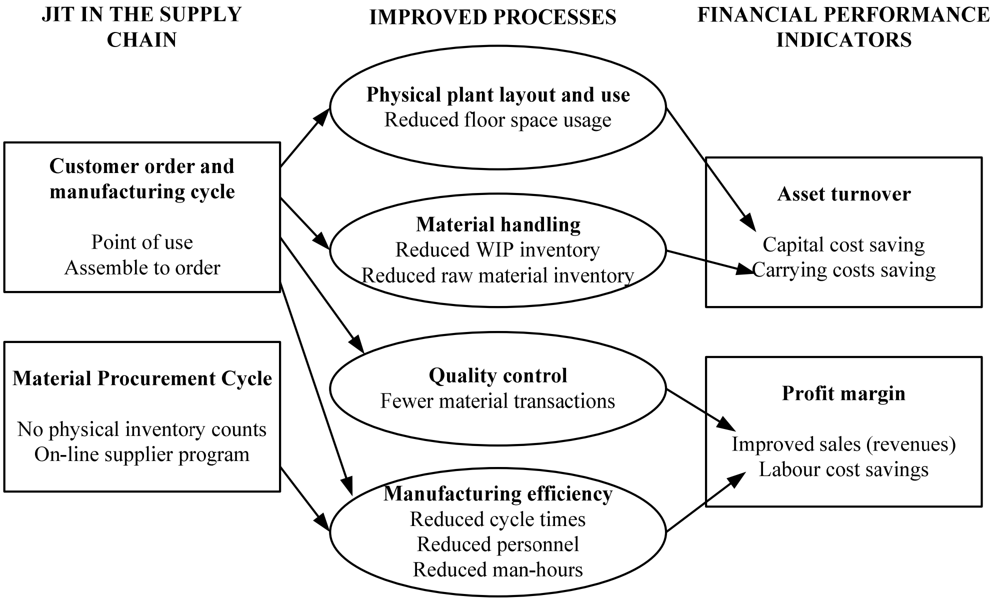


Figure 4.8: Data Supported Model of JIT Driven Profitability (Mistry, 2005)

The conceptual models developed by Fullerton *et al.* (2003) and Mistry (2005) were aimed at assessing the impact of selected JIT techniques on financial performance. Sakakibara *et al.*, (1997), Cua *et al.*, (2001) and Shah and Ward (2003) on the other hand, studied the impact of JIT/lean techniques on selected operational performance measures. The studies of Sakakibara *et al.*, (1997), Sriparavastu and Gupta (1997), Cua *et al.*, (2001) and Fullerton *et al.* (2003) were intended to identify the relationship of the JIT concept with TQM and other infrastructural practices, and assess the significance of joint implementation on performance.

The aforementioned performance measurement models have their strengths and weaknesses. These models were either limited to financial or operational performance measurement or developed based on few JIT techniques. The abovementioned models, and their strengths and weaknesses are therefore taken into account in developing a conceptual performance measurement model (refer to Figure 4.10) for this research study.

4.2.2 Data Acquisition from Informal Interviewing in JIT Production Plants

Three plants that had implemented JIT were visited to further refine and analyse the list of JIT techniques given in Table 2.3. Informal interviews/discussions were carried out with some production managers and shop floor operators (refer to Section 5.5.2). The plants were in three different industries (i.e. automotive, construction and manufacturing), and were located in the West Midlands.

Table 4.1 presents the findings of informal interviews/discussions carried out amongst top-level managers and shop floor operators in three different manufacturing organisations: Denso Manufacturing (UK) Ltd., Metsec Plc., and Bemason Ltd. The researcher had an opportunity to visit the sites to conduct interviews/discussions and was shown around the premises. Observation was also useful for data acquisition on JIT practice implemented and performance in the case study production environments. The informal interview organisations, participants and typical questions raised during informal interviews/discussions are presented in Section 5.5.2. These discussions and observations offered valuable insights and were useful in identifying the following:

- JIT practices implemented in their own production environments
- performance measures used to evaluate the plant performance

According to the informal interview findings, the different organisations used different JIT techniques, performance measurement systems and measures. All organisations studied used both financial and non-financial measures to assess firm performance. The number of performance measures and complexity of PMS increased with the size of the company and the complexity of the product or process. The degree of specification and frequency of usage of operational measures were high at production cell/line level, whereas the degree of specification and frequency of usage of financial and customer satisfaction measures were high at company level. Profitability was the common financial measure and lead-time, on-time delivery performance and scrap levels were common operational performance measures for all three companies. It was also observed that most of the JIT techniques were implemented at factory floor level.

Table 4.1: Summary of JIT Techniques and Performance Measures in Sample Case Organisations

Organization	Nature of Business	JIT Techniques Implemented	Frequently used Performance Measures
Denso Manufacturing (UK) Ltd.	▪ Manufacture automotive heaters, blowers and air conditioner units ▪ Number of employees - 1600 ▪ Large enterprise	▪ Kanban ▪ Line Balancing ▪ Setup time elimination plans ▪ Group technology ▪ Fast inventory transportation systems ▪ Quality control ▪ TPM ▪ Integrated process and product design ▪ Work place organization plan ▪ Effective communication ▪ Employee training ▪ Multifunction employee	▪ Profitability/Turnover ▪ Productivity ▪ Hourly output ▪ Output per operator/line ▪ Frequency of customer complaints ▪ On-time delivery ▪ Lead time ▪ Takt time ▪ Scrap/defects ▪ Safety marks/accident ▪ Total man hour ▪ Idle time
Metsec Plc.	▪ Manufacture cold rolled sections such as purlins, cable trays, struts, beams and welded and irregular shaped profiles such as tractor cab frames, bridge supports, shelving and racking, fencing systems and window systems ▪ Number of employees - 450 ▪ Large enterprise	▪ Kanban ▪ Setup time elimination plans ▪ Group technology ▪ Fast inventory transportation systems ▪ TPM ▪ Integrated process and product design ▪ Work place organization plan ▪ Effective communication ▪ Employee training ▪ Multifunction employee	▪ Profit ▪ Productivity ▪ Sales price per tonne ▪ Labour cost per hour ▪ Lead time ▪ On-time delivery ▪ Gross margin per tonne ▪ Scrap percentage ▪ Number of quality rejects
Bemason Ltd.	▪ Manufacture ball type valves for gas and water applications and back flow prevention devices ▪ Number of employees - 30 ▪ Small and medium enterprise	▪ Quality control ▪ Quality circles ▪ Setup time elimination plans ▪ Level schedules ▪ Work place organization plan ▪ TPM ▪ Effective communication ▪ Employee training ▪ Multifunction employee ▪ Other control systems	▪ Profit ▪ Customer complaints ▪ Setup time ▪ Machine and line rejects ▪ Obsolete stock ▪ On-time delivery ▪ Vender rating ▪ Scrap
COMPARISON / COMMON FEATURES		▪ Different combinations of JIT techniques are implemented in different assembly lines / production cells ▪ Line / cell manager have power to select suitable JIT techniques to improve line performance	▪ No proper PMS available in all three organizations ▪ Different ad-hoc performance measures are used in different production lines / cells ▪ Financial measures are used for top management decision making and operational measures are used for middle and production floor managers decision-making.

Having considered the above discussion and the requirements of companies, it can be concluded that a dynamic performance measurement system is essential in a JIT manufacturing environment fully considering financial, customer, employee, supplier, internal business processes, socio-environmental groups and innovation and growth performance measurement perspectives.

4.3 AN INTEGRATED FRAMEWORK OF JIT PRACTICES

Most studies on JIT philosophy tend to investigate unique, TQM related and human/strategic oriented JIT practices separately; only a few researchers have explored some of these relationship empirically (Flynn *et al.*, 1995, Vuppalapati *et al.*, 1995, Sakakibara *et al.*, 1997, Cua *et al.*, 2001, Fullerton *et al.*, 2003 and Shah and Ward, 2003). When a manufacturing plant seeks to capitalise on the implementation of one of these streams, the benefits can be maximised by also applying techniques from the other two streams (Sandanayake *et al.*, 2007). Therefore, there should be a synergistic effect of integrating all three practices where possible.

Based on the foregoing analysis (refer to Section 4.2), the twenty (20) JIT techniques listed in Table 2.3, are divided into three categories as follows:

- Unique JIT practices
- TQM related JIT practices
- Human/strategic oriented JIT practices

4.3.1 Unique JIT Practices

Western countries started implementing JIT before TQM philosophy was recognised as an underlying framework for Japanese manufacturing excellence (Vuppalapati *et al.*, 1995). Sakakibara *et al.*, (1997) and Shah and Ward (2003) combined all practices directly related to a production system under unique JIT practices, while McLachlin (1997) categorised all production flow related techniques under JIT flow elements. According to Fullerton *et al.* (2003), JIT manufacturing dimension comprised indicators that explain the extent to which companies have implemented advanced manufacturing techniques associated with JIT.

Similarly, in this study, technical and more process oriented JIT techniques are categorised under unique JIT practices. Thus, eight JIT techniques have been identified and classified under this category from the review of recent literature (refer to Table 2.3) and personal judgement based on the definitions of the JIT techniques (refer to Section 2.5). These are kanban systems, line balancing, setup time elimination plans, JIT purchasing, level schedules, group technology, focused factory and efficient inventory transportation system. Strategies such as line balancing, group technology, focused factory and fast inventory transportation systems streamline manufacturing operations and reduce inventory levels, while techniques such as kanban, setup time elimination, JIT purchasing and level schedules minimise raw materials, work-in-progress and finished goods inventories.

4.3.2 TQM Related JIT Practices

There is no single universal definition for quality. Reid and Sanders (2005) listed some definitions for “quality” as follows:

- performance to standards
- meeting the customer’s needs
- satisfying the customer
- conformance to specification (how well a product or service meets the target and tolerances determined by its designers)
- fitness for use (how well the product performs for its intended use)
- value for price paid (quality defined in terms of product or service usefulness for the price paid)
- support services (support services provided after the product or service is purchased)
- psychological criteria (judgemental evaluation of what constitutes product or service excellence)

Quality concepts promulgated by American quality gurus such as Edwards Deming, Joseph Juran, Philip Crosby and the Japanese gurus such as Kaoru Ishikawa, Genichi

Taguchi and Shigeo Shingo, are aggressively seeking to improve product quality by eliminating causes of product defects and making quality an all-encompassing organisational philosophy (Charantimath, 2006). Table 4.2 shows the contribution of quality gurus.

Table 4.2: Contribution of Quality Gurus (Adapted from Charantimath, 2006)

Quality Guru	Contribution
Edward Deming	First American quality expert to teach Japanese managers methodically about quality and propound continuous improvement and PDCA cycle
Joseph Juran	Published *Quality Control Handbook* in 1951, which is the standard reference book on quality world. Juran's quality trilogy includes quality planning, improvement and control
Philip Crosby	Introduced four absolutes of quality: the definition, the system, the performance standard and the measurement
Kaoru Ishikawa	Introduced quality circles and seven quality control tools
Genichi Taguchi	Introduced Taguchi approach to study all factors that can hamper uniformity between products and their long-term stable performance and build in safeguards at the product design stage
Shigeo Shingo	Propounded the principles of quality in JIT environments and zero defect and single minute exchange of die

In TQM philosophy, quality is expected to be built into the product instead of being inspected into it. The goals of TQM are continuous improvement of all processes, customer driven quality, production without defects, improvement of processes rather than criticism of people and data based decision making (Flynn *et al.*, 1995). Laugen *et al.* (2005) categorised quality management as a former best practice, which lost that position in the present manufacturing environment and that regarded as a routine practice, supporting companies to qualify for the market place. Empirical results of Powell (1995) suggested that TQM can produce competitive advantage, but it is apparently not necessary for success. Further study showed a significant correlation between TQM concept and performance, however, it did not strictly prove that TQM caused performance improvement. Flynn *et al.* (1995) argued that TQM practices reduce process variance and as a result there is less need for safety and cycle stock. Cua *et al.* (2001) found that TQM has a positive and significant relationship through JIT with low cost, superior quality and strong delivery performance. However, Abdel-Maksoud *et al.*, (2005) argued that TQM and TPM may be associated with a general intensity of management rather than the more production-targeted JIT approach.

The causal linkages in a BSC strategy map developed by Kaplan and Norton (2001) enhance quality programs by articulating the two ways, i.e. quality improvements in the internal perspective should improve one or more outcome measures in the customer perspective, and quality improvements can lead to cost reduction, an outcome in the financial perspective. The scorecard focuses quality initiatives on improving performance of newly identified processes such as JIT/lean rather than just improving existing processes (Kaplan and Norton, 2001).

According to McLachlin (1997), Cua *et al*. (2001), Fullerton *et al.* (2003) and Shah and Ward (2003), JIT quality dimension comprised of indicators that explain the extent to which companies have implemented procedures for improving product and process quality. Having considered the above discussions, in this study, quality oriented JIT techniques are classified under TQM related JIT practices. A review of recent literature reveals six major TQM related JIT practices as being quality control activities, quality circles, value analysis, integrated product and process design, total productive and preventive maintenance and workplace organisation plan (refer to Table 2.3 for relevant references and Section 2.5 for definitions).

4.3.3 Human/Strategic Oriented JIT Practices

JIT requires all parties concerned with the process to be involved and contribute towards it. Dealing effectively with production related problems in JIT environment requires motivated, skilled and adaptable work force (MacDuffie, 1995). The researcher further mentioned that "developing an integrated conception of production system requires that workers directly encounter problems, through the decentralisation of production responsibilities such as quality inspection, equipment maintenance and job specification". JIT philosophy increases the interdependencies among departments, employees within those departments and outside stakeholders. The approach and philosophy of management dictates most of the company culture and is autocratic in nature (Mazany, 1995). Respect for people includes treating employees as human beings and making full use of their capabilities, both mental and physical (White and Ruch, 1990). Vuppalapati *et al.* (1995) found that unique JIT techniques did not prove effective unless implemented by a cross-trained, multi-skilled staff member with a high level of motivation. According to Spencer and Guide (1995), the human relations aspects of JIT are important components in achieving higher performance.

In this research study, six major human/strategic oriented JIT practices were identified through an extensive literature review (refer to Table 2.3 and Section 2.5). They are effective communication, supplier integration, employee training, multifunction employee, innovation and investment plans and other control techniques (as defined in Chapter 2).

An integrated framework of JIT practices has been developed and is presented in Figure 4.9 to demonstrate the relationship between aforementioned unique, TQM related and human/strategic oriented JIT techniques.

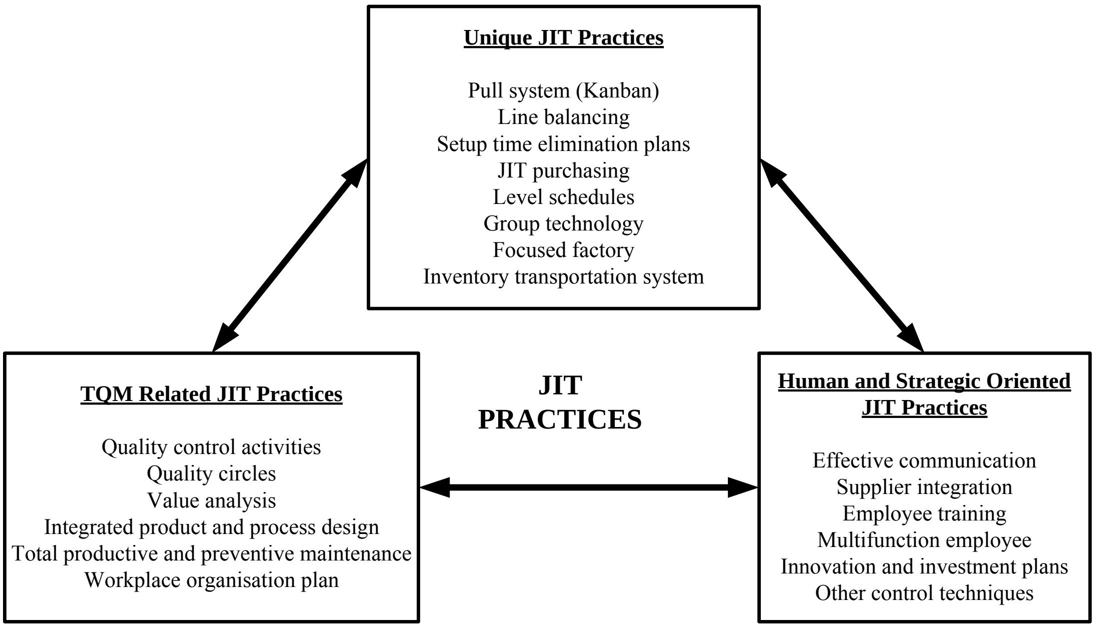

Unique JIT Practices
Pull system (Kanban)
Line balancing
Setup time elimination plans
JIT purchasing
Level schedules
Group technology
Focused factory
Inventory transportation system
JIT PRACTICES
TQM Related JIT Practices
Quality control activities
Quality circles
Value analysis
Integrated product and process design
Total productive and preventive maintenance
Workplace organisation plan
Human and Strategic Oriented JIT Practices
Effective communication
Supplier integration
Employee training
Multifunction employee
Innovation and investment plans
Other control techniques

Figure 4.9: An Integrated Framework of JIT Practices

The unique, TQM related and human/strategic oriented JIT practices are inter-related and internally consistent practices. Altogether, these three practices form a comprehensive and consistent set of JIT practices, which will generate excellent performance.

The literature review documented in Chapters 2 and 3, and Section 4.2.1, findings from the informal interviews presented in Section 4.2.2 and the integrated framework of JIT practices developed above and the extended BSC introduced in Section 3.8 were all used in developing a conceptual model suitable for performance measurement in JIT plants, which is described in the following section.

4.4 DEVELOPMENT OF A CONCEPTUAL MODEL FOR PERFORMANCE MEASUREMENT IN JIT PRODUCTION PLANTS

A conceptual model covers the main features of research such as aspects, dimensions, factors, variables and their presumed relationships with probable outputs (Robson, 1993). An extensive literature review and informal interviews/discussions with site personnel were used to design and develop a conceptual model for this research study.

A key objective is to develop a performance measurement model, which is generic to most JIT enabled manufacturing environments. The proposal is to identify key JIT variables that drive performance and measure output using a PMS such as the extended BSC. Figure 4.10 illustrates the proposed conceptual model and inter-relationships between JIT drivers and performance.

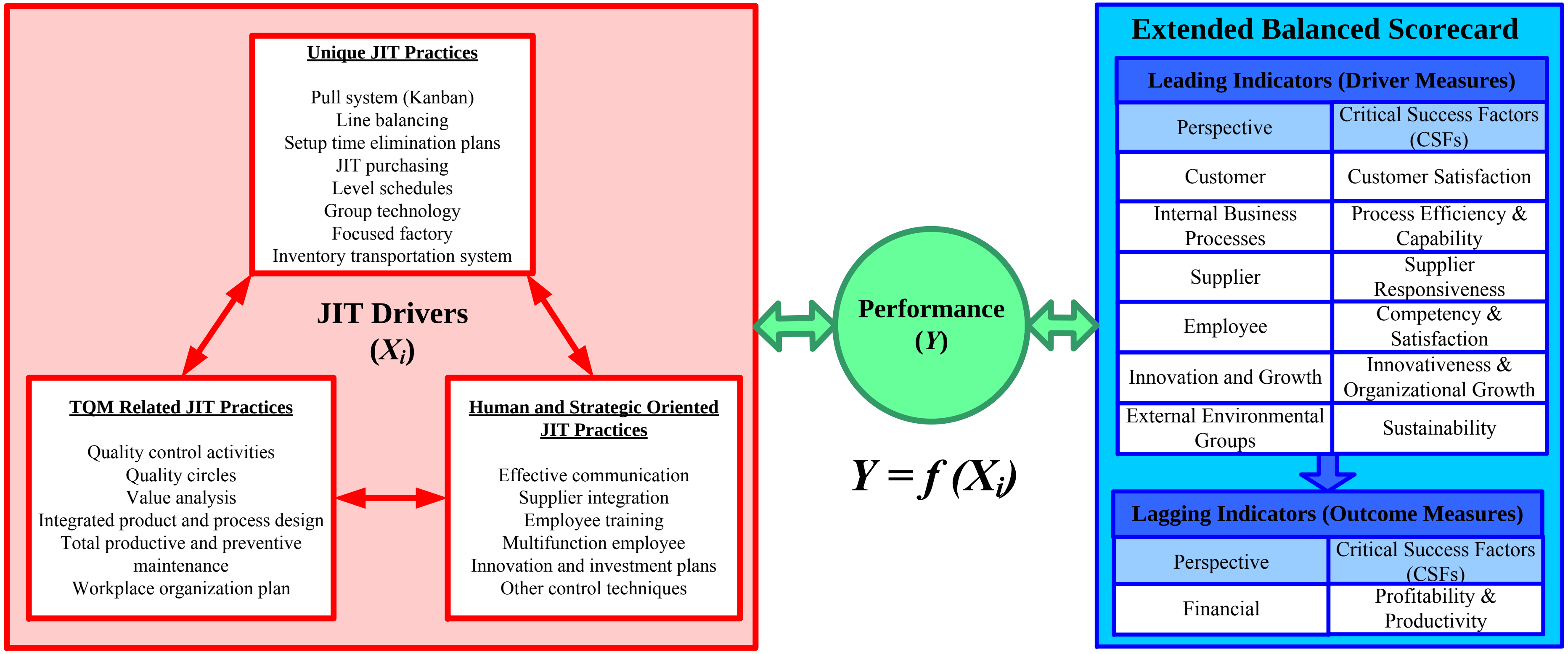
The conceptual model is divided into two parts. The left side of the conceptual model lists an extensive set of JIT techniques, which theoretically drive enterprise performance. JIT techniques are divided into three groups: unique JIT practices, TQM related JIT practices and human/strategic oriented JIT practices. These three categories have similar fundamental objectives, which are to assist pull production, minimise waste and lead-time, and achieve continuous improvement. Unique JIT practices consist of pull system (kanban), line balancing, setup time elimination plans, JIT purchasing, level schedules, group technology, focused factory and inventory transportation systems. TQM related JIT practices include quality control activities, quality circles, value analysis, total productive and preventive maintenance, integrated product and process design and workplace organisation plan. Effective communication, supplier integration, employee training, multifunction employee, innovation and investment plans, and other control techniques are variables categorised under human and strategic oriented JIT practices (refer to Section 4.3).

Traditionally, productivity has been measured mainly from the financial perspective. One disadvantage of traditional financial PMS especially in JIT manufacturing is that it tends to ignore performance in terms of business innovation and growth, customer and employee satisfaction, supplier efficiency, sustainable production and internal business process perspectives, even though they are key drivers of financial performance. Quantitative non-financial measures such as takt time, defect rate, inventory levels, productivity and on-time delivery and qualitative non-financial measures such as customer satisfaction, worker skill flexibility, supplier relationship, employee morale and innovation have commonly been ignored in traditional financial PMSs.

In designing a good PMS, industry practitioners and academic researchers must consider the needs of the various stakeholders as stated in the company strategic plan. The company strategy is determined based on company vision and mission and it is driven by critical success factors (CSFs). Both financial and non-financial performance measures have a direct relationship on the CSFs of the company, while JIT practices have direct and indirect influence both on performance and CSFs.

The right side of the conceptual model therefore depicts performance measurement using extended BSC as a robust, multidimensional and elaborate PMS to assess enterprise performance not only from economic and financial standpoints (lagging indicators or outcome measures) but also based on the influence of the customer, supplier, employee, internal business processes, external environmental groups as well as innovation and growth perspectives (leading indicators or driver measures) (refer to Section 3.8).

The integrated framework of JIT practices and the restructured extended BSC tool have been used in developing a suitable conceptual performance measurement model (Figure 4.10) for JIT enabled manufacturing plants. The conceptual model links key JIT drivers (X_i) and measurable performance (Y) through a linear mathematical model (i.e. $Y = f(X_i)$) with an aim to assist managers in the systematic identification of the influence of key JIT drivers on organisational competitive priorities.


Unique JIT Practices
Pull system (Kanban)
Line balancing
Setup time elimination plans
JIT purchasing
Level schedules
Group technology
Focused factory
Inventory transportation system
JIT Drivers
(X_i)
TQM Related JIT Practices
Quality control activities
Quality circles
Value analysis
Integrated product and process design
Total productive and preventive maintenance
Workplace organization plan
Human and Strategic Oriented JIT Practices
Effective communication
Supplier integration
Employee training
Multifunction employee
Innovation and investment plans
Other control techniques
Performance
(Y)
$Y = f(X_i)$
Extended Balanced Scorecard

Leading Indicators (Driver Measures)

Perspective	Critical Success Factors (CSFs)
Customer	Customer Satisfaction
Internal Business Processes	Process Efficiency & Capability
Supplier	Supplier Responsiveness
Employee	Competency & Satisfaction
Innovation and Growth	Innovativeness & Organizational Growth
External Environmental Groups	Sustainability

Lagging Indicators (Outcome Measures)

Perspective	Critical Success Factors (CSFs)
Financial	Profitability & Productivity

Figure 4.10: Conceptual Model Showing the Relationship between Operational JIT Drivers and Multidimensional Measurable Performance

The conceptual model has achieved one of the major objectives of the study, namely to establish cause and effect relationships between JIT drivers and performance. In performance measurement model implementation, the integrated framework of JIT practices will provide relevant JIT techniques and the extended BSC will offer key performance indicators to establish cause and effect relationships between the most influential JIT drivers and measurable performance. The resultant performance measurement model will assist managers to take necessary actions to optimise JIT manufacturing performance in a continuous improvement exercise.

The robust multidimensional performance measurement model developed here can be used to assess the impact of JIT drivers on operational and company performance using the extended Balanced Scorecard concept. The performance measurement model will assist managers to identify the operational competitive priorities and their relative importance in overall performance measurement. For instance, it will now be possible to simulate input parameters (X_i) in the mathematical model to achieve the desired operational performance (Y). The generic model serves as a guide to managers to capture the influence of key JIT drivers on overall performance of the organisation.

This study will also apply design of experiments (DoE), simulation and linear mathematical modelling to establish the relationship quantitatively between JIT variables and operational performance in production environments. A multi-criteria decision making tool such as analytic hierarchy process analysis will be applied to identify an organisation's competitive priorities and to analyse the impact of selected key JIT drivers on overall performance in a manufacturing environment.

Chapter 6 will illustrate the multidimensional performance measurement model implementation procedure, and the use of design of experiments, simulation, linear mathematical modelling, and the analytic hierarchy process tool on the testing, validation and application of the conceptual performance measurement model in a JIT enabled production environment.

4.5 SUMMARY

An extensive review of the literature and informal interviews suggest that JIT techniques have a direct and indirect influence on financial and operational performance. There are currently no performance measurement models to assess the impact of key JIT drivers on both operational performance and organisational competitive priorities in a JIT enabled production environment. Literature findings and informal interviews also show that there are no universally accepted JIT techniques or performance measures as they vary from organisation to organisation. Many of the past studies have suggested that unique, TQM related and human/strategic oriented JIT practices are inter-related and internally consistent concepts. An integrated framework has been introduced which puts into consideration the relationships among the above categories in a modern manufacturing context.

Comprehensive literature review, findings from informal interviews, an integrated framework of JIT practices and extended balanced scorecard were used in developing a suitable conceptual performance measurement model in JIT plants. The conceptual model establishes a mathematically determined link between key JIT drivers (X_i) and measurable performance (Y). The generic performance measurement model will assist managers to identify the strategic influence of those JIT drivers on organisational competitive priorities using an extended BSC tool.

The next chapter will present the research framework, methodology and methods adopted for this study.

CHAPTER 5: RESEARCH METHODOLOGY

5.1 INTRODUCTION

The aim of this chapter is to outline the research framework, methodology and methods adopted for this study. The first part of the chapter describes the characteristics of management research and the related methodologies. The second part describes the way the aforementioned methodologies have been applied in this study. Research was conducted in three phases. Phase I involved a thorough review of the literature and informal interviews/discussions in order to identify the research problem, define the aim and objectives, develop a conceptual model, and design and develop a performance measurement model implementation procedure. Phase II adopted a case study approach to test and validate the conceptual performance measurement model. Finally, Phase III used action research and case study in order to apply the performance measurement model to wider JIT enabled environments. These phases are discussed in detail, including the methods used for data collection, analysis, and validation. Descriptions of participants and the limitations of the data collection methods are also presented.

5.2 MANAGEMENT RESEARCH

The purpose of a research study according to the Remenyi *et al.*, (1998) is to add value to the body of accumulated knowledge and to attempt to provide suitable solutions to unsolved problems. In business and management studies, there are even more unanswered questions than in many other areas of study because of the fast changing nature of the subject (Remenyi *et al.*, 1998). Management research raises both theoretical and practical problems, which are not usually encountered in physical and social sciences research (Lancaster, 2005). Anderson and McAdam, (2004) defined management research as “finding out things in a systematic way in order to increase knowledge about people and processes involved in the management of work organisations”. Easterby-Smith *et al.*, (2002) identified the three main factors that make management distinctive for research.

- *The practice of management is largely eclectic*: Managers need to work across technical, cultural and functional boundaries and need to be knowledgeable in other disciplines such as sociology, economics, statistics and mathematics.
- *Managers tend to be powerful and busy people*: They are unlikely to allow research access to their organisations unless they can see some commercial or personal benefit to be derived from it.
- *Management requires both thought and action*: Not only do most managers feel that research should lead to practical consequences, they are quite capable of taking actions themselves in the light of research results.

Empirical research is the dominant paradigm in business and management research and concentrates on issues related to improving efficiency and effectiveness of the business and management process (Remenyi *et al.*, 1998). Lancaster (2005) identified three different types of management research: (1) theory building research, (2) theory testing research and (3) problem centred/practical research. The type of management research depends on the research context. Having considered the context of this research, which is to design and develop a multidimensional performance measurement model for JIT enabled manufacturing environments, this study can be categorised under theory building research. The rationale for the research methodology and data collection methods now follows.

5.3 CHOICE OF RESEARCH METHODOLOGY AND METHODS

Decisions on suitable methodologies and methods depend on research paradigms and their assumptions (Easterby-Smith *et al.*, 2002). Remenyi *et al.*, (1998) defined research methodology as a procedural framework within which the research is conducted. According to Easterby-Smith *et al.* (2002), methodology is a combination of techniques used to enquire into a specific situation, while methods are individual techniques for data collection and analysis. The roots of the modern view of science in which rigorous mathematical formulations are combined with careful experimentation date from Kepler's (1571-1630) studies of the orbits of the planets in which, for the first time, mathematical relationships were used to describe a natural phenomenon (Remenyi *et al.*, 1998).

Previous researchers introduced various research paradigms such as empirical-theoretical and positivistic-phenomenological (Remenyi *et al.*, 1998 and Easterby-Smith *et al.*, 2002). The research methods normally used to collect and analyse evidences within these paradigms are listed in Table 5.1.

Table 5.1: Typical Research Tactics/Designs (Adapted from Remenyi *et al.*, 1998 and Easterby-Smith *et al.*, 2002)

1. Action research	5. Grounded theory
2. Case study	6. Participant-observation
3. Ethnography	7. Surveys (In-depth and Large-scale)
4. Experiments (Field and Laboratory)	8. Simulation

Surveys and case studies are the most common techniques used in management research studies according to the literature review presented in Chapters 2, 3 and Section 4.2.1. According to Inman and Mehra (1993), evidence of JIT implementation comes mostly from individual case studies, and then generalised to apply to the entire manufacturing population. Relatively few researchers (for example, Sarkar and Fitzsimmons, 1989 and Polat and Arditi, 2005) have applied experiments and simulations with case studies to investigate the impact of JIT techniques on selected performance measures and to compare two or more JIT strategies in manufacturing industry (more details are given in Section 6.2.1). Ramarapu *et al.* (1995) identified conceptual and empirical based studies as common research methods and simulation and mathematical modelling as less frequently applied research methods in JIT implementation research.

Table 5.2 summarises the research methods (focus group survey, case study approach, experiments and simulation) and data analysis tools (statistical data analysis tools and AHP method), which have been used in the past by key researchers working in fields relevant to this study.

Table 5.2: Research Methodologies and Data Analysis Methods used in Key Literature

Key Literature Reference	**Aim and Objectives of Key Research Studies**	**Research Approach**			**Data Analysis Method**	
		Focus Group Survey	**Case Study**	**Experiments / Simulation**	**Statistical Analysis Tools**	**AHP Method**
Sarkar and Fitzsimmons (1989)	Compare performance of push and pull systems		✓	✓	✓	
McLachlin (1997)	Test six management initiatives for the implementation of JIT at six plants	✓	✓		✓	
Fernando and Luis (2002)	Test the impact of three JIT techniques on total completion time			✓	✓	
Polat and Arditi (2005)	Compare JIT and JIC systems in terms of total cost of inventory		✓	✓	✓	
Mistry (2005)	Establish a relationship between JIT practices and financial performance indicators	✓	✓		✓	
Rangone (1996)	Measure and compare the overall performance of different manufacturing departments on the basis of multi-attribute financial and non-financial performance criteria	✓	✓			✓
Rahnejat and Khan (1998)	Investigate the impact of main and sub KPIs on optimal production planning systems and compare four production systems	✓	✓			✓
Clinton *et al.* (2002)	Investigate the impact of KPIs on BSC perspectives and overall performance	✓				✓
Searcy (2004)	Investigate the use of the AHP at the first level of the BSC with data from six firms	✓	✓			✓

As can be seen from Table 5.2, aforementioned studies mainly used survey and case study approaches to investigate performance in JIT enabled manufacturing environments. Some researchers such as Rangone (1996), McLachlin (1997), Rahnejat and Khan (1998), Searcy (2004) and Mistry (2005) have combined case study approach with focus group surveys (company based surveys) to achieve their research aims and objectives. Few other researchers such as Sarkar and Fitzsimmons (1989) and Polat and Arditi (2005) have combined a case study approach with other approaches such as experiments and simulation to examine the impact of JIT techniques on selected performance measures or different production scenarios. However, as yet, no researchers have combined case study approach with observations, surveys, experiments and simulation in order to investigate the impact of JIT techniques on operational and overall performance in the manufacturing industry. Moreover, among the aforementioned key studies, most of the researchers have used statistical analysis tools to analyse data, while few others applied the AHP method as a suitable analysis technique in their own research context.

In this study, the tactics listed in Table 5.1 were considered in order to choose an appropriate research approach. After careful review of the research objectives, grounded theory, ethnography, and participant-observation were all excluded. This is due to the fact that grounded theory is more applicable to a given social situation when deriving the theory of a process, action or interaction, based on the views of participants in a study (Creswell, 1998). Ethnographic research requires the researcher to become part of the tribe and to fully participate in its society, where as in participant-observation method, the researcher joins the team of individuals who are part of the phenomenon being studied (Remenyi *et al.*, 1998). The remaining methodologies were case study, survey, experiments, simulation and action research; the following section discusses the reasons for selecting these techniques for this study.

5.4 THE RESEARCH FRAMEWORK

The context of this research is to design and develop a multidimensional performance measurement model for JIT enabled manufacturing environments. A comprehensive literature review was carried out to identify research problems, define aim and objectives and design a conceptual model. An integrated framework of unique, TQM related and human/strategic oriented JIT practices has been presented in Section 4.3 and the extended BSC tool was introduced in Section 3.8; these were used to develop the conceptual model. Both literature review and informal interviews/discussions helped in assessing the JIT techniques, PMSs and their implementation in automotive and non-automotive industries and hence, in the design of a multidimensional performance measurement model and implementation procedure for the manufacturing environments. The comprehensive literature review further provided appropriate data collection and analysis tools to test and validate the conceptual model.

According to the literature review presented in Chapter 3, a good PMS should provide a non-perspective template, where managers can develop own measures to match their business strategy and vision. Moreover, the literature review (refer to Chapters 2, 3 and Section 4.2.1) and informal interviews (refer to Section 4.2.2) revealed that the JIT techniques and performance measures appeared to vary from production cell to cell, plant to plant, organisation to organisation, industry to industry and even from culture to culture. Therefore, this suggested a case study approach to test and validate the conceptual model. Observations, documents, surveys and interviews were used to collect evidence; typical quality management tools, design of experiments and dynamic simulations were used to process data; statistical tools and an analytic hierarchy process method were used to analyse results in the case study approach.

The research framework developed for this study is divided into three phases and further broken into a set of logical stages as depicted in Figure 5.1. The subsequent sections of this chapter discuss the data collection methods used in each phase of this research study.

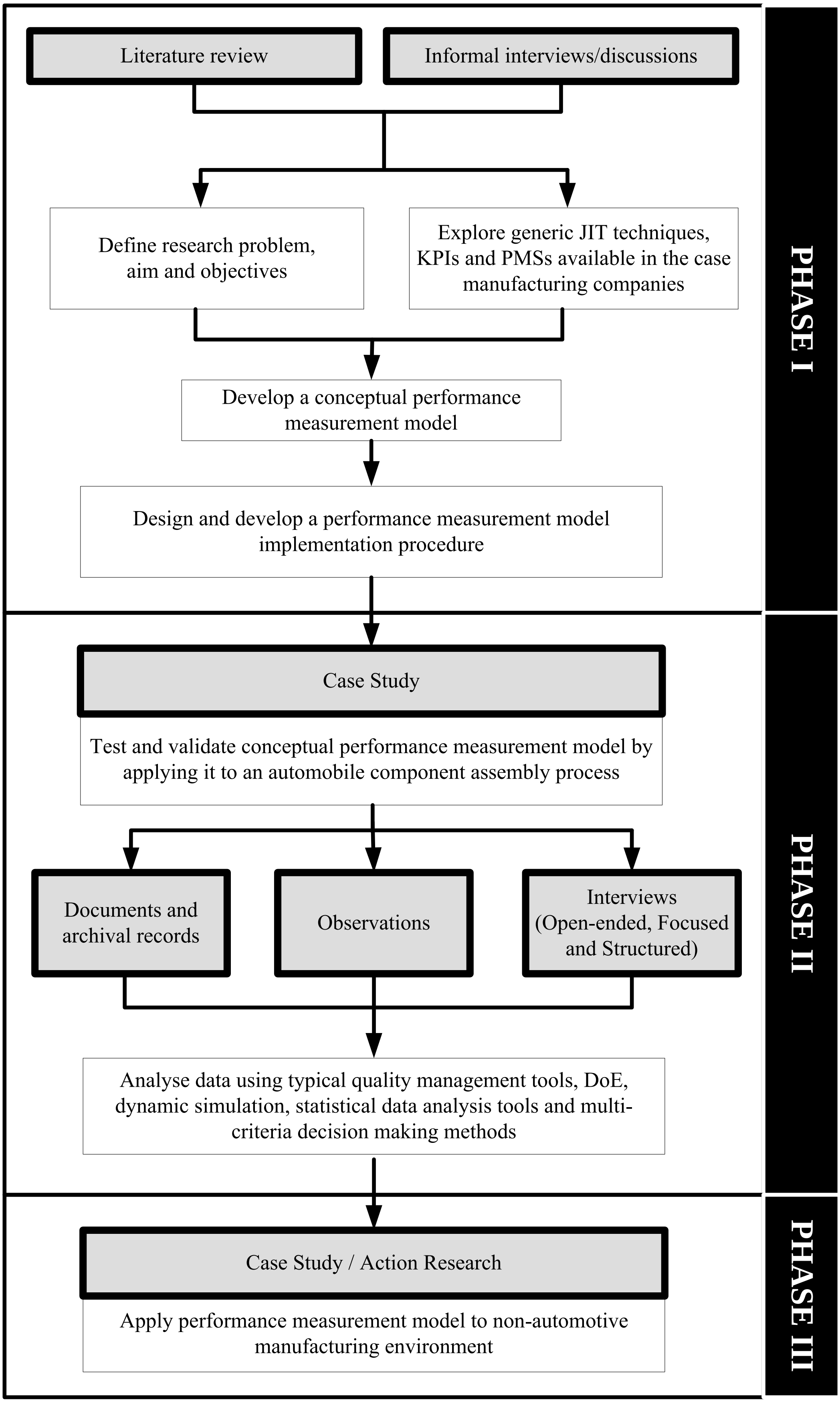

Literature review
Informal interviews/discussions
Define research problem, aim and objectives
Explore generic JIT techniques, KPIs and PMSs available in the case manufacturing companies
Develop a conceptual performance measurement model
Design and develop a performance measurement model implementation procedure
PHASE I
Case Study
Test and validate conceptual performance measurement model by applying it to an automobile component assembly process
Documents and archival records
Observations
Interviews (Open-ended, Focused and Structured)
Analyse data using typical quality management tools, DoE, dynamic simulation, statistical data analysis tools and multi-criteria decision making methods
PHASE II
Case Study / Action Research
Apply performance measurement model to non-automotive manufacturing environment
PHASE III

Figure 5.1: The Research Framework

5.5 RESEARCH METHODS

5.5.1 Literature Review

The methodology adopted started with a review of existing literature to develop a theoretical understanding prior to empirical study. An effective review of the literature examines the context of the research problem and identifies relevant concepts, issues and methods (Anderson, 2004). It helps to identify gaps in the available literature, refine a focus and enable the researcher to set conceptual boundaries on what is relevant (Gill and Johnson, 2002).

Phase I of this study involved a comprehensive literature review undertaken to:

- investigate the knowledge gap, identify research problems, explain rationale behind project and define aim and objectives
- select research methodology, data collection methods and data analysis tools to achieve aim and objectives
- develop a performance measurement model and implementation procedure

The literature review was broken down into four major areas as follows:

- *Just-in-Time (JIT)*: JIT philosophy, goals, elements and techniques, JIT implementation in the UK, West and far East demonstrating socio-cultural impact on JIT performance and associated problems, and benefits from JIT implementation (refer to Chapter 2).
- *Performance Measurement Systems (PMSs)*: Traditional financial performance measures, limitations of financial performance measures, multidimensional PMSs in production environment and comparison of multidimensional PMSs (refer to Chapter 3).
- *JIT and PMSs*: PMSs in JIT environment, simulation of quantitative PMS in a JIT enabled manufacturing environment and application of analytic hierarchy process method in management research (refer to Section 4.2.1).
- *Methodology*: Research methods, data collection and analysis tools about JIT and PMS (refer to Chapters 2, 3, 4, 5 and 6)

While there was a vast amount of literature written separately on JIT and PMSs, the lack of relevant literature on performance appraisal systems applied in JIT environments became apparent during the literature review. The development of a PMS specifically applied to JIT environments therefore became a prime objective of the study.

5.5.2 Informal Interviews / Discussions

Due to the lack of literature on PMSs in JIT environments, informal interviews and surveys were carried out to determine a suitable PMS and performance measures for JIT processes. Academic experts and industry practitioners were interviewed during plant visits and also through telephone conversations and emails. The academic experts and industry practitioners interviewed were as follows:

- Academic experts
    - Academic research supervisors
    - Researchers in manufacturing management
    - Delegates at international conferences and seminars
- Industry practitioners
    - Production Control Manager and Human Resource Manager – Denso Manufacturing (UK) Limited (Large enterprise)
    - Quality Manager and Technical Manager – Metsec Plc. (Large enterprise)
    - Production Manager and Quality Manager – Bemason Limited (Small enterprise)
    - Production Manager – Jaguar Cars Limited (Large enterprise)
    - Account Development Manager – Lanner Group Limited
    - Simulation Software Expert – Production Modelling Limited

The researcher had an opportunity to visit the Jaguar Cars Limited plant and was shown around the premises. The company has implemented most of the JIT techniques and the plant is running under ideal JIT manufacturing conditions.

Sample survey instrument introduced by Callen *et al.* (2000) was used as a guide to develop a questionnaire survey instrument for informal interviews. Informal interviews/discussions were carried out with a few production managers and shop floor operators in three JIT enabled production plants: Denso Manufacturing (UK) Ltd., Metsec Plc. and Bemason Limited. Some typical questions raised during informal interviews/discussions are as follows (refer to Section I of Appendix 1):

- Background of the business (what are the products, who are the customers, number of employees, plant layout)
- What are the production planning and scheduling systems used in your plant?
- What are the performance / productivity measures used in your plant?
- To what extent has each of the JIT techniques been implemented in your firm?
- How do you use those measures to interpret performance in your plant?
- To what extent has JIT improved the production?
- What problems do you encounter in applying JIT techniques in your plant?

The findings from the informal discussions confirmed the key issues elicited from literature review (White and Ruch, 1990, Billesback *et al.*, 1991, Funk, 1995 and White and Prybutoc, 2001) that there are no universally accepted JIT techniques and performance measures. They appear to vary from plant to plant, organisation to organisation, industry to industry and also from culture to culture. The informal interview findings are presented in Section 4.2.2 and Table 4.1.

The findings from literature review and informal interviews/discussions were then used to compile a comprehensive list of JIT techniques (refer to Section 2.5) and to select a BSC tool (refer to Section 3.7) for performance measurement in JIT enabled manufacturing environments. An integrated framework of JIT techniques and an extended BSC tool were then incorporated into a conceptual performance measurement model, addressing Objective 3 of this research study (refer to Figure 4.10). The literature review and informal interview findings were then used to design a performance measurement model implementation procedure (refer to Section 6.3 and Figure 6.11).

Discussions with managers from the Lanner Group and Production Modelling Limited were helpful in comparing 'Witness™', 'Quest™' and 'ProModel™' simulation software to allow the selection of the most suitable software for this study. Witness, Quest and ProModel dynamic discrete event simulators are data driven systems with little programming required. The above software can be used to model production processes in order to optimise process performance. All of the above three software packages can be used to achieve the objectives of this study. They were all considered and finally ProModel software was chosen partly because it was part of the university collection and also because it had the all features necessary for this analysis. ProModel simulation and modelling software therefore was selected for the simulation modelling.

5.5.3 Case Study Approach

Case study research is becoming increasingly accepted as a scientific tool in management research especially in general management, leadership, marketing, corporate strategy and accounting (Gummesson, 2000). It involves the study of a phenomenon in its real-life context (Yin, 2003) and incorporates the views of participants in the case under study.

> *"A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." (Yin, 2003)*

Yin (2003) further identified six sources of evidence in case studies: documents, archival records, open ended interviews, focus interviews, structured interviews and surveys and observations. According to Anderson and McAdam (2004), the data collection methods depend on the nature of the research, expectations of participants, implications of participants and the subsequent use of data.

Table 5.3 presents the advantages and disadvantages of the different data collection methods and the most favourable circumstances for each method.

Table 5.3: Comparison of Methods for the Empirical Investigation (Adapted from Barnes, 2001)

Method	Advantages	Disadvantages	Most favourable circumstances
Interviews	▪ Effective for collecting large quantities of in-depth data ▪ Researcher is not required to spend long periods on site	▪ Interviewing is time consuming ▪ High quality analysis of interview data s especially time consuming ▪ Requires the researcher to be able to gain full access to the knowledge and meaning of informants	▪ The researcher can gain access to a range of suitable informants ▪ The researcher is limited to at most a few days on site
Observations	▪ Extremely effective for collecting large quantities of in-depth data ▪ The researcher gains an understanding of the research subjects and their context	▪ Highly inefficient of researcher time as it requires researcher to spend long periods on site ▪ Objectivity of researcher can be compromised	▪ The researcher can spend long periods of time within the organization, perhaps in the capacity of a practitioner-researcher or a participant-observer
Documents and Archival Records	▪ Strategy can be traced back over time ▪ Plans as well as actions may be recorded ▪ Multiple sources can facilitate data triengulation	▪ Documents may be limited, unavailable, biased or unsuitable for their purpose	▪ Records exist that can be accessed by the researcher
Questionnaire	▪ Very time efficient for researcher and respondents ▪ Responses can be quantified for ease of analysis ▪ Less chance of political responses	▪ Data collection depends on respondents' goodwill ▪ Quantity of data collected is limited ▪ No opportunity for clarification and deeper questioning ▪ Additional data may be needed in order to interpret the questionnaire results meaningfully	▪ The researcher has limited time for on site work ▪ The researcher can not gain access to the site ▪ The researcher has an on site champion to encourage a high response rate

Phase II of this study involved testing and validation of the conceptual performance measurement model (refer to Figure 4.10). The case study was selected as the most suitable approach for testing and validation of a conceptual model in a JIT enabled production plant. Data collection methods such as documents, interviews and observations were used for data acquisition and tools such as design of experiments, simulation and analytic hierarchy process tool were used for data analysis and validation.

Denso Manufacturing (UK) Ltd. (DMUK) – Case Organisation

'Denso Manufacturing (UK) Ltd.' (DMUK), a subsidiary of 'DENSO Corporation' in Japan was chosen to be the subject of the case study. DMUK was founded in 1990 as one of the largest manufacturers of advanced automotive components and the first European businesses to manufacture and supply advanced automotive systems and components globally. The company produces an extensive range of products such as air conditioner units, heaters, blowers and panels for world leading automotive manufacturers; Toyota, Honda, Rover, Jaguar, NCC, MCC and Land Rover. Study on DMUK was carried out between April 2004 and October 2006. A full description of case study is presented in Chapter 7.

Three data collection methods were used to acquire both quantitative and qualitative data from DMUK for testing and validation of the conceptual model:

- open ended and structured interviews with top managers, plant managers and production line associates
- direct observation of the plant in operation
- documents and archival records

The aforementioned methods were selected based on their practicality and how well they fulfilled the criteria established by the objectives. Data acquisition was conducted in such a manner as to minimise disruption to the assembly lines while ensuring maximum cooperation and support from top managers, line managers and floor operators. Data collection methods were designed to maintain confidentiality and sensitivity of operations and performance related data.

5.5.3.1 Documents and Archival Records

Systematic searches for relevant documents are important in any data collection plan (Barnes, 2001 and Yin, 2003). Documentation exists in many forms such as:

- letters, memoranda, minutes of meetings, agendas, announcements and other written reports including formal studies and project implementation evaluations
- administrative documents such as proposals, progress reports, company annual reports, government reports and other internal records

- newspaper articles published in mass media and magazines, and newsletters produced by the company

Documentation evidence collected for this research included hard copies of reports, minutes of meetings, plant layouts as well as electronic documents stored in general areas such as CIGMA (Co-operated Information System for Global Manufacturing) and specific departmental, assembly line or personnel areas. Documentation information such as company profiles, annual reports, news letters and magazines were used to describe the background to the organisation and to show plant layout and assembly line layouts in the thesis. By analysing meeting minutes, project implementation plans, progress reports and company annual reports that contain plant performance related data for the period 2003-2006, it was possible to obtain a deeper insight into how JIT techniques were implemented, assembly line changed and whether performance enhancements were as a result of JIT implementation. Documentation evidence was very useful since most line managers have either forgotten the performance related issues or moved to other assembly lines.

Documentation in CIGMA can be divided into two. One set is in the public domain and is available to everyone within the organisation. These are in the form of company annual reports, newsletters and weekly progress reports. The other set is made up of documents linked to departments, which are made available within the intranet, and are used by personnel in a specific section or department. These documents are stored in areas accessible only by personnel of the specific department. These documents include daily production schedules, productivity and performance results and resource schedules.

The researcher was given access to relevant documents in the public domain and authorised access areas of the intranet. It was also possible to review JIT implementation plans such as the outline of the target line before and after change. Intranet documentation information such as elemental operation procedures and data in assembly stations was used for assembly line simulation modelling. Performance results from work configuration efficiency ratio charts, line balancing worksheets, process time analysis and KPI analysis collected by shop floor managers were also used for identification of the most critical production related problem, causes and sub causes during cause and effect analysis.

However, considering that the data provided could be inaccurate, outdated or biased, the researcher was able to obtain more accurate, unbiased and up to date data during observation sessions.

5.5.3.2 Observations

Observations are two-fold: participant observation and non-participant observation. Participant observation is a method by which a researcher systematically observes people and processes while also taking an active part in the activities. Non-participant observation is where the researcher observes behaviour from a distance without interacting with the process being studied. This study mainly used a non-participant observation method to minimise disruption to the assembly lines. The researcher was able to observe plants in operation and attend daily progress meetings.

Observations were used to collect two types of data:

- qualitative data – production related problems, factors that may contribute to the problem, and possible causes and sub causes to establish relationship between key JIT drivers and measurable performance
- quantitative data – assembly times, setup times, production schedules and assembly line details such as number of associates, conveyor length, speed, distance between assembly stations, and material storage points and assembly stations for model validation using simulation

Data collected were documented by extensive field notes and photographs. The assembly process was video recorded with the permission of top management. The field notes, opinions and facts were further discussed during interviews. A stopwatch was used to determine the assembly time wherever necessary.

The observation method was found to be very useful in overcoming some of the criticisms of quantitative methods such as validity and bias. Although the plant managers believe that the company has implemented proper line balancing and quality control techniques; high labour idle times, delivery delays, and wastage were observed to be rampant.

Continuous monitoring initially caused problems due to the Hawthorne Effect, a phenomenon, which was discovered in an experiment at the Western Electric Hawthorne plant in Illinois in the early 1930s claiming that subjects may react differently under experimental conditions. This factor was thought to be the artificial nature of an observation experiment, causing workers to react differently. During the initial observation of assembly times, it was thought that line associates become more active and highly focussed on their activities than the associates in the other assembly lines. The researcher therefore reassured the associates that she was not a member of staff of DMUK, in order to minimise the Hawthorne Effect. Long-term observation helped to encourage natural behaviour. It facilitated the identification of production related problems and line associates opinions to improve production processes.

Throughout this study, the researcher assumed the roles of a line associate, a line manager and a production manager. It was a good opportunity to experience different job functions and obtain a real life overview of an actual manufacturing process improvement project and also to recognise problems that would be encountered during implementation. The study was focused on one assembly line where several different types of heaters are produced. The progress of the study was constantly affected by daily production schedules, machine breakdowns, cancellation of orders and frequent delays from downstream sub-assembly suppliers. The assembly time for each activity at every station was recorded using a stopwatch. The plan was to take 20 readings for each activity; however, it was reduced to 10 readings due to the aforementioned problems.

5.5.3.3 Interviews

Interviews are one of the most important sources of information and useful in capturing data especially in case studies (Remenyi *et al.*, 1998). To gain the most complete understanding of the operations strategy, it is essential to interview a number of key players, striking a balance between those who can offer insights into strategic intentions and those who can reveal the extent to which those intentions have been realised. Interviews can be classified in to three (Robson, 1993, Remenyi *et al.* 1998 and Yin, 2003):

- *Open-ended interviews*: Interviewees are asked to give their opinion about events and to propose their own insights into certain occurrences and the interviewer may use such propositions as the basis for further inquiry
- *Focused interviews*: Respondent is interviewed for a short period of time; the interviews may still remain open-ended and assume a conversational manner, but are more likely to follow a certain set of questions derived from the case study protocol
- *Structured interviews or surveys*: Interviews are conducted with the use of structured questions similar to a formal survey or questionnaire specially designed to produce quantitative data as a part of the case study evidence

In this study, all three types of interviews were conducted with senior managers, line managers and line associates to gather qualitative and quantitative data. The interviews with line managers and top management were audio recorded with the permission of interviewee. Those interviews were conducted on site and typically one interview lasted from 30-45 minutes.

(a) Open-Ended Interview

The major objective of open-ended interviews was to identify the problems associated with the assembly line and to determine the key JIT drivers and KPIs. Open ended interviews were carried out with four line associates, two process associates, four line managers, two process managers and two top management staff. Typical questions posed during the open-ended interviews are given in Appendix 1 (Open-ended interview instrument).

Tools based on cause and effect and relations diagrams were used to analyse data gathered from interviews. The open-ended interview was suitable in this study as it allowed respondents to add information that the researcher had not thought about, especially in the early stages of the study. This type of interview provided an overall insight into the operations of the organisation, production related problems, and their causes and impact on performance, productivity and profitability. Individual open-ended interviews were used where the respondents are reluctant to give their opinion and criticisms in public or in a written format.

(b) Focused Interview

Focused interviews were carried out to validate findings obtained from observations, documents and archival records, and open-ended interviews. This interview method was further used to:

- identify the organisation's approach towards performance measurement
- check whether the company has considered BSC as a suitable multidimensional performance measurement system
- investigate KPIs and performance targets for every perspective of the PMS
- identify factors affecting customer satisfaction, financial stability, performance of internal business processes, employee productivity, supplier efficiency, innovation and growth and sustainability of the organisation

Focused interviews were conducted with line managers and top managers from Finance, Production Control, Human Resources, Purchasing, and Environmental Departments in line with structured interviews. A questionnaire survey instrument was used to collect the aforementioned information during focused interviews (refer to Questions (i), (ii), (iii) and (v) in Part II of Appendix 2).

(c) Structured Interview and Survey

A structured interview with a questionnaire was used to gather quantitative data to select important perspectives and to quantify the impact of selected key JIT drivers on BSC perspectives and overall performance of the organisation (refer to Part I and Question (iv) in Part II of Appendix 2). An analytic hierarchy process (AHP) tool was also used in data analysis collected from all the managers in Finance, Production Control, Human Resources, Purchasing and Environmental Departments. The number of participants from each department is given in Chapter 7, Table 7.7 while participants responses matched against the different BSC perspectives are presented in Table 7.8

5.5.3.4 Validation

Four different tests have been commonly used to establish the validity of case studies: reliability, construct validity, internal validity and external validity (Yin, 2003). Reliability tests determine whether the evidence and the measures used are consistent and stable, while internal validity tests establish cause and effect and relationships between the events. Internal validity testing may involve experimentation. The outcome should be a function of the variables that are measured, controlled or manipulated in the study. Construct validity tests involve the use of multiple sources of evidence to establish the correct operational measures for the concept, ideas and relationships being studied (Remenyi *et al.*, 1998). Data triangulation is commonly applied to increase construct validity. External validity tests finally define the degree to which the conclusions drawn from the study would be applicable to other situations.

In this study, construct validity was achieved through data triangulation, providing multiple confirmation of the same phenomenon. Questionnaires, semi-structured interviews with plant managers and factory floor workers, direct observation of the plant in operation, documents and archival records were all sources for data collection. A combination of different methods was used to achieve different project objectives depending on the prevailing circumstances. For example, documents, observation and open-ended interviews were used to identify key JIT drivers and KPIs, while focused and structured interviews were carried out to investigate the impact of selected key JIT variables on the extended BSC perspectives of the performance measurement system. Inconsistent outcomes were re-addressed by conducting further interviews with the same person or group of persons or by using another data collection method to seek other relevant data for construct validity.

Project outcomes were internally validated through experimentation and mathematical modelling to establish the relationship correctly between JIT variables (X_i) and measurable performance (Y) in a JIT enabled manufacturing environment. Chapter 7 presents the findings of the first case study conducted to test and validate the conceptual model.

5.5.3.5 Application of the Performance Measurement Model – Action Research

Phase III of this study involved the application of a performance measurement model to a non-automotive production environment (Risane Ltd.). Application of the performance measurement model and details of the implementation procedure were undertaken by staff of Risane (an SME) with the assistance of the researcher in order to improve both operational and overall performance. This study used 'action research' to apply the performance measurement model to Risane Ltd. Action research is found to be participatory and used for problem solving in a research setting by individuals working with others (Remenyi *et al.*, 1998).

Risane Ltd. was founded in 2003 as a small and medium enterprise (SME) with the objective of providing innovative solutions to the packaging industry. The company is continuously changing and improving products and production processes according to the customer's requirements. The study on Risane Ltd. was carried out between December 2006 and May 2007 and the findings are presented in Chapter 8.

5.6 SUMMARY

Chapter five has described the research methodology applied in this study. The overall research framework adopted has been presented concisely in Figure 5.1. The research framework is made up of three phases:

- Phase I constitutes a literature review and informal interviews/discussions, which enabled development of a conceptual performance measurement model and implementation procedure (refer to Chapters 2, 3, 4 and 6)
- Phase II describes the application of a case study to test and validate the conceptual performance measurement model. This phase also showed data collection and analysis techniques employed with experimentation to achieve internal validity and construct validity of case study findings (refer to Chapter 7)
- Phase III demonstrates action research / case study for application of the performance measurement model to a non-automotive manufacturing environment (refer to Chapter 8)

The research does not attempt to provide a common PMS for every JIT manufacturing organisation; rather it tries to develop a generic robust performance measurement model, which can be suitably amended and applied to any JIT enabled production environment to build a plant specific PMS.

CHAPTER 6: PERFORMANCE MEASUREMENT MODEL IMPLEMENTATION PROCEDURE

6.1 INTRODUCTION

This chapter presents the performance measurement model implementation procedure in a JIT enabled manufacturing environment in order to achieve the fourth objective of this research study. The chapter reviews key literature and presents a rationale for selecting linear mathematical modelling and computer based dynamic simulation to quantify the impact of key JIT drivers on operational performance. The chapter further presents key literature that support the selection of Analytic Hierarchy Process (AHP) tool for questionnaire survey analysis in order to assess the influence of those JIT drivers on organisational competitive priorities. The chapter then introduces an eight-step procedure to implementing the multidimensional performance measurement model. This novel procedure can be used to transform the generic conceptual model into a practical PMS. Each activity of the eight-steps in the model is discussed in turn. This chapter finally summarises the activities necessary for the performance measurement model implementation.

6.2 TECHNIQUES USED TO IMPLEMENT MULTIDIMENSIONAL PERFORMANCE MEASUREMENT MODEL

The fourth objective of this study is to develop a multidimensional performance measurement model implementation procedure to capture the influence of JIT practices on both operational and enterprise performance. The conceptual model presented in Chapter 4 provides a broad performance measurement model in order to achieve the following two goals:

(a) quantify the impact of JIT techniques (refer to Section 2.5) on operational performance

(b) identify the strategic influence of those JIT drivers on the organisation’s competitive priorities using the extended BSC tool described in Section 3.8

These two goals will be achieved using the tools and techniques shown in Figure 6.1.

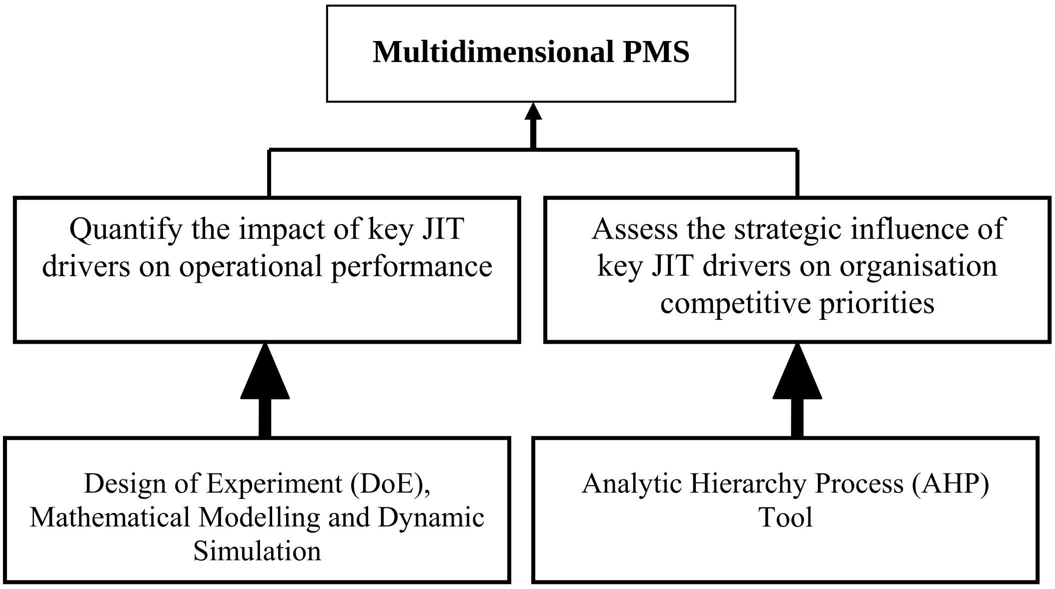

Multidimensional PMS
Quantify the impact of key JIT drivers on operational performance
Assess the strategic influence of key JIT drivers on organisation competitive priorities
Design of Experiment (DoE), Mathematical Modelling and Dynamic Simulation
Analytic Hierarchy Process (AHP) Tool

Figure 6.1: Techniques Used for Testing, Validation and Application of Conceptual Performance Measurement Model in a JIT Manufacturing Environment

The following two sections discuss the key literature that guide the selection of the aforementioned techniques for testing, validation and implementation of conceptual performance measurement model in JIT enabled manufacturing environments.

6.2.1 The Use of Simulation in JIT Studies and Quantitative Performance Measurement Systems

Chu and Shih (1992) working on the application of simulation to JIT production identified three research methodologies that have been used in JIT studies namely:

- an analytical approach to model JIT production
- field or empirical based methodologies to address the behaviour impact
- computer simulation to study related design and adaptability problems

Quantitative information is helpful in implementing JIT production techniques and computer simulation can be a valuable tool in designing, implementing or changing JIT practices in a production system (Fernando and Luis, 2002). Computer simulation and modelling tools help to visualise, analyse and optimise complex production processes using computer animation to minimise the time and cost of a process (Sandanayake *et al.*, 2008). These are powerful tools, which can be used to measure the performance of the running of an existing plant as well as plants introducing new production philosophies. Simulation can quantify performance improvements expected from applying lean manufacturing shop-floor principles of continuous flow, JIT inventory management, quality at source, and level production schedules (Detty and Yingling, 2000). Simulation is also a good method for aiding the understanding of the internal and/or external factors affecting the success of JIT implementation and for investigating the effect of demand and process time variances (Chu and Shih, 1992). Chu and Shih (1992) outlined two main reasons for the use of simulation in JIT studies, namely that it can be used to evaluate the relative performance of JIT production compared to other types of production systems and/or identify factors detrimental to the success of JIT implementation.

Sarkar and Fitzsimmons (1989) stated that while many researchers have addressed the concept of JIT philosophy, very few researchers have performed any analytical or simulation studies on JIT techniques. They employed simulation to investigate the effects of the variability of operator performance and the unequal distribution of task times on the performance of push and pull systems. Chu and Shih (1992) argued, “Though simulation has been unanimously accepted as a useful tool for studying JIT production, little effort has been put into synthesising the related literature, or in examining the status quo”. The researchers found that most of the models in use are relatively small in scale and that most of the studies involved only one end product. Chu and Shih (1992) concluded that assumptions such as perfect production process (no scrap, waste or machine breakdowns) may reflect well on the characteristics of JIT but contradict the actual production environment.

Fallon and Browne (1988) employed DoE and SLAM (Simulation Language for Alternate Modelling), a multi-orientation simulation language to model a five station synchronous assembly line in order to investigate how JIT principles might be incorporated in conventional batched-based production systems, and to what extent these can be effectively manipulated within a batch production environment. Sarkar and Fitzsimmons (1989) used simulation experiment to investigate the efficiency of push and pull systems using a production line with nine stages sequentially arranged with eight inter-stage storage points. This study was limited only to a few cases; sequential push and pull system, sequential push and pull system with machine breakdowns, and the effect of buffer storage in pull system. Welgama and Mills (1995) used the SIMAN (SIMulation ANalysis) simulation language to model and experiment one of the leading chemical companies in Australia when changing from a traditional manufacturing system to JIT. Savsar (1996) developed a simulation experiment to investigate the effect of two different kanban policies (fixed withdrawal kanban and variable withdrawal kanban) in a JIT environment, and only considered the effect of Kanban and line length on performance. Detty and Yingling (2000) used simulation in an electronic product assembly process to demonstrate JIT and lean principles in terms of improvement (reduction) in inventory, floor space, transportation, manpower and equipment requirements, time based performance measures (model change over time, order lead time, and system flow time) and to reduce variability in supplier demand.

Polat and Arditi (2005) also used DoE and simulation and modelling to compare JIT and Just-in-Case (JIC) material management systems in terms of total cost of inventory. A simulation model was developed to mimic the actual material management system of rebar used by the contractor and to see how the JIT system would perform under special conditions. Their simulation framework is shown in Figure 6.2 and the mathematical model (Eq: 6.1) developed for test is given below.

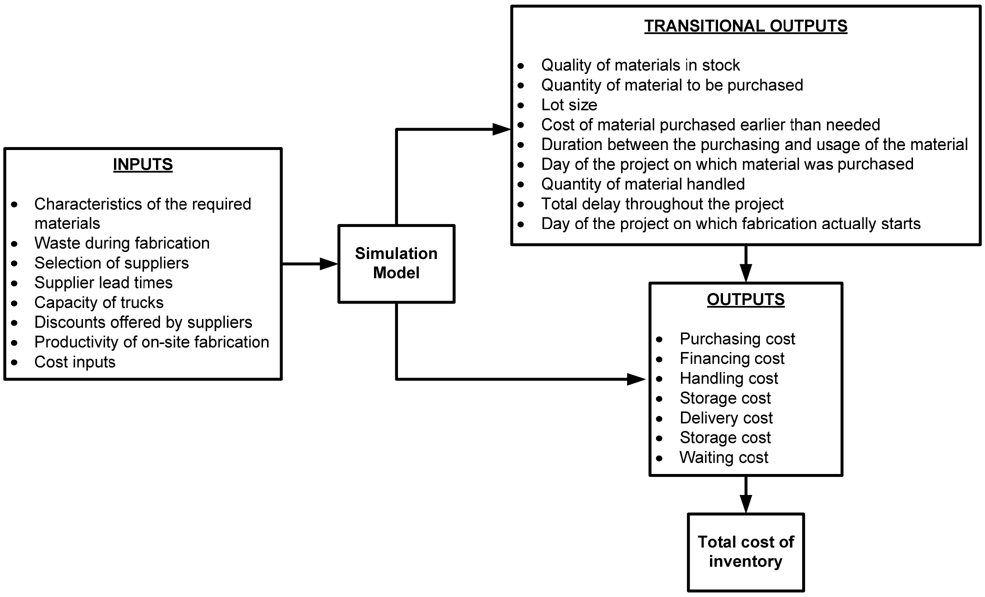

TRANSITIONAL OUTPUTS
Quality of materials in stock
Quantity of material to be purchased
Lot size
Cost of material purchased earlier than needed
Duration between the purchasing and usage of the material
Day of the project on which material was purchased
Quantity of material handled
Total delay throughout the project
Day of the project on which fabrication actually starts
INPUTS
Characteristics of the required materials
Waste during fabrication
Selection of suppliers
Supplier lead times
Capacity of trucks
Discounts offered by suppliers
Productivity of on-site fabrication
Cost inputs
Simulation Model
OUTPUTS
Purchasing cost
Financing cost
Handling cost
Storage cost
Delivery cost
Storage cost
Waiting cost
Total cost of inventory

Figure 6.2: Framework of the Simulation Model to Compare JIT and JIC Material Management System (Adapted from Polat and Arditi, 2005)

$$TCI = [C_{pi} * Q_{li}] + [C_t * (Q_{li} / S_t)] + [C_d * D_{pr}] + [C_w * D_{pr}] \quad \textbf{Eq: 6.1}$$

Where, TCI : Total cost of inventory

C_{pi} : Current unit cost of material at the time it was purchased

Q_{li} : Lot size

C_t : Unit cost of delivery per truck load

S_t : Capacity of truck

C_d : Cost of daily delay

D_{pr} : Total delay throughout the project

C_w : Cost of daily waiting

A coefficient of variance of 0.3% was targeted in this study and was reached when the model was run 100 times. The cost components and the total cost of inventory for JIT and JIC material management systems are presented in Table 6.1.

Table 6.1: Output Variable and Total Cost of Inventory for JIT and JIC Material Management Systems (Source: Polat and Arditi, 2005)

Output Variable	JIC System ($)	JIT System ($)
Purchasing Cost	372, 143	405,000
Financing Cost	13,571	-
Delivering Cost	30,714	34,286
Handling Cost	714	-
Storage Cost	5,714	-
Shortage Cost	-	2,143
Total Cost of Inventory	422,857	441,429

Polat and Arditi (2005) concluded that,

- JIT system made purchasing cost more vulnerable to price changes
- The early purchase of materials in JIC system added an extra financing cost
- The savings was obtained in the JIC system by purchasing large lot sizes
- Purchasing large lot sizes in JIC system brought about double handling and storage cost

- Systematically purchasing of small lot sizes made the production more vulnerable to possible delays in material supply which leads to shortage cost in a JIT system. Shortage cost is zero in the JIC system
- Total cost of inventory would be higher than in a JIC system

However, the authors have tested their mathematical model using only one project. Therefore, it can not conclude that the JIT system is neither effective nor economical.

Fullerton *et al.* (2003) developed a multiple linear regression model (Eq: 6.2) to link JIT measures with profitability. To separate the control variables from the explanatory variables, hierarchical multiple linear regression were run independently for each of the profitable measure (return on assets, return on sales and cash flow margin). The model was defined as follows:

$$\Pi_{i,j} = \beta_{0,j} + \beta_{1,j}^{JIT} M_i + \beta_{2,j}^{JIT} Q_i + \beta_{3,j}^{JIT} U_i + \beta_{1,j}^{C} S_i + \beta_{2,j}^{C} IN_i + \beta_{3,j}^{C} P_i + \beta_{4,j}^{C} IY_i + \varepsilon_i \ldots \quad \textbf{Eq: 6.2}$$

Where; $\Pi i,j$ is the j^{th} measure of profitability for the i^{th} firm (ROA, ROS, CFL)

JIT Variables:

Mi is the JIT manufacturing measure for the i^{th} firm

Qi is the JIT quality measure for the i^{th} firm

Ui is the JIT unique measure for the i^{th} firm

Control Variables:

Si is the organisational structure measure for the i^{th} firm

INi is the innovation measure for the i^{th} firm

Pi is the product life cycle dummy variable for the i^{th} firm

IYi is the inventory margin measure for the i^{th} firm

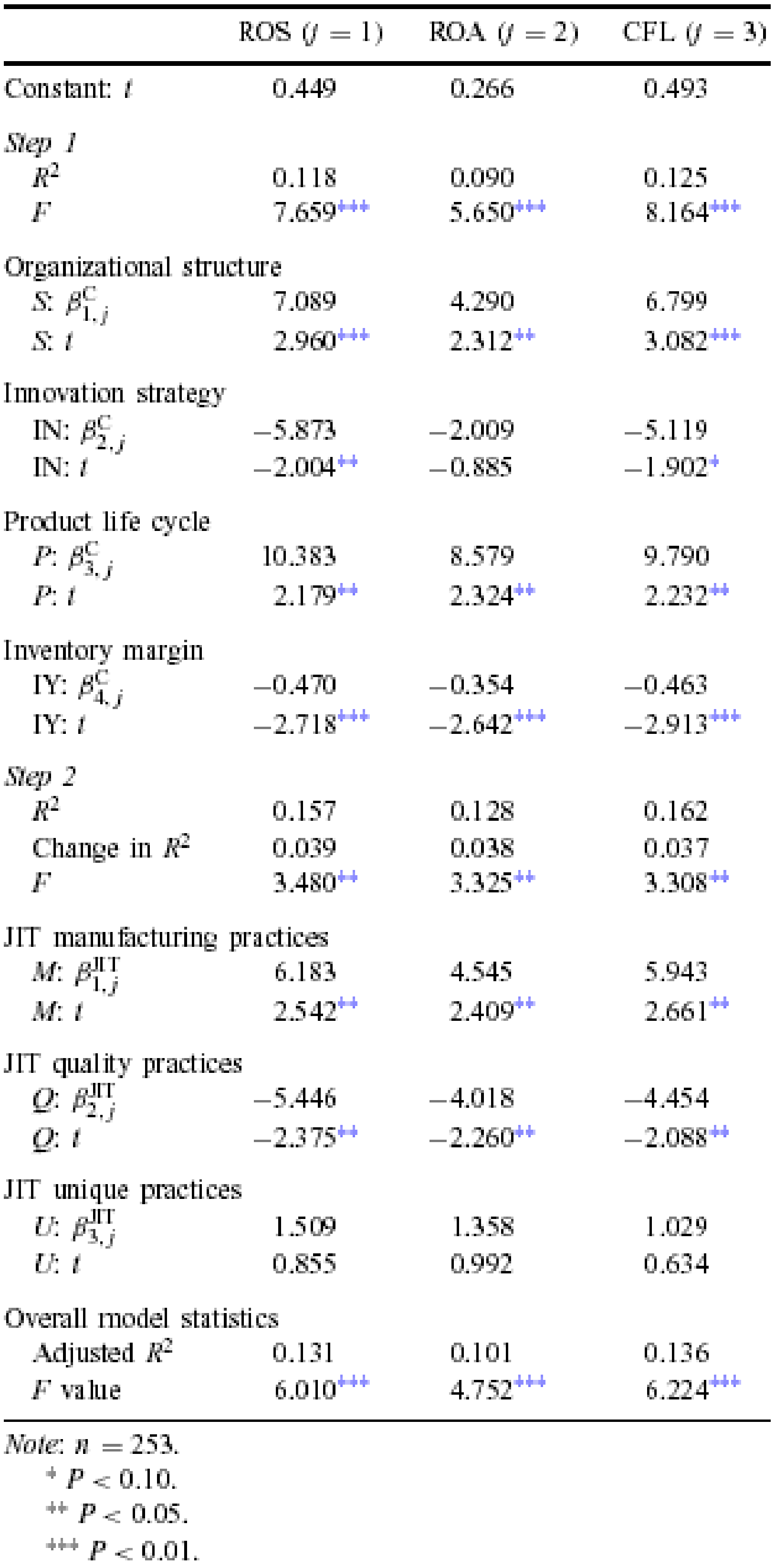
$\beta_{i,j}$ is the intercept coefficient

$\beta_{i,j}^{JIT}$ is the j^{th} effect coefficient for the respective JIT variable for the i^{th} firm

$\beta_{i,j}^{C}$ is the j^{th} effect coefficient for the respective control variable for the i^{th} firm

In each regression, the four control variables were first entered into the equation followed by independent variables. Table 6.2 shows the regression results for the relationship between JIT practices and firm profitability.

Table 6.2: The Regression Results for the Relationship between JIT Practices and Firm Profitability (Source: Fullerton *et al.*, 2003)



	ROS ($j = 1$)	ROA ($j = 2$)	CFL ($j = 3$)
Constant: t	0.449	0.266	0.493
Step 1			
R^2	0.118	0.090	0.125
F	7.659^{+++}	5.650^{+++}	8.164^{+++}
Organizational structure			
S: $\beta^{C}_{1,j}$	7.089	4.290	6.799
S: t	2.960^{+++}	2.312^{++}	3.082^{+++}
Innovation strategy			
IN: $\beta^{C}_{2,j}$	−5.873	−2.009	−5.119
IN: t	−2.004^{++}	−0.885	−1.902^{+}
Product life cycle			
P: $\beta^{C}_{3,j}$	10.383	8.579	9.790
P: t	2.179^{++}	2.324^{++}	2.232^{++}
Inventory margin			
IY: $\beta^{C}_{4,j}$	−0.470	−0.354	−0.463
IY: t	−2.718^{+++}	−2.642^{+++}	−2.913^{+++}
Step 2			
R^2	0.157	0.128	0.162
Change in R^2	0.039	0.038	0.037
F	3.480^{++}	3.325^{++}	3.308^{++}
JIT manufacturing practices			
M: $\beta^{JIT}_{1,j}$	6.183	4.545	5.943
M: t	2.542^{++}	2.409^{++}	2.661^{++}
JIT quality practices			
Q: $\beta^{JIT}_{2,j}$	−5.446	−4.018	−4.454
Q: t	−2.375^{++}	−2.260^{++}	−2.088^{++}
JIT unique practices			
U: $\beta^{JIT}_{3,j}$	1.509	1.358	1.029
U: t	0.855	0.992	0.634
Overall model statistics			
Adjusted R^2	0.131	0.101	0.136
F value	6.010^{+++}	4.752^{+++}	6.224^{+++}

Note: $n = 253$.

$^{+}$ $P < 0.10$.

$^{++}$ $P < 0.05$.

$^{+++}$ $P < 0.01$.

Both the control variables and the JIT variables make a significant separate contribution to the model. Although the majority of the explained variances are from the control variables, JIT variables make a significant contribution to each of the models, suggesting that the relationship between JIT implementation and financial performance is robust across different indicators of firm profitability (Fullerton *et al.* 2003). Their research findings indicated that the implementation of a greater degree of JIT quality practices decreased a firm's profitability and provided additional insight into the ongoing and wide spread debate on the cost of quality. Further, JIT unique measures demonstrated no significant relationship with profitability. However, their study was limited to financial performance measures.

Most recently, Fernando and Luis (2002) applied DoE and simulation to a JIT enabled production system and developed a mathematical model (Eq: 6.3) to estimate how three factors (setup time, kanban number and operator number) affect performance in terms of total completion time of a U-shape line. They also determined whether these factors interact with each other. However, Fernando and Luis did not disclose the reasons behind the selection of the three aforementioned factors. Their simulation models were generic and no real data were analysed.

Total completion time is one of the key performance indicators in a JIT manufacturing environment. In the following model, the main effect (*e*) of factor '*i*' is the average change in the response (*R*) due to changing factor *i* from its '–' level to its '+' level while holding other factors fixed.

$$y = \mu + \frac{e_1}{2}X_1 + \frac{e_2}{2}X_2 + \frac{e_3}{2}X_3 + \frac{e_1e_2}{2}X_1X_2 + \frac{e_1e_3}{2}X_1X_3 + \frac{e_2e_3}{2}X_2X_3 + \frac{e_1e_2e_3}{2}X_1X_2X_3 + u \ldots \textbf{Eq: 6.3}$$

Where,y: total completion time

μ: intercept

X_1 : setup time

X_2 : kanban number

X_3 : operator number

u: error term

$$e_1 = \frac{(R_2-R_1)+(R_4-R_3)+(R_6-R_5)+(R_8-R_7)}{4} \quad \text{Eq: 6.4}$$

$$e_2 = \frac{(R_3-R_1)+(R_4-R_2)+(R_7-R_5)+(R_8-R_6)}{4} \quad \text{Eq: 6.5}$$

$$e_3 = \frac{(R_5-R_1)+(R_6-R_2)+(R_7-R_3)+(R_8-R_4)}{4} \quad \text{Eq: 6.6}$$

All aforementioned studies have used DoE, mathematical modelling, and simulation to compare production systems or to identify the factors affecting one objective function. Most of the previous studies on simulation of JIT manufacturing systems have not examined the interaction effect of more than two parameters at a time (Yavuz and Satir, 1995).

A major objective of this study is to apply design of experiments, linear mathematical modelling and simulation tools to develop a robust mathematically determined performance measurement model which links key JIT drivers (X_i) to operational performance (Y) (refer to Figure 4.10).

The next section will review literature on AHP tool, which is selected to assess the influence of JIT drivers on overall performance of the organisation.

6.2.2 Applications of Analytic Hierarchy Process Tool in Key Management Research Studies

Clinton *et al.* (2002) suggested the Analytic Hierarchy Process (AHP) as a tool to solve the dilemmas of how to systematically choose appropriate metrics and how to compare alternatives with differing metrics. The AHP is a method for determining the priorities or weights of criteria that verify the achievement of a goal (Saaty, 1980). Recently, AHP has been applied to decision making in the areas of investment options (Arinze *et al.,* 1995 and Kodali and Routroy, 2006), production planning systems (Razmi *et al.,* 1998 and Singh *et al.,* 2006), vendor selection (Haq and Kannan, 2006) and performance measurement (Norris, 1992, Rangone, 1996, Clinton *et al.,* 2002, Hafeez *et al.*, 2002, Searcy, 2004 and Yurdakul and Ic, 2005).

Chan and Lynn (1991) devised a performance evaluation scheme and suggested that the AHP tool could be used to derive an overall measure for evaluating the divisions of Chynn Corp. The nine evaluation criteria used for divisional performance appraisal are profitability, productivity, marketing effectiveness, operating effectiveness, hedging effectiveness, employee morale, customer satisfaction, product and technology innovation and operating efficiency. The researchers concluded that, "profitability is the most important criterion for performance evaluation whereas employee morale is of least importance".

Norris (1992) used an AHP tool to evaluate the relative importance of six JIT techniques (setup time reduction, group technology, uniform plant load, pull system, total preventive maintenance and JIT purchasing) in order to increase manufacturing efficiency and effectiveness (Figure 6.3). Norris also introduced a specially designed questionnaire for data collection for AHP analysis.

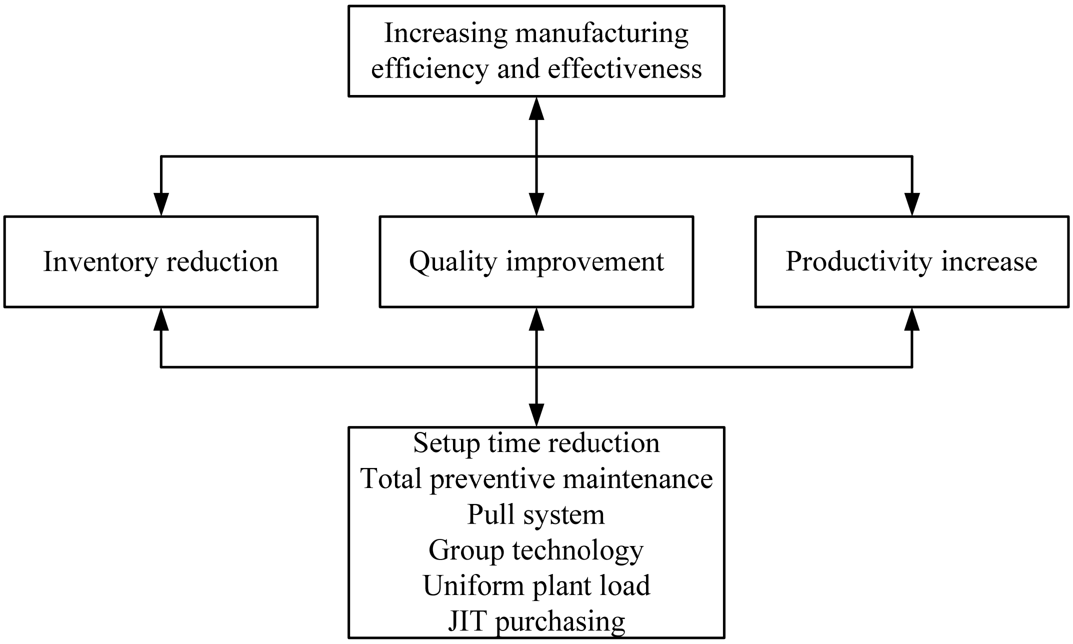


Figure 6.3: AHP Hierarchy to Evaluate Relative Importance of Six JIT Techniques on Manufacturing Efficiency and Effectiveness (Norris, 1992)

Rangone (1996) used an AHP tool to measure and compare the overall performance of different manufacturing departments on the basis of multi-attribute financial and non-financial performance criteria. Figure 6.4 shows the performance hierarchy designed to determine the relative importance of competitive priorities (quality, flexibility and environmental compatibility) and performance measures in a hypothetical situation.

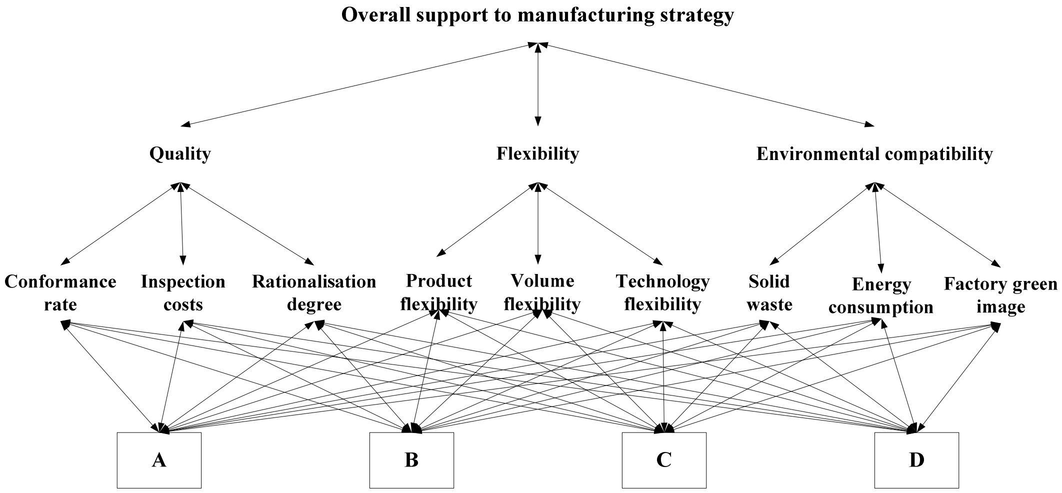


Figure 6.4: The Performance Hierarchy for Determination of Relative Importance of Competitive Priorities and Performance Measures (Rangone, 1996)

Rahnejat and Khan (1998) thereafter applied an AHP method to determine the optimal production planning system for certain environments and devised a four-level hierarchical model. The first level focussed on the main objective of production planning, i.e. the optimal production planning system. The main objective is divided into three main attributes, which are cost, flexibility and market issues. The third level included sub attributes and the fourth level consisted of four production planning alternatives: i.e. order scheduling, MRP, hybrid and kanban systems. However, the researchers used only hypothetical data to illustrate their model.

Lee *et al.* (2008) proposed an approach for evaluating the IT manufacturing performance based on fuzzy AHP and BSC. The researcher used fuzzy AHP, due to the fuzziness and vagueness of human decision making process. Clinton *et al.* (2002) suggested AHP as a valuable tool to choose metrics for the companies who have PMS such as BSC. According to their study, the first level of a BSC hierarchy consists of four BSC perspectives and the second level consists of the metrics used within each perspective. The researchers have introduced a sample questionnaire survey instrument for data collection.

The research carried out by Hafeez *et al.* (2002) provided two structured frameworks to determine the key capabilities of a firm using an AHP method. The researchers have considered both financial and non-financial measures in a capability evaluation process. These frameworks are generic in nature and have been tested by being applied to one of the leading steel manufacturers in the UK.

Taking in to account the findings of Clinton *et al.* (2002), Searcy (2004) investigated the applicability of an AHP tool at the first level of a BSC hierarchy with data from six firms. The researcher applied Kaplan and Norton's BSC, but the internal business processes perspective was divided into three sub categories: operating performance, safety and product quality. Searcy (2004) demonstrated the application of Excel in AHP analysis and presented a sample survey instrument.

According to the research context of this study, one major task is to develop a generic performance measurement approach to capture the influence of key JIT variables on organisational competitive priorities and to assess their relative importance in overall performance measurement. The aforementioned key studies suggested that an AHP tool should be selected to investigate the impact of JIT drivers on extended BSC perspectives and overall performance in JIT manufacturing environments. Sample survey instruments introduced by Norris (1992), Clinton, *et al.* (2002) and Searcy (2004) were used as a guide to develop a questionnaire survey instrument for this study (refer to Appendix 2).

The next section therefore introduces a performance measurement model implementation procedure using the aforementioned tools and techniques.

6.3 PERFORMANCE MEASUREMENT MODEL IMPLEMENTATION PROCEDURE

Comprehensive literature review and informal discussions show that most manufacturing organisations have implemented different JIT techniques and have different competitive priorities. This suggests that PMS should be unique to the production environment. The performance measurement conceptual model introduced in Section 4.4 provides a generic, comprehensive and non-perspective template where managers can develop their own PMS to match the company strategy. This section therefore introduces a methodical system to transform a conceptual model into a practical PMS. The key research studies that guided the selection of appropriate tools and techniques for performance measurement model implementation were discussed in Section 6.2.

The proposed performance measurement model implementation procedure is divided into three main phases and further broken up into a set of logical steps. An eight-step implementation procedure is given in Table 6.3. The subsequent sections of this chapter discuss the following steps in detail.

Table 6.3: Eight-Step Performance Measurement Model Implementation Procedure

Phase	Step	Activity	Objective
Phase I	Step 1	Determination of key JIT drivers and KPIs	Identify key JIT drivers (X_i) and quantify their impact on operational performance (Y)
	Step 2	Experimental design and linear mathematical modelling	
	Step 3	Simulation and modelling	
	Step 4	Simulation result analysis and mathematical modelling	
Phase II	Step 5	Development of performance hierarchy	Assess the strategic influence of key JIT drivers on BSC perspectives and overall performance
	Step 6	Conduct survey	
	Step 7	AHP analysis	
Phase III	Step 8	Comparison of the results of Phase I and II	Process management and performance optimisation

6.3.1 Determination of Key JIT Drivers and KPIs

Kaplan and Norton’s BSC neither provided a list of performance measures nor criteria to select KPIs and CSFs. Inman and Mehra (1993) stated that “to describe a variable as a component of JIT implementation and then designate it as a benefit utilised in measuring the level of success of JIT implementation is a circular logic”. There is no evidence in the literature of a comprehensive mechanism to identify and narrow down possible JIT variables to a meaningful and manageable list for the purpose of system optimisation (Sandanayake *et al.*, 2007 and 2008). Neely *et al.*, (1995) argued that there should be a technique for managers to reduce the list of “possible” measures to a meaningful set in their future research agenda. Mazany

(1995) and Suwignjo *et al.*, (2000) recognised this gap and introduced a quantitative model for performance measurement using new management tools such as cognitive maps, cause and effect diagrams and the AHP. They used the following three main steps in developing their model:

- identification of factors affecting performance and their relationship
- structuring the factors hierarchically
- quantifying the effect of the factors on performance

Determination of key JIT variables and associated KPIs is the first step of the performance measurement model implementation procedure. The typical management tools such as 'cause and effect analysis' and 'relations diagrams' can be used to identify key JIT factors and KPIs that drive manufacturing performance. A cause and effect diagram provides a pictorial display of all potential causes that could result in a single possible effect. A relations diagram highlights the root causes contributing to major effect or measurable outcome.

(i) Cause and Effect Diagram

A cause and effect diagram can also be known as a fishbone diagram or Ishikawa diagram; it is a pictorial representation of the problem, the factors that may contribute to the problem and possible causes and sub causes of the problem. This diagram leads to immediate identification of major causes, points to the potential remedial actions and indicates the best potential areas for further exploration. Figure 6.5 shows a typical cause and effect diagram.

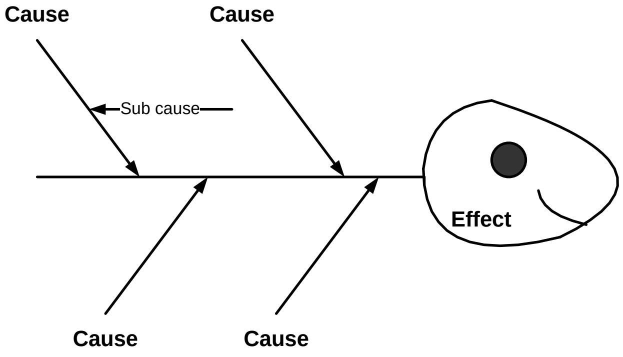
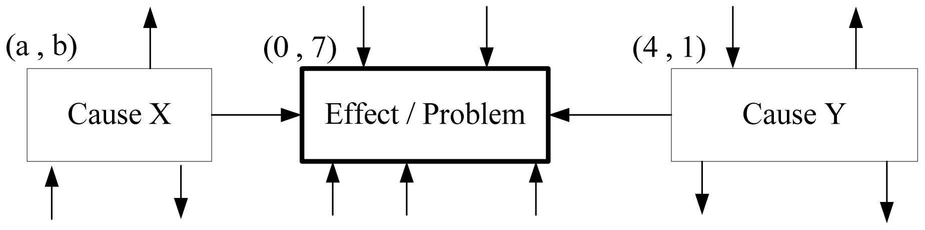


Figure 6.5: Typical Cause and Effect Diagram

As a powerful management tool, a cause and effect diagram can be used to establish cause and effect relationships between JIT drivers and performance measures. The application of this tool to identify production related problems, causes and sub-causes using observations, company documents, archival records and open-ended interviews in two production environments are presented in Sections 7.5 and 8.3.1.

(ii) Relations Diagram

A relations diagram helps to identify any major problems to determine their underlying causes. It facilitates the identification of both primary and secondary causes of a given effect and establishes the inter-relationships between a multitude of items that have no linear relationship to each other. The relations diagram addresses these situations by showing relationships between items with a network of boxes and arrows. The outgoing arrows represent basic causes and incoming arrows represent effects. The number of incoming and outgoing arrows is used as an importance indicator for each key cause or effect (Figure 6.6).



In (a , b), a: number of causes and b: number of effects

Figure 6.6: Typical Relations Diagram

Relations diagram therefore can be used to identify relationships between causes and their effects in JIT enabled manufacturing environments. The magnitudes of relationships help to identify key effect and causes; hence it is possible reduce all potential operational problems into their root causes. Interviews and discussions with the production managers can be used to identify underlying JIT drivers of the selected root causes. The relations diagram can therefore be used to narrow down operational problems to their root causes, which is an advantage at the experimental design stage. The application of relations diagram tool to identify major effect and key causes in JIT production environments are presented in Sections 7.5 and 8.3.1.

6.3.2 Design of Experiments (DoE) and Linear Mathematical Modelling

Based on the findings of the relations diagram, the next step in performance measurement model implementation procedure is to establish the relationship between key JIT drivers and measurable performance using design of experiments and linear mathematical modelling.

The Design of Experiment (DoE) technique has been used to study both independent and interaction effects of various factors on performance in several case studies. This technique was introduced by Sir R. A. Fisher in the early 1920s.

> *"DoE is a statistical technique used to study the effect of multiple variables simultaneously. By studying the effect of individual factors on the result, the best factor combination can be determined." (Roy, 2001)*

The experiments are simple when there is only one factor affecting on outcome. However, in an industrial situation, multiple factors could pose a problem (Sandanayake *et al.*, 2008). Fractional factorial design rather than full factorial design in a case involving more than two system parameters was reported by Yavuz and Satir (1995). Factorial design can be used to study the linear effect of multiple factors on performance in a manufacturing environment. The outcomes from the experiment consist of interactions between the factors, which are the driving forces in many processes.

DoE can be used to study the effect of JIT drivers on operational performance and to determine the best factor combination for system optimisation. Hence, 2^k two-level full factorial DoE is applied to establish the relationship between selected key JIT drivers (k number of factors) and the system performance. The decision on selecting full or fractional factorial design depends on the number of key JIT drivers and the complexity of the mathematical model. Fractional factorial design can therefore be used initially to select a subset of combinations in order to screen out JIT drivers with little or no impact on performance.

Screening DoE is a methodology to identify important factors affecting process output. The output is expressed as a linear polynomial equation relating the response (Y) to the relevant design factors (X_i). For instance the linear mathematical model linking *i* number of JIT drivers to a measurable KPI is described as Eq: 6.7 (Fox, 1997):

$$Y_n = a_0 + a_1X_{n1} + a_2X_{n2} + a_3X_{n3} + ...+ a_iX_{ni} + \varepsilon_n \quad \text{...............................} \quad \textbf{Eq: 6.7}$$

Where: Y_n is n^{th} observation for the KPI

a_0 is intercept coefficient and a_1 to a_i are effect coefficients

X_{n1} to X_{ni} are n^{th} run for *1* to i^{th} JIT factor

ε is error term

The main effect of each factor is independent of the other factors and the interaction effect is useful in determining the interaction between factors. The following matrix notation (Eq: 6.8) is used to express the aforementioned linear mathematical model in a matrix format showing the intercept, effect and interaction coefficients as well as the error term (Eq: 6.9):

$$\boldsymbol{Y = X.a + \varepsilon} \quad \text{...} \quad \textbf{Eq: 6.8}$$

Where,

$$\boldsymbol{Y} = \begin{bmatrix} Y_1 \\ Y_2 \\ : \\ Y_n \end{bmatrix} \quad \boldsymbol{X} = \begin{bmatrix} 1 & X_{11} & X_{12} & ....X_{1i} \\ 1 & X_{21} & X_{22} & ....X_{2i} \\ : & : & : & : \\ 1 & X_{n1} & X_{n2} & ....X_{ni} \end{bmatrix} \quad \boldsymbol{a} = \begin{bmatrix} a_1 \\ a_2 \\ : \\ a_n \end{bmatrix} \quad \boldsymbol{\varepsilon} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ : \\ \varepsilon_n \end{bmatrix} \text{...........} \quad \textbf{Eq: 6.9}$$

Applying the least square approach, the regression coefficient of vector '*a*' can be expressed as follows (Eq: 6.10):

$$\boldsymbol{a = (X'X)^{-1}X'Y} \quad \text{...} \textbf{Eq: 6.10}$$

Where, $\boldsymbol{X'}$ is the transposed $\boldsymbol{X}$ matrix and $\boldsymbol{(X'X)^{-1}}$ is the inverse of $\boldsymbol{X'X}$.

The error (ε) between the DoE and predicted model is (Eq: 6.11),

$$\boldsymbol{\varepsilon = Y - \hat{Y}} \quad \text{...} \quad \textbf{Eq: 6.11}$$

Where, the predicted response, $\hat{Y}$, is (Eq: 6.12),

$$\hat{Y} = aX \qquad \text{Eq: 6.12}$$

Hence, the linear mathematical models developed based on Eq: 6.7 for single (Eq: 6.13), two (Eq: 6.14), three (Eq: 6.15) and four (Eq: 6.16) factors are as follows:

- Single factor

$$Y = a_0 + a_1X_1 + \varepsilon \qquad \text{Eq: 6.13}$$

- Two factors

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_1X_2 + \varepsilon \qquad \text{Eq: 6.14}$$

- Three factors

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_1X_2 + a_5X_1X_3 + a_6X_2X_3 + a_7X_1X_2X_3 + \varepsilon \qquad \text{Eq: 6.15}$$

- Four factors

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_1X_2 + a_6X_1X_3 + a_7X_1X_4 + a_8X_2X_3 + a_9X_2X_4 + a_{10}X_3X_4 + a_{11}X_1X_2X_3 + a_{12}X_1X_2X_4 + a_{13}X_1X_3X_4 + a_{14}X_2X_3X_4 + a_{15}X_1X_2X_3X_4 + \varepsilon \qquad \text{Eq: 6.16}$$

Where, Y is the KPI

a_0 is the intercept coefficient

a_1 to a_i are the main effects (effect coefficients) and interactions (two-way, three-way, four-way interaction coefficients)

ε is the error term

X_1 to X_i are the JIT variables.

As shown in the above four equations, the complexity of the mathematical model increases with the number of key JIT variables. This is the main reason for the introduction of the two-step approach to identify and narrow down JIT drivers to a meaningful and manageable list (refer to Section 6.3.1). Moreover, fractional factorial design can be used where there are more than four key JIT drivers affecting system performance, in order to screen out those drivers with little or no impact on performance.

DoE, therefore can be used to identify critical JIT drivers by fitting a polynomial to the experimental data in a multiple linear regression analysis. The DoE developed to test the impact of JIT drivers on operational performance in two JIT production environments are presented in Sections 7.6 and 8.3.2. The next step of the performance measurement model implementation procedure is to conduct simulation experiments with the mathematical model.

6.3.3 Simulation and Modelling using ProModel

Computer simulation is an imitation of a dynamic system using a computer model. It is a trial and error methodology, and does not directly provide explanations for the observed system behaviour (Tsai, 2002). According to Galbraith and Standridge (1994) and Tsai (2002), simulation is very helpful to analyse, schedule and plan manufacturing systems instead of using complicated mathematical model equations.

After a careful and systematic review of ‘Witness™’, ‘Quest™’ and ‘ProModel™’ dynamic simulators, it was found that while all three software packages can be used to conduct simulation experiments to achieve the objectives of the study, ProModel software, which is currently using in the university was selected for this study for the following reasons.

ProModel is a powerful visual simulation tool, which can be used to model manufacturing systems such as job shops, conveyors, mass production, assembly lines, flexible manufacturing systems and JIT systems (Harrell *et al.*, 2003) and enable the rapid evaluation of alternative operating methods and business scenarios to support and aid business decisions (ProModel, 2005).

ProModel simulation and modelling software enables the user to conduct experiments, run multiple replications and automatically calculate confidence intervals (ProModel, 2005). This software has the ability to read external files, for example, text files and Excel spreadsheets, to obtain data such as cycle times, breakdown rates and shift patterns. It further provides an animated display of both the operation and comprehensive three-dimensional statistical reports. ProModel provides the ‘Stat::Fit’ utility package to analyse and statistically fit user-input data to an appropriate empirical distribution. ProModel also provides the ‘SimRunner’ package, which gives intelligent support in:

- *Optimisation Analysis* – helps to identify input factors that are affecting the objective function and the significance of their effect
- *Simulation Optimisation* – compares various combinations of input factors to derive the best objective function value

ProModel has the ability to reproduce and randomise replications of a simulation model. Each replication uses an independent seed to generate a random number stream. The outcomes from replications are therefore independent of each other. Replicates provide an estimate of pure error or experimental error, which helps to determine whether observed differences in the data are statistically different.

ProModel helps to determine whether changes in a given input JIT variable affect the objective function and indicate the significance of the effects without disrupting the current manufacturing process (Sandanayake *et al.*, 2007 and 2008). It enables the determination of the best combination of input factor values in order to optimise the objective function. ProModel simulation software therefore can be applied to model a JIT enabled assembly line, in order to identify, modify and optimise JIT drivers affecting the plant performance. Simulation results can be used to develop performance measurement mathematical models to establish cause and effect relationships between key JIT variables (X_i) and operational performance (Y). The experiments with ProModel simulation software to test the impact of JIT drivers on operational performance in two JIT enabled manufacturing environments are presented in Sections 7.7 and 8.3.3.

Overall, it is not compulsory to use ‘ProModel™’ simulation software to conduct experiments in a real life situation as managers or researchers can use other software packages such as ‘Witness™’ and ‘Quest™’ and also conduct experiments with the actual system. However, it would be a time consuming, disruptive and expensive process.

6.3.4 Simulation Results Analysis and Mathematical Modelling

MINITAB statistical software provides a valuable statistical tool to analyse DoE results and to identify factors that drive performance (Minitab, 2003). Hence, MINITAB can be used to analyse simulation results in order to establish relationships between JIT drivers and KPIs.

MINITAB provides several analytical and graphical tools to analyse experimental results. The software allows the user to name factors, specify the number of levels for each factor and number of replications and it automatically displays all available designs. The response data can then be entered in the results column to analyse experimental results and to generate statistical reports and graphs in order to evaluate the effects and interactions of factors of the experimental design.

Graphing the parameter effects can provide more insight at a glance (Unal *et al.*, 1993). MINITAB generates three types of factorial plots:

(1) *Effect Plots* – The main effect plot shows the main effects of factors on performance and helps to compare the relative strengths of the different effects (Figure 6.7). In the effect plot, the x-axis represents experimental levels (e.g.: lower and upper values) and the y-axis represents mean value of result (*Y*). If the line is horizontal, then there is no main effect present. If the line is at a slope, on the other hand, there is a main effect present and its significance increases with increasing magnitude of slope.

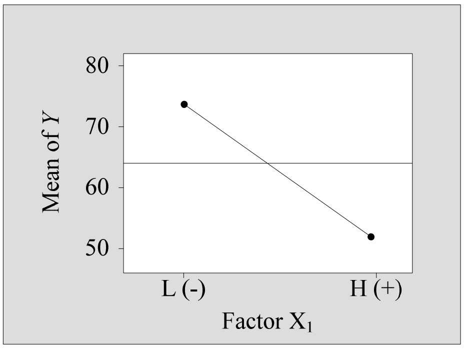


Figure 6.7: Typical Effect Plot (Adopted from Minitab, 2003)

(2) *Interaction Plots* – The interaction plot illustrates the interaction effect between two factors and compares the relative strength of their interaction

(Figure 6.8). In the interaction plot, the x-axis represents experimental levels of one factor, the y-axis represents the mean value of result (*Y*) and the lines in the plot represent experimental levels of the other factor. If the lines are parallel, then there is no interaction. If the lines are not parallel, then there may be an interaction present; the greater the degree of departure from being parallel, the stronger the effect.

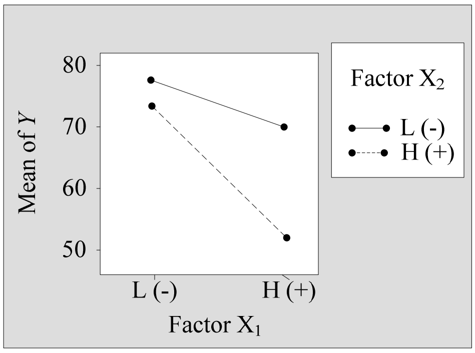


Figure 6.8: Typical Interaction Plot (Adopted from Minitab, 2003)

(3) *Normal Probability Plots* – The normal probability plot compares the relative magnitudes and statistical significance of main and interaction effects (Figure 6.9). The standardised effect is plotted on the x-axis and normal probability is plotted on y-axis. MINITAB draws a line to indicate where the points would be expected to fall if there were no effects. Points located a significant distance from the fitted line denote the important effects, while points located very close to the fitted line denote non-important effects.

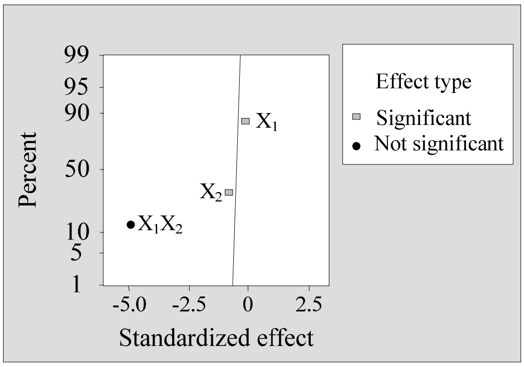


Figure 6.9: Typical Normal Probability Plot (Adopted from Minitab, 2003)

Few researchers such as Bukchin (1998), Zeramdini *et al.* (2000) and Fernando and Luis (2002) used ANOVA for statistical analysis of simulation results. The factorial fit and analysis of variance (ANOVA) tables provide a summary of the coefficients of main effects, interactions and p-values. The coefficient of the main and interaction effects of JIT factors determine their relative strengths. The higher the coefficient, the greater the effect or interaction of the factor/s on the response.

The p-value shows statistically significant effects and interactions of the model. An effect is significant, if the p-value is less than or equal to alpha (α). The probability of making a type I error can also be called the α error. When there is no effect, and yet the test concludes that there is an effect, a type I error is made. α is also referred to as the significance level.

The factorial fit table, the ANOVA table and the factorial plots can all be used to develop mathematically guided and determined performance measurement models and draw conclusions at the end of Phase-I of the performance measurement model implementation process. The coefficients of the factorial fit table can be used to construct linear regression equations by linking key JIT variables to operational performance. Simulation results analysis in case manufacturing environments are presented in Sections 7.8 and 8.3.4.

6.3.5 Development of Performance Hierarchy for Analytic Hierarchy Process (AHP) Analysis

Phase II of the performance measurement model implementation procedure involves identification of the impact of selected key JIT techniques on the organisation’s competitive priorities using an extended BSC tool. According to key literature findings summarised in Section 6.2.2, the AHP tool is the most suitable method for assessing the impact of selected JIT drivers on BSC perspective and overall performance of the organisation.

The next step was therefore to develop a performance hierarchy for AHP analysis. In a typical performance hierarchy, the first level consists of an overall objective, the second level consists of sub performance categories and the third level comprises decision alternatives. Figure 6.10 shows the performance hierarchy developed for this study.

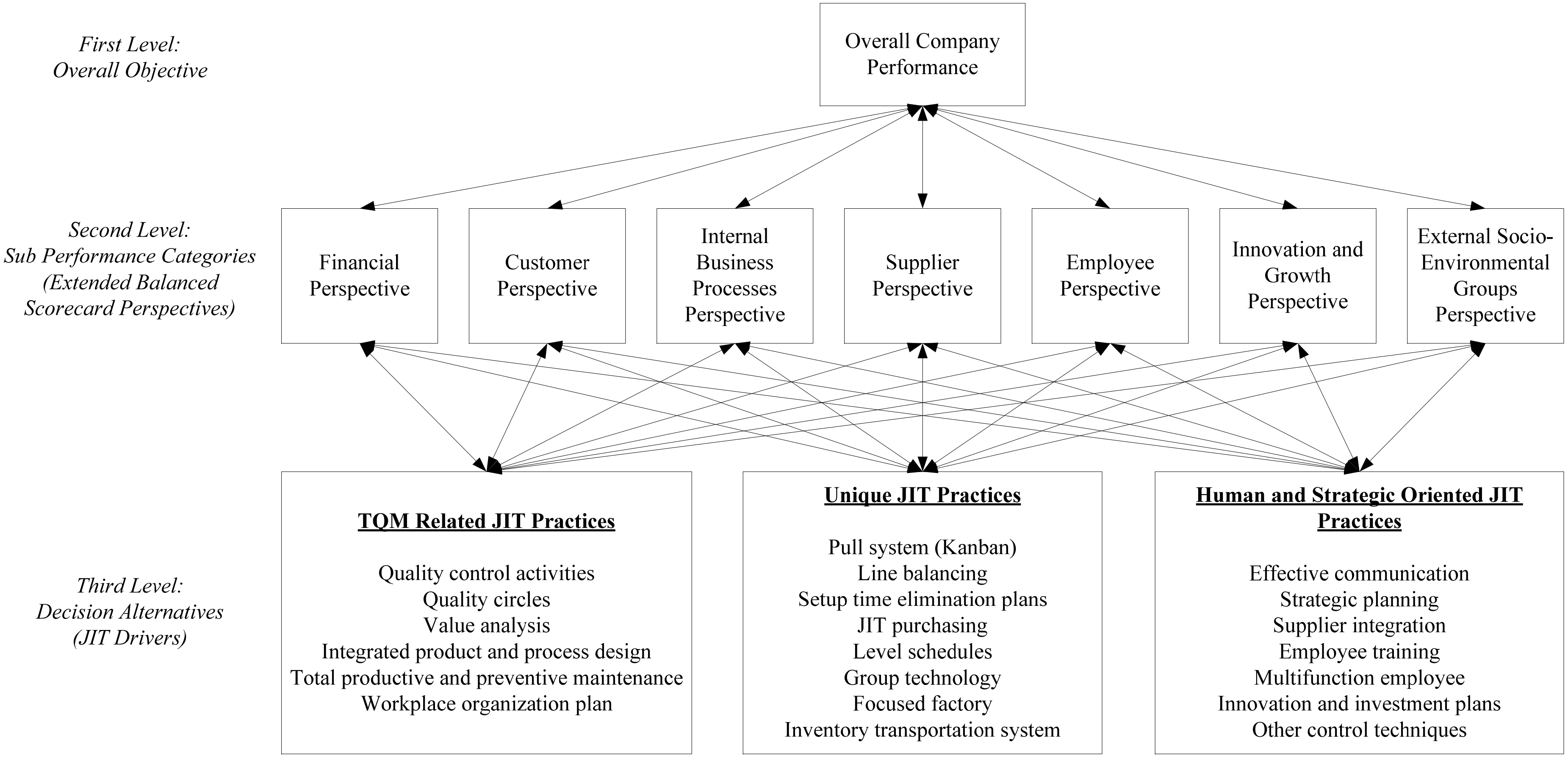

First Level:
Overall Objective
Overall Company Performance
Second Level:
Sub Performance Categories
(Extended Balanced Scorecard Perspectives)
Financial Perspective
Customer Perspective
Internal Business Processes Perspective
Supplier Perspective
Employee Perspective
Innovation and Growth Perspective
External Socio-Environmental Groups Perspective
Third Level:
Decision Alternatives
(JIT Drivers)
TQM Related JIT Practices
Quality control activities
Quality circles
Value analysis
Integrated product and process design
Total productive and preventive maintenance
Workplace organization plan
Unique JIT Practices
Pull system (Kanban)
Line balancing
Setup time elimination plans
JIT purchasing
Level schedules
Group technology
Focused factory
Inventory transportation system
Human and Strategic Oriented JIT Practices
Effective communication
Strategic planning
Supplier integration
Employee training
Multifunction employee
Innovation and investment plans
Other control techniques

Figure 6.10: Performance Hierarchy in a JIT Environment

The top level of the structure shows the overall goal of JIT implementation, which is 'improved overall company performance'. The second level shows seven different BSC performance measurement perspectives, which are sub categories of the overall PMS. The third level depicts the JIT drivers that could lead to manufacturing excellence.

The key JIT variables identified from Step 1 of Phase I should be incorporated into a customised performance hierarchy in performance measurement model implementation in a JIT enabled manufacturing environment (refer to Sections 7.9.1 and 8.3.5).

The AHP method is used to identify high priority tasks or issues based on weighted selection criteria (Saaty, 1980). It is a matrix diagram where the variables in the rows and columns are the same (refer to Table 6.4). This multi-criteria decision support system uses a 5 to 1/5 scale (5, 4, 3, 2, 1, 1/2, 1/3, 1/4 and 1/5) to assign rate based on pairwise comparison among key factors (refer to Appendix 2). For example, point 5 is awarded for the situation where the row in a paired comparison matrix is 5 times more significant than the column. The main advantage of this ratio-scale over a Likert-scale is, in Likert-scale, a score of 2 could not be interpreted as twice as important as a score of 1, whereas, with ratio-scale, that statement can be made (Norris, 1992).

Another advantage of the AHP method is the Consistency Ratio (CR), which is a measure of the consistency of individual elements in a pairwise comparison. Cheng and Li (2001) mentioned that AHP is likely to be more reliable than simple rating method, because CR prevents respondents from making arbitrary, incorrect and non-professional judgements. Inconsistency refers to a lack of transitivity of preference (Saaty, 1980). Cheng and Li (2001) further clarified that respondents who filled the questionnaire but could not build up their judgements logically would not achieve the consistent comparisons. A CR of 0.10 or less is considered acceptable (Saaty, 1980). If the CR is larger than desired, Saaty (2004) suggested the following three steps to overcome the inconsistency:

- find the most inconsistent judgment in the matrix,

- determine the range of values to which that judgment can be changed corresponding to which the inconsistency would be improved,
- ask the decision maker to consider, if he can, change his judgment to a plausible value in that range

Harker and Vargas (1987) and Searcy, (2004) proved that using a different ratio-scale does not violate the theoretical foundation of the AHP as long as the scale used is a bounded ratio scale. Rangone (1996) suggested two different approaches to follow in order to consider the AHP judgements of several people:

- appoint a facilitator to arrive at a consensus on the judgements of the members
- aggregate the individual paired judgements on the basis of geometric mean

Although this study suggests the AHP tool to analyse linear hierarchical relationships, when there are interactions within clusters of elements (inner dependencies) and between clusters (outer dependencies) with a looser network structure, an AHP is no longer suitable (Saaty, 2001 and 2004). Thus, Analytic Network Process tool (AHP) can be used to assess looser network structures, where different KPIs are driven by different JIT techniques.

6.3.6 Design Questionnaire and Conduct Survey for Analytic Hierarchy Process Analysis

A questionnaire was designed to conduct focused and structured interviews with case study companies (refer to Appendix 2). The questionnaire is used to compare and evaluate the relative importance of extended BSC perspectives on the overall performance of the company. It also evaluates the impact of selected key JIT drivers on extended BSC perspectives and can be designed to:

- check whether the company has considered BSC perspectives in their mission and vision statements
- identify the company/manager’s perception on extended BSC perspectives
- investigate the existing KPIs and performance targets of each perspective

- recognise the factors affecting customer satisfaction, financial stability, internal business processes efficiency, employee productivity, supplier efficiency, innovation and growth and sustainability of the organisation

Focused interview data analysis can be used to recognise the link between company vision, mission and KPIs. These brainstorming interviews will be helpful in assessing the impact of JIT techniques on BSC perspectives. Furthermore, the AHP analysis can be used to:

- structure the extended BSC perspectives hierarchically in order to identify the organisation's competitive priorities
- organise the key JIT drivers hierarchically in order to identify the most influential JIT technique on each BSC perspective and overall performance

Saaty (2004) stated that "there are people who are more expert than others in some areas and their judgments should have precedence over the judgments of those who know less as in fact is often the case in practice". Therefore, subjectivity and inconsistency of AHP weights can be reduced by considering the geometric mean of judgements of experienced, skilled and educated personnel from relevant departments. For example, the influence of selected JIT variables on financial, employee, customer, supplier, internal business processes, environmental, and innovation and growth perspectives should be judged by the managers from Finance, Human Resource Management, Customer Care, Purchasing, Production Control, Environment, and Research and Development Departments respectively. The design of questionnaires for focused and structured interviews are presented in Sections 7.9.2 and 8.3.6 while the summaries of the focused interview findings are presented in Sections 7.9.3 and 8.3.7.

6.3.7 Analytic Hierarchy Process Analysis

The next step of Phase II is an analysis of the questionnaire survey data using an AHP tool. Normally, there are four steps to be followed in AHP analysis, as described in the following paragraphs.

Step 1: Enter data to the pairwise comparison table

The first step is to enter the pairwise comparison responses into the comparison table. Table 6.4 displays the matrix format for AHP analysis. For example, if factor A is evaluated as W_1 times (W_1 is 5, 4, 3, 2, 1, 1/2, 1/3, 1/4 or 1/5) as factor B, the reciprocity axiom must be $1/W_1$ (i.e. when F_{ij} is a comparison judgements for column *i* and row *j*; then, $F_{ji} = 1/ F_{ij}$.). It is worthwhile to use the geometric mean of individual value judgements to increase the accuracy of the data. The sum of each column will be used in Step 2 (e.g: S_1 is the sum of the components of Column 1).

Table 6.4: Pairwise Comparison

STEP 1 : PAIRWISE COMPARISON			
Factors	**A**	**B**	**C**
A	1	W_1	W_2
B	$1/W_1$	1	W_3
C	$1/W_2$	$1/W_3$	1
SUM	S_1	S_2	S_3

Step 2: Normalise the comparison

The second step of AHP analysis is normalising the pairwise comparisons. In this step, the relative preferences are simply added up and normalised to 1. This step starts with dividing each element of the matrix by its column sum. The pairwise normalised comparison is shown in the Table 6.5. An average of each row in the normalised matrix is the performance score of each factor. Performance score shows the relative importance or impact of each factor on overall objective.

Table 6.5: Pairwise Normalised Comparison

STEP 2 : PAIRWISE NORMALIZED COMPARISON					
Factors	**A**	**B**	**C**	**SUM**	**PERFORMANCE SCORE**
A	$1/S_1$	W_1/S_2	W_2/S_3	x_1	$x_1/X = Y_1$
B	$1/W_1S_1$	$1/S_2$	W_3/S_3	x_2	$x_2/X = Y_2$
C	$1/W_2S_1$	$1/W_3S_2$	$1/S_3$	x_3	$x_3/X = Y_3$
				$X = x_1+x_2+x_3$	$Y_1 + Y_2 + Y_3 = 1$

Step 3: Consistency calculations

However, factor A compared to factor B, may not precisely reflect how the respondent feels about B compared to A. Hence, the pairwise comparison matrix may not be consistent. This could lead to a problem if it is restricted to simple normalising vectors. Thus, it is essential to calculate the Consistency Ratio (*CR*). The eigenvector formulation handles such cases with ease. The first sub-step in this process is to multiply the matrix of comparison (refer to Table 6.4) by the performance score vector (refer to Table 6.5) to obtain a new vector (Eq: 6.17). The new vector is shown in the SUM column of Table 6.7.

$$\textit{New vector} = \begin{bmatrix} 1 & W_1 & W_2 \\ 1/W_1 & 1 & W_3 \\ 1/W_2 & 1/W_3 & 1 \end{bmatrix} \cdot \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} \quad \text{.. Eq: 6.17}$$

The second sub-step is to divide the sum of the first component of the new vector (Z_i) (refer to 'sum' column of Table 6.7) by the first component of the performance score vector (Y_i) (refer to 'performance score' column of Table 6.5) and the sum of second component of new vector by the second component of the performance score vector and so on. λ_{max} is the maximum eigenvalue and it can be calculated by taking the average of the components of the resultant vector. The resulting vector simply reflects a composite view of the two conflicting judgments and provides a single and unequivocal result. The results are more consistent when λ_{max} is close to n (the number of factors) (Saaty, 1980).

CR is the ratio between the Consistency Index (*CI*) and the Random Index (*RI*) (Eq: 6.18).

$$\textit{Consistency Ratio (CR)} = \frac{\textit{Consistency Index (CI)}}{\textit{Random Index (RI)}} \quad \text{.................................... Eq: 6.18}$$

Where:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \text{.. Eq: 6.19}$$

λ_{max} is an average consistency measure for all the alternatives (refer to Table 6.7), ***n*** is the number of factors and *RI* is given in Table 6.6:

Table 6.6: Random Index (*RI*) Table

Number of Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The above *RI* table was developed by Saaty (1980) by filling the *n*-by-*n* reciprocal matrix with randomly selected ratio scale values and calculating the average *CI* for a sample size of 500. This average value of *CI* is called *RI*. The consistency ratio calculations are shown in Table 6.7.

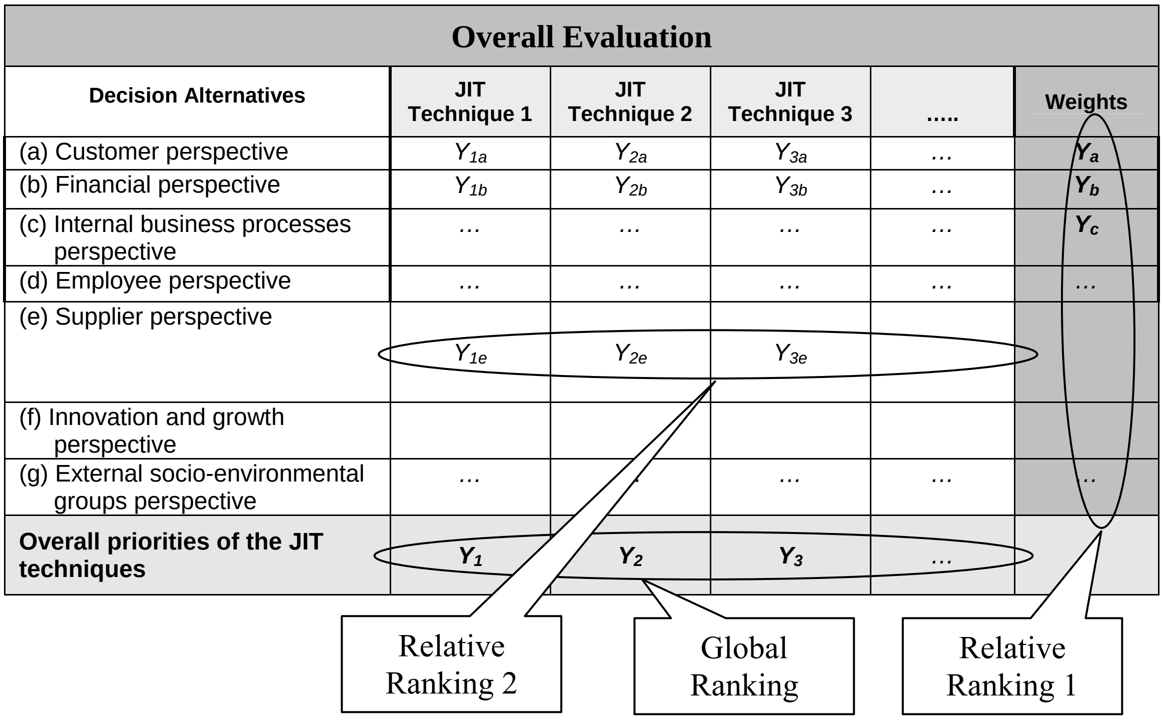
Table 6.7: Consistency Ratio (*CR*) Calculations

STEP 3 : CONSISTENCY CALCULATIONS					
Factors	**A**	**B**	**C**	**SUM**	**CONSISTENCY MEASURE**
A	$1*Y_1$	W_1*Y_2	W_2*Y_3	Z_1	$Z_1/Y_1 = \propto_1$
B	$(1/W_1)*Y_1$	$1*Y_2$	W_3*Y_3	Z_2	$Z_2/Y_2 = \propto_2$
C	$(1/W_2)*Y_1$	$(1/W_3)*Y_2$	$1*Y_3$	Z_3	$Z_3/Y_3 = \propto_3$
					$\lambda max = Avg\ (\propto_1, \propto_2, \propto_3)$

Step 4: Overall Evaluation

The final step of the AHP analysis is an overall evaluation of the pairwise judgements in order to identify the strategic influence of JIT factors on performance. The survey instrument (refer to Appendix 2) is designed to develop three performance rankings to reach three major conclusions. These three rankings are shown in Table 6.8.

Table 6.8: Overall AHP Evaluation – An Example


Relative Ranking 2
Global Ranking
Relative Ranking 1

Overall Evaluation					
Decision Alternatives	**JIT Technique 1**	**JIT Technique 2**	**JIT Technique 3**	**.....**	**Weights**
(a) Customer perspective	Y_{1a}	Y_{2a}	Y_{3a}	…	$\boldsymbol{Y_a}$
(b) Financial perspective	Y_{1b}	Y_{2b}	Y_{3b}	…	$\boldsymbol{Y_b}$
(c) Internal business processes perspective	…	…	…	…	$\boldsymbol{Y_c}$
(d) Employee perspective	…	…	…	…	…
(e) Supplier perspective	Y_{1e}	Y_{2e}	Y_{3e}		
(f) Innovation and growth perspective					
(g) External socio-environmental groups perspective	…	…	…	…	..
Overall priorities of the JIT techniques	$\boldsymbol{Y_1}$	$\boldsymbol{Y_2}$	$\boldsymbol{Y_3}$	…	

(1) *Relative Ranking (1) of BSC Perspectives in terms of Overall Performance* – The AHP analysis based on Part I of the survey instrument helps to identify the impact of each extended BSC perspective on overall performance of the company. Managers can use Relative Ranking (1) to recognise the organisation's competitive priorities. Relative Ranking (1) helps to identify the most and least important BSC perspectives in overall performance measurement of the company.

(2) *Relative Ranking (2) of Key JIT Drivers in terms of BSC Perspectives* – The AHP analysis based on Part II of the survey instrument helps to recognise the impact of key JIT drivers on each BSC perspective. Relative Ranking (2) guides managers to identify the most and least influential JIT techniques on each BSC perspective. This ranking further assists managers to take necessary actions to change those JIT parameters in order to enhance performance of the respective BSC perspective.

(3) *Global Ranking of Key JIT Drivers in terms of Overall Performance* – Global ranking of JIT drivers helps to identify the most and least influential JIT techniques on overall performance of the organisation. Managers can use this ranking as a guide in a continuous improvement exercise in order to enhance the overall performance of the organisation.

Therefore, as a whole, the AHP analysis helps to identify organisational competitive priorities and quantify the influence of key JIT drivers on competitive priorities and overall performance of the organisation. The application of an AHP tool in two JIT enabled manufacturing environments is presented in Section 7.9.4 and 8.3.7.

6.3.8 Comparison of Results for Performance Optimisation

The final step of the performance measurement model implementation procedure involves the comparison of the results of Phase I and II in order to take necessary actions to optimise both operational and overall performance of the company. For example, a change/improvement of one JIT factor may have a positive impact on operational performance, but a negative impact on BSC perspective/s or overall performance. Phase I assesses the real impact of changes of JIT drivers on operational performance; Phase II shows the strategic influence of those JIT drivers on BSC perspectives and overall performance of the organisation. Therefore, a manager's tacit knowledge, experience, commitment and communication with floor level managers and workers are essential aspects for striking a balance between operational and overall performance of the company. It is essential to consider organisational competitive priorities in conjunction with improvements and management of processes. Furthermore, it is vital to offer rewards and recognitions for performance improvements in order to uplift employees' morale. Finally, periodic re-evaluation of company vision, mission, core competencies, strategies, production problems, key JIT drivers, KPIs and competitive priorities are essential in a continuous improvement exercise. The comparison of results for process optimisation in two JIT enabled manufacturing environments is presented in Section 7.10 and 8.3.8.

Figure 6.11 summarises the performance measurement model implementation procedure. This process has been applied to a JIT enabled automotive component manufacturing environment in order to test and validate the conceptual model. The system was then applied to a non-automotive manufacturing environment and the findings from these studies are presented in Chapter 7 and 8 respectively.

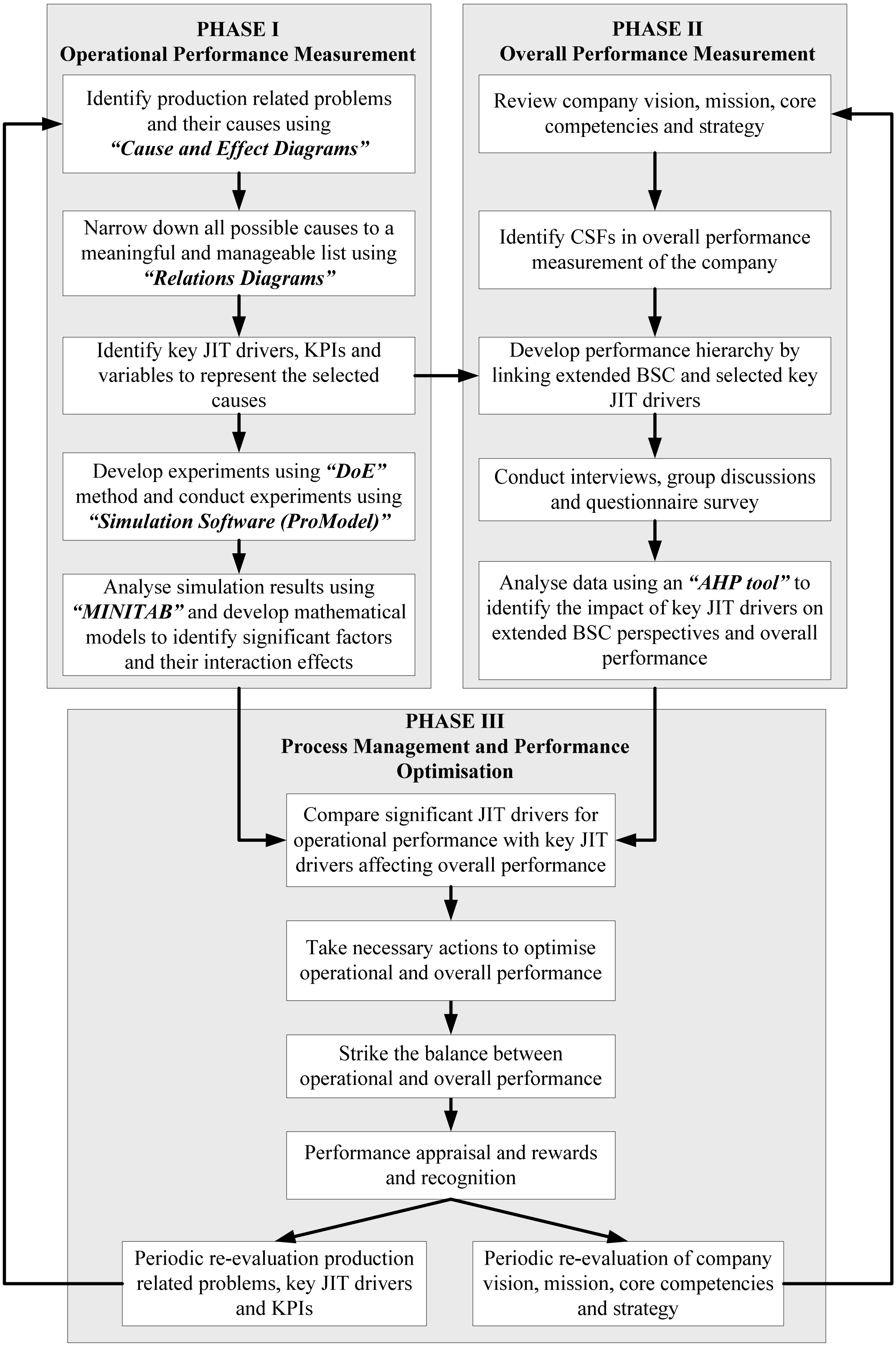

PHASE I
Operational Performance Measurement
Identify production related problems and their causes using "Cause and Effect Diagrams"
Narrow down all possible causes to a meaningful and manageable list using "Relations Diagrams"
Identify key JIT drivers, KPIs and variables to represent the selected causes
Develop experiments using "DoE" method and conduct experiments using "Simulation Software (ProModel)"
Analyse simulation results using "MINITAB" and develop mathematical models to identify significant factors and their interaction effects
PHASE II
Overall Performance Measurement
Review company vision, mission, core competencies and strategy
Identify CSFs in overall performance measurement of the company
Develop performance hierarchy by linking extended BSC and selected key JIT drivers
Conduct interviews, group discussions and questionnaire survey
Analyse data using an "AHP tool" to identify the impact of key JIT drivers on extended BSC perspectives and overall performance
PHASE III
Process Management and Performance Optimisation
Compare significant JIT drivers for operational performance with key JIT drivers affecting overall performance
Take necessary actions to optimise operational and overall performance
Strike the balance between operational and overall performance
Performance appraisal and rewards and recognition
Periodic re-evaluation production related problems, key JIT drivers and KPIs
Periodic re-evaluation of company vision, mission, core competencies and strategy

Figure 6.11: Performance Measurement Model Implementation Procedure

6.4 SUMMARY

Chapter 6 of this thesis has presented the performance measurement model implementation procedure. The chapter has further highlighted key literature that guides the selection of tools and techniques for testing, validation and implementation of conceptual model in JIT enabled manufacturing environments. The eight steps for robust, multidimensional and elaborate performance measurement model implementation can be summarised as follows:

- ***Step 1:*** Identify production related problems and their causes using *'cause and effect analysis'* and narrow down all possible causes to a meaningful and manageable list using *'relations diagrams'*; identify key JIT techniques and KPIs behind those key causes and effects respectively (refer to Section 6.3.1)
- ***Step 2:*** Design experiments using the *'DoE'* technique and develop linear polynomial equations by linking the output (Y) to the relevant design factors (X_i) (refer to Section 6.3.2)
- ***Step 3:*** Conduct experiments with the model using simulation software to obtain performance results to test and validate the model (e.g.: *ProModel simulation and modelling software*) (refer to Section 6.3.3)
- ***Step 4:*** Analyse simulation experiment results (using *MINITAB software*) and establish cause and effect relationships between key JIT drivers and operational performance using a *'linear mathematical model'* (refer to Section 6.3.4)
- ***Step 5:*** Appreciate company vision, mission and core competencies; recognise company strategy and CSFs; develop performance hierarchy by linking key JIT drivers and extended BSC (refer to Section 6.3.5)
- ***Step 6:*** Design survey instrument and conduct questionnaire survey with top and middle management (refer to Section 6.3.6)
- ***Step 7:*** Conduct *'AHP analysis'* and identify organisational competitive priorities and the influence of key JIT techniques on BSC perspectives and overall performance of the organisation (refer to Section 6.3.7)

- ***Step 8:*** Conduct performance appraisal, optimisation and periodic re-evaluation of performance measurement model (refer to Section 6.3.8)

The implementation procedure proposed here will be helpful in capturing the influence of JIT practices on operational and company performance, assessed by a multidimensional performance measurement model. This novel approach is introduced to transform a generic conceptual model into a practical PMS. Hence, Objective 4 of this study has been addressed. The application of the proposed performance measurement model and implementation procedure to a JIT enabled automotive component manufacturing environment in order to test the conceptual model is presented in Chapter 7.

CHAPTER 7: TESTING AND VALIDATION OF PERFORMANCE MEASUREMENT MODEL – A CASE STUDY

7.1 INTRODUCTION

The preceding two chapters presented the conceptual model, and an eight-step approach to transform the conceptual performance model to a practical PMS. This chapter applies the eight-step implementation procedure, which has been presented in Chapter 6, to test and validate the conceptual performance measurement model developed in Chapter 4. The chapter presents and analyses the findings of a case study, which is based on the JIT enabled automotive component manufacturer, Denso Manufacturing (UK) Ltd. Sections 7.2 to 7.4 give an introduction to the company and the JIT practices implemented in their production processes. Section 7.5 discusses production related problems and presents the application of typical management tools such as cause and effect, and relations diagrams to analyse data in order to identify key JIT drivers. The customised performance measurement model developed for the company is also presented in this chapter. Sections 7.6 and 7.7 apply the DoE, computer based simulation and linear mathematical modelling tools to identify the impact of selected key JIT drivers on operational performance. The simulation results are then analysed in Section 7.8. Section 7.9 presents the application of the AHP tool to identify the competitive priorities and the impact of JIT drivers on overall performance of the company. This chapter finally concludes with combining the results of Sections 7.8 and 7.9 to provide recommendations to the case study manufacturing organisation.

7.2 CASE MANUFACTURING COMPANY: DENSO MANUFACTURING (UK) LTD. (DMUK)

'Denso Manufacturing (UK) Ltd.' (DMUK) is a subsidiary of 'DENSO Corporation' in Japan, which was founded in 1949. It's global network is divided into four regions, Japan; America; Europe; Australia and Asia, covering 31 countries and employing more than 104,000 employees. DMUK was founded in 1990 as one of the first European manufacturing sites to produce and supply advanced automotive systems and components globally. The company mission is to *"contribute both to people's happiness and society's growth by creating value together with a vision for the future"*. DMUK has set the following four steps to achieve their mission:

- put a great value on customer satisfaction, by paying careful attention to their customers' voices and supplying them with attractive products
- seek continuous growth, by anticipating change in order that the company stay one step ahead
- co-exist and harmonise with society, by adopting modern technology and encouraging every associates' creativity and dedication in order to contribute to environmental protection, improved safety and comfort
- establish an energetic company, by creating an environment which respects the individual and also assists them to realise their full potential

DMUK produces an extensive range of over 110 product varieties of air conditioner units, heaters, blowers and panels for world leading automotive manufacturers such as Toyota, Honda, Rover, Jaguar, NCC, MCC and Land Rover (DENSO, 2007). The plant layout is shown in Figure 7.1.

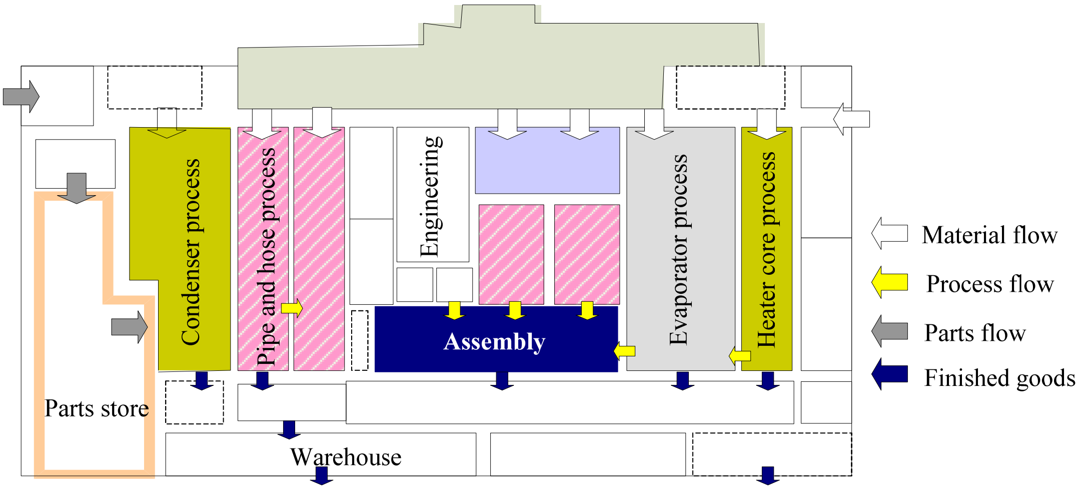


Figure 7.1: Plant Layout of DMUK

DMUK has 1600 employees to satisfy sporadic demand for its products. 970 of the employees are involved in manufacturing operations while the rest are involved in executive, administrative and sales matters. The company manufactures approximately 17.8 million parts per year in 9 process lines and 11 assembly lines and achieved £200 million turnover in the year 2003. In this organisation, there are two major production lines – process line and assembly line. As shown in Figure 7.2 some products such as pipes and hoses are processed and sent directly to the final customer. Products such as heating, ventilation and air conditioning (HVAC) casings are processed and sent to the assembly line for further assembly. The company's process operations are done in manufacturing cells and assembly operations are arranged as continuous assembly lines. Both process and assembly lines are operating in batch production mode.

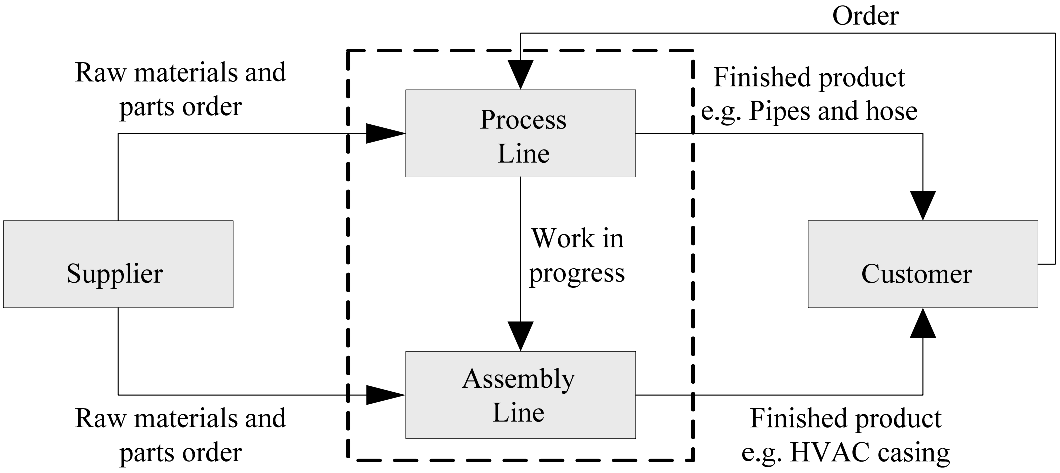

Order
Raw materials and parts order
Process Line
Finished product e.g. Pipes and hose
Work in progress
Supplier
Customer
Assembly Line
Raw materials and parts order
Finished product e.g. HVAC casing

Figure 7.2: Production Process in DMUK

7.3 JIT PRACTICE IN DMUK

With the exception of a few traditional production systems such as push system, implemented initially, DMUK has been using continuous improvement exercises since it was established. DMUK's traditional production systems are based on production plans developed by the Production Control Department using both demand forecasts and customer orders. During continuous improvement exercise, DMUK has identified a few problems associated with their traditional production system. Problems identified are depicted in Figure 7.3.

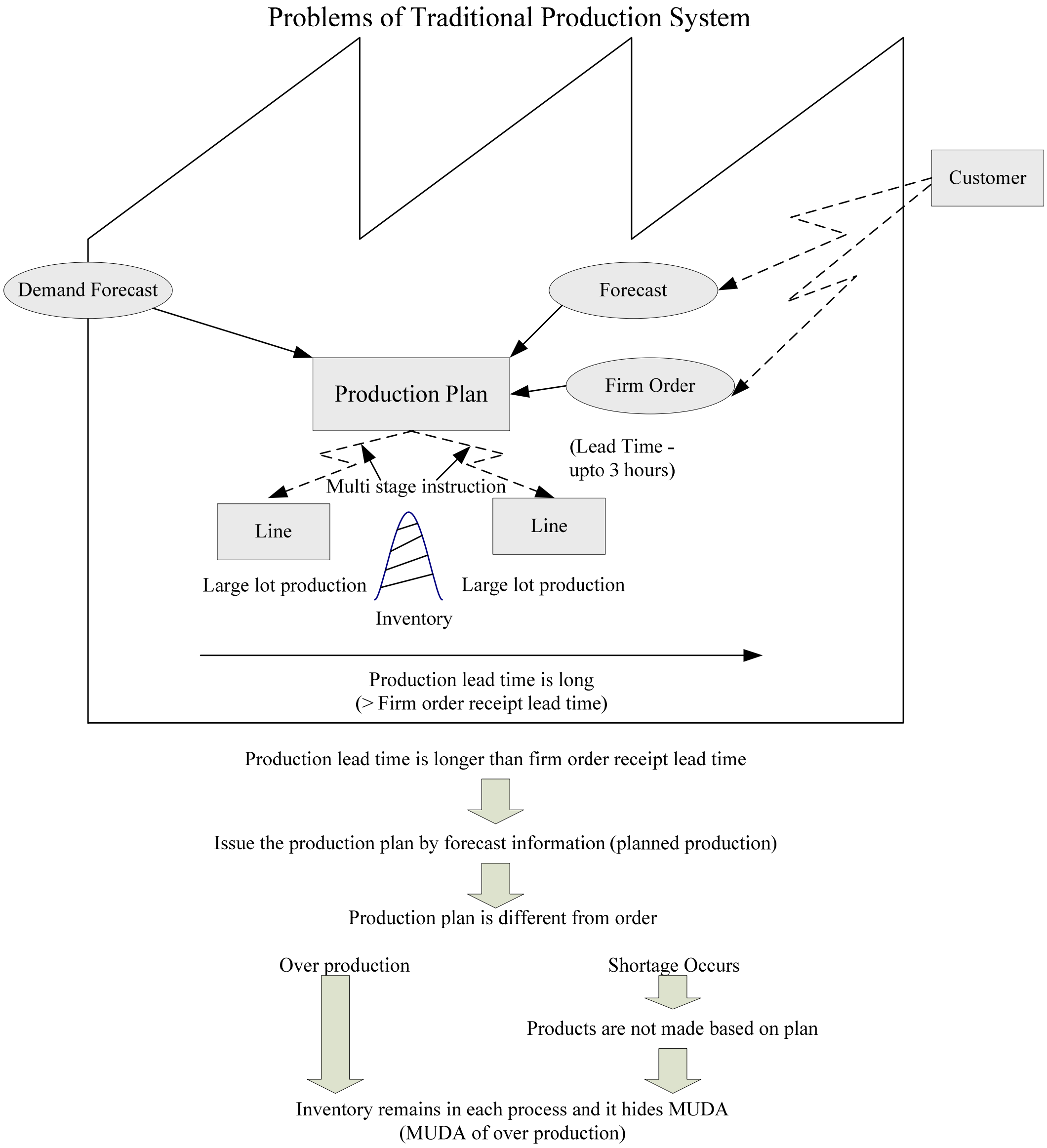

Problems of Traditional Production System
Customer
Demand Forecast
Forecast
Production Plan
Firm Order
(Lead Time - upto 3 hours)
Multi stage instruction
Line
Line
Large lot production
Large lot production
Inventory
Production lead time is long
(> Firm order receipt lead time)
Production lead time is longer than firm order receipt lead time
Issue the production plan by forecast information (planned production)
Production plan is different from order
Over production
Shortage Occurs
Products are not made based on plan
Inventory remains in each process and it hides MUDA
(MUDA of over production)

Figure 7.3: Problems of Traditional Production System (Source: DMUK)

The organisation has experienced a longer production lead-time than order receipt lead-time. Consequently, the production lines were unable to cope with the high demand for their products. Hence, production lines started working to production plans based on forecast information, which led to over production or shortages. Overproduction is one form of muda and DMUK’s muda concept is shown in Figure 7.4.

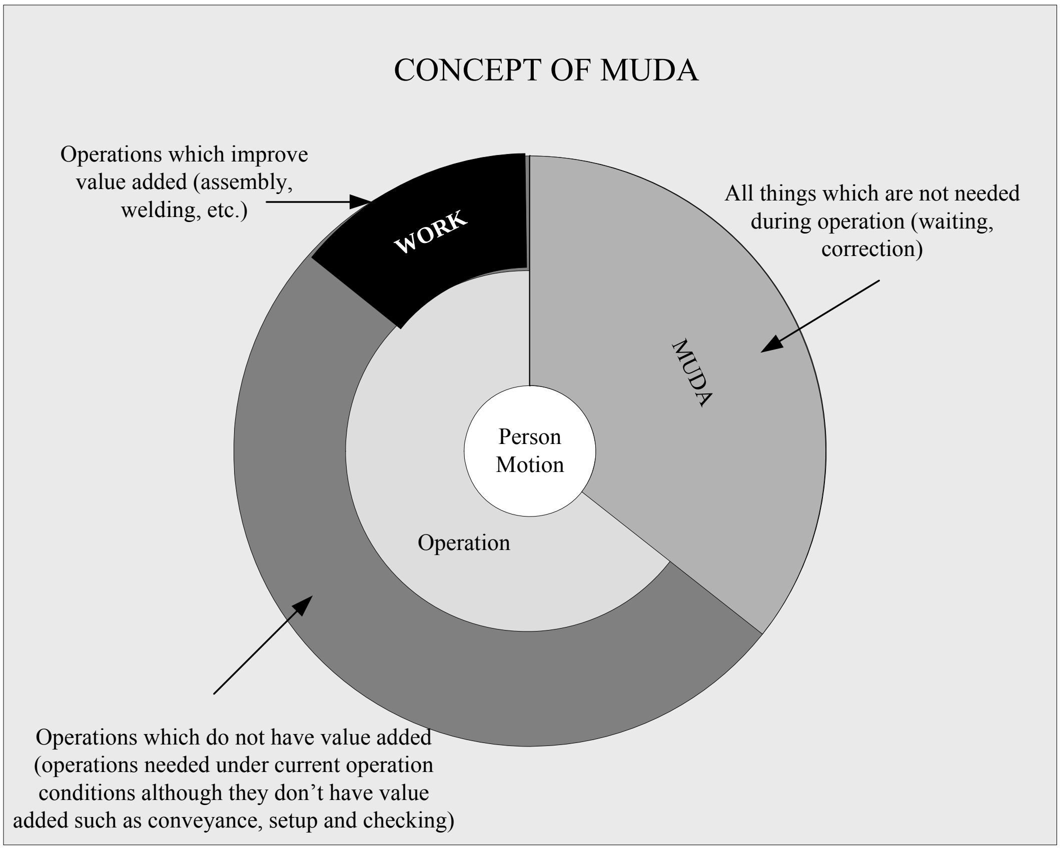

CONCEPT OF MUDA
Operations which improve value added (assembly, welding, etc.)
WORK
All things which are not needed during operation (waiting, correction)
MUDA
Person Motion
Operation
Operations which do not have value added (operations needed under current operation conditions although they don't have value added such as conveyance, setup and checking)

Figure 7.4: DMUK's Concept of Muda (Source: DMUK)

The company has divided muda into 3 categories, namely operations that add value (assembly, welding), operations that do not add value but needed under current working conditions (setup, conveyance and quality checking) and processes that are not needed during operation (waiting time and repairs). DMUK has introduced a Total Industrial Engineering (TIE) plan in order to minimise muda. The target of the TIE plan is to establish 'an effective production system, which can confirm customer orders timely'. It's control principle is to make muda appear visually and it's production principle is to remove muda completely. DMUK management has introduced JIT and JIDOKA philosophies to their production processes to achieve the aforementioned control and production principles. The TIE plan is presented in Figure 7.5.

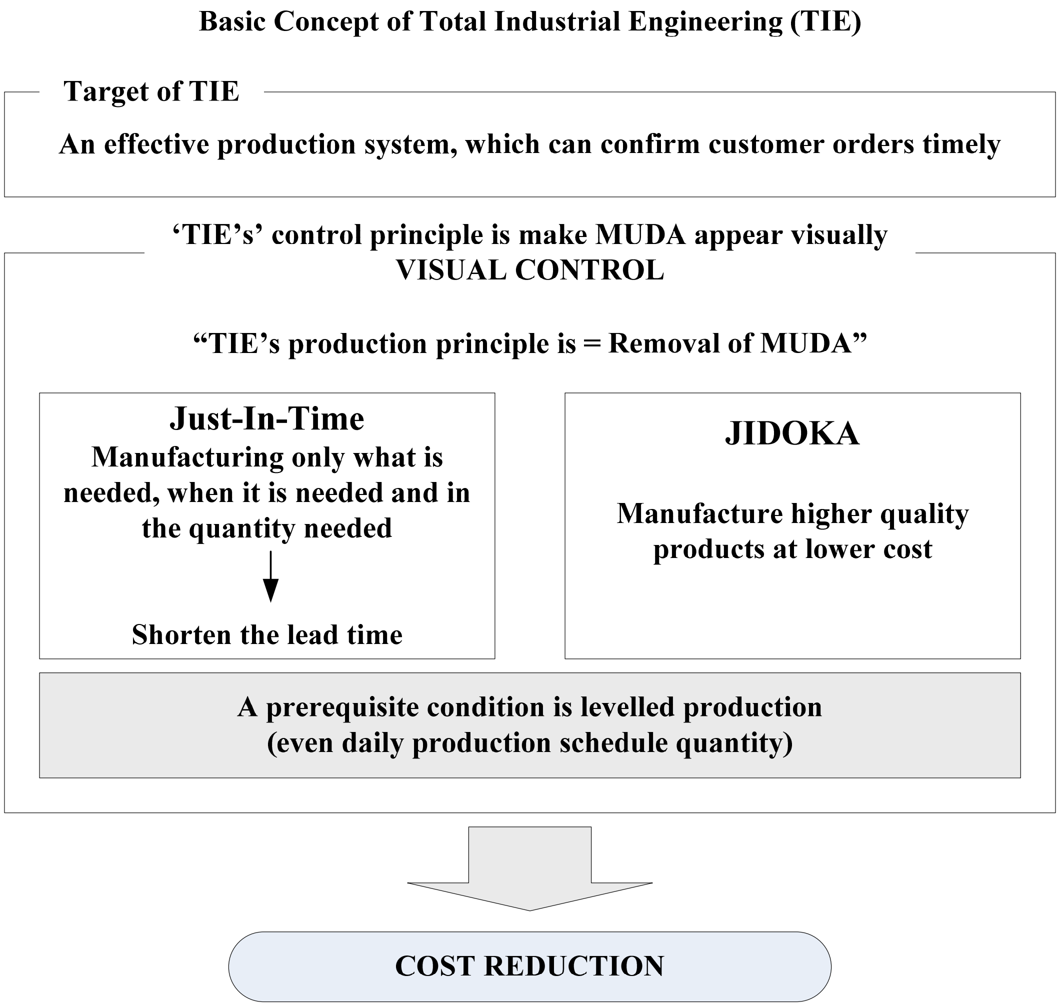

Basic Concept of Total Industrial Engineering (TIE)
Target of TIE
An effective production system, which can confirm customer orders timely
'TIE's' control principle is make MUDA appear visually
VISUAL CONTROL
"TIE's production principle is = Removal of MUDA"
Just-In-Time
Manufacturing only what is needed, when it is needed and in the quantity needed
Shorten the lead time
JIDOKA
Manufacture higher quality products at lower cost
A prerequisite condition is levelled production
(even daily production schedule quantity)
COST REDUCTION

Figure 7.5: DMUK's Basic Concept of Total Industrial Engineering (TIE) Plan (Source: DMUK)

The company has defined DMUK's JIT philosophy as "manufacturing only what is needed, when it is needed and in the quantity needed" in the TIE plan. DMUK has introduced JIT philosophy in order to eliminate muda and reduce the cost of production using the following three rules:

- reduce takt time
- implement continuous flow process
- implement pull system

DMUK has implemented a kanban and conveyance system with a pre-condition of levelled production, and the company's JIT philosophy is depicted in Figure 7.6.

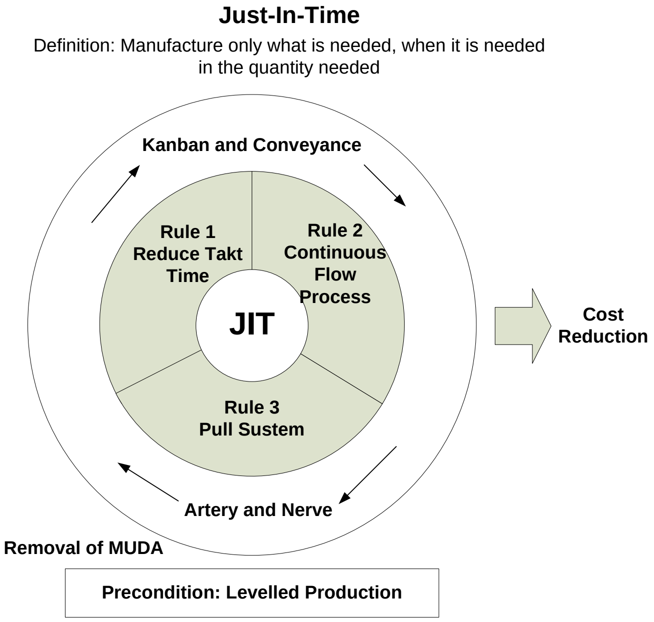

Just-In-Time
Definition: Manufacture only what is needed, when it is needed in the quantity needed
Kanban and Conveyance
Rule 1 Reduce Takt Time
Rule 2 Continuous Flow Process
JIT
Rule 3 Pull Sustem
Cost Reduction
Artery and Nerve
Removal of MUDA
Precondition: Levelled Production

Figure 7.6 : DMUK's JIT Philosophy (Source: DMUK)

During preliminary interview sessions, two managers were asked to indicate to what extent JIT practices have been applied in their plant (refer to Appendix 1). The managers agreed that JIT has improved production and confirmed that

- waste, inventory levels and storage space extremely reduced
- setup time, lead time, unit cost and equipment downtime reduced
- productivity and profitability increased, after the introduction of JIT philosophy.

The managers identified factory floor layout, working hours, legislation, regulations, policies and health and safety considerations (such as fatigue, repetitive strain injuries, upper body muscular-skeletal disorders) as barriers in JIT implementation.

7.4 NCC AND MCC HEATER ASSEMBLY LINE 3

The JIT production system considered in this research is an 11 station NCC heater assembly line. It is a mixed model assembly line, which produces heaters for MCC, MCC Roadster, and NCC automobile manufacturers. Figure 7.7 shows the product range of heater assembly line 3.

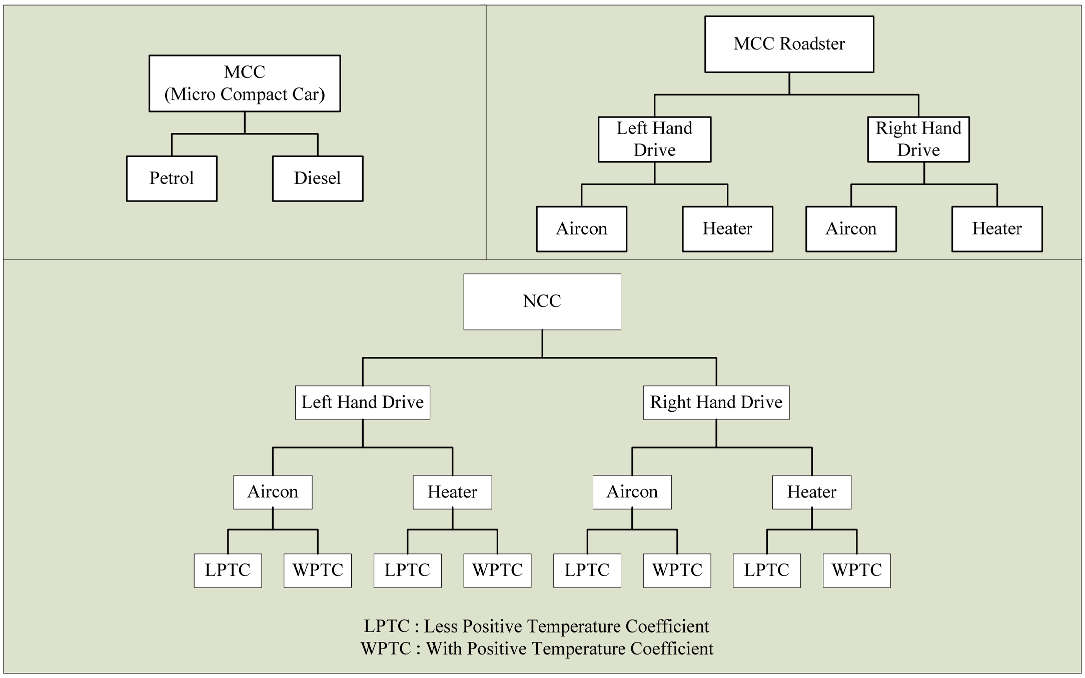


Figure 7.7: Product Range of Heater Assembly Line 3

Figure 7.8 (a) and (b) are photographs of heater assembly line 3 and a heater unit respectively.

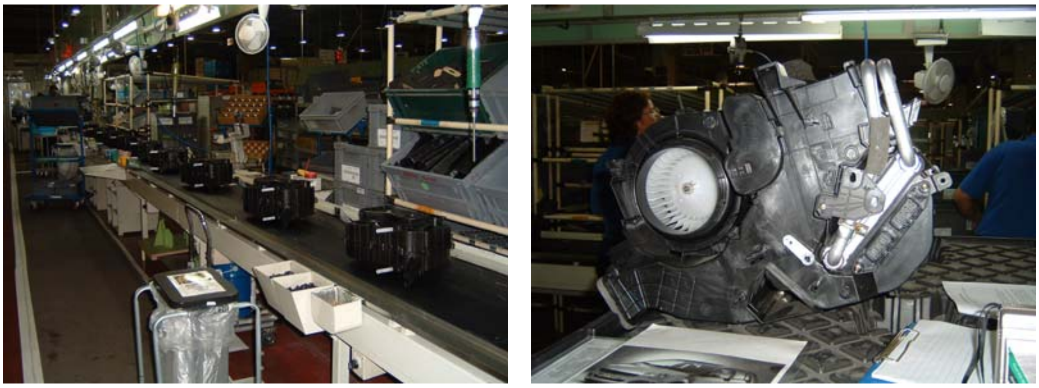


Figure 7.8: (a) Heater Assembly Line 3 and (b) Heater Unit

This is a manually operated assembly line and each station employs one associate. As shown in Figure 7.9, the line consists of a team leader, setter, part picker, ten on-line associates and a quality assurance associate. Figure 7.10 shows the production process of the 11 station heater assembly line. Denso calls their subordinate members (blue colour members) "*Associates*" in order to increase their morale, loyalty and to inculcate organisational citizenship.

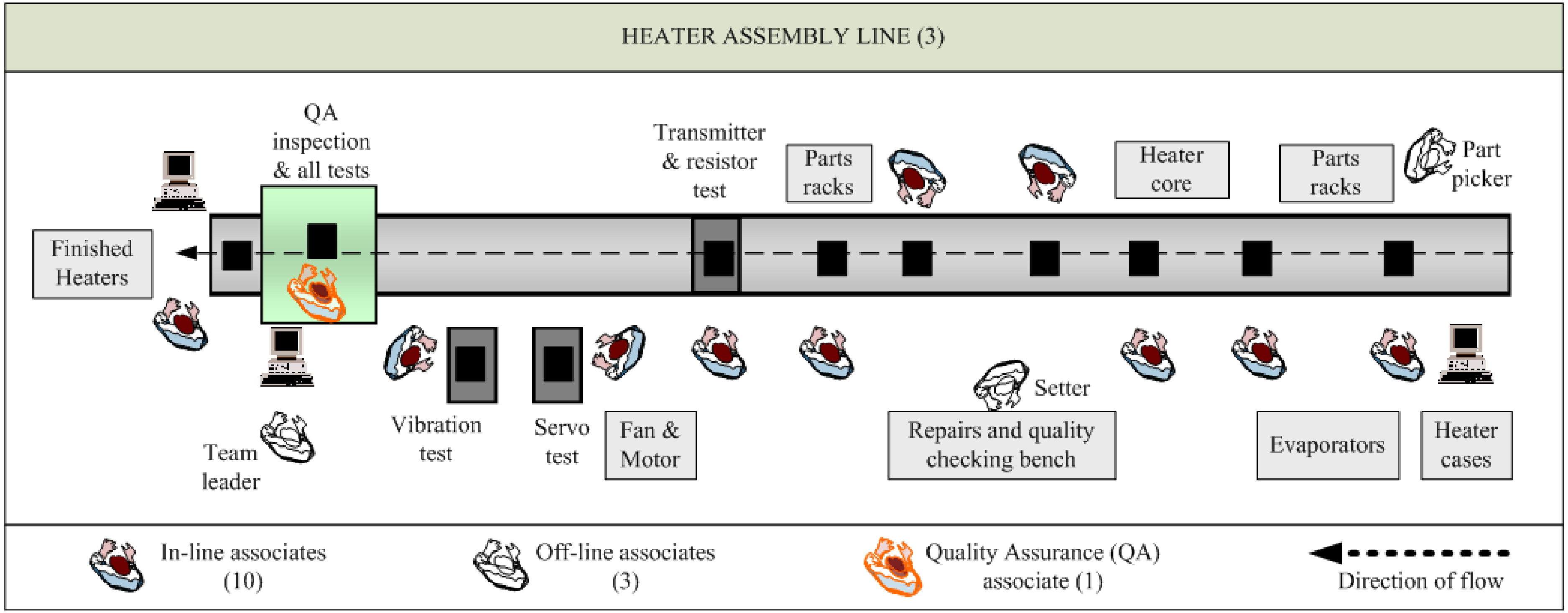


Figure 7.9: Heater Assembly Line (3) Layout

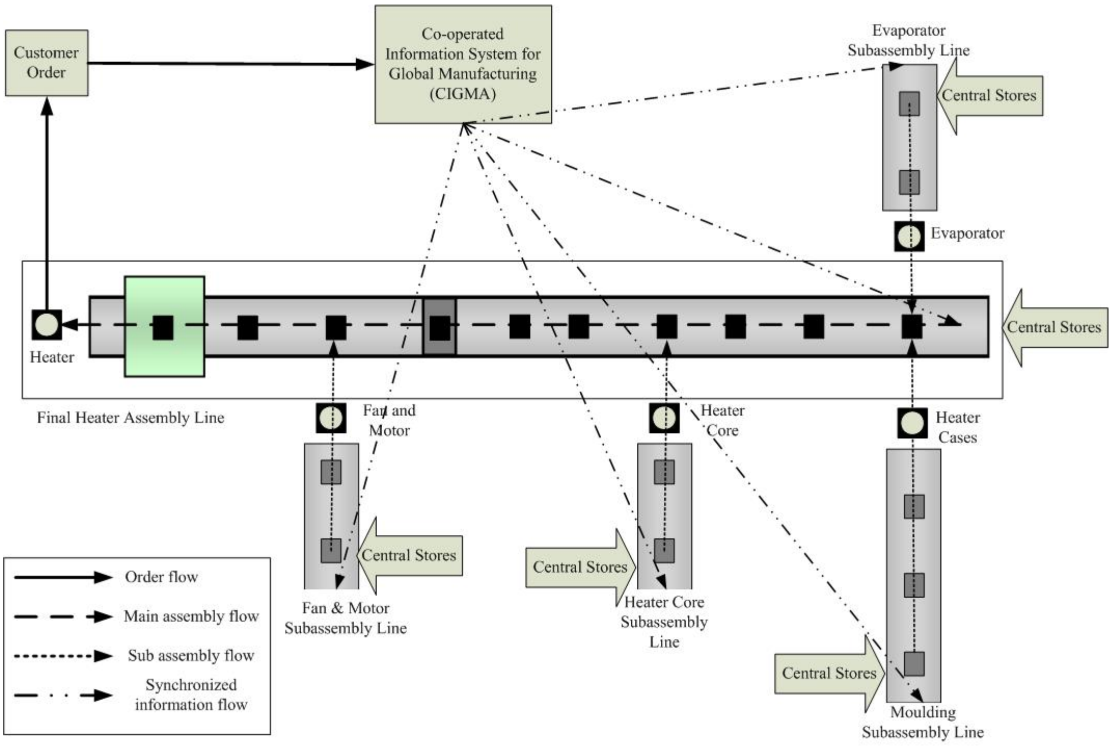

Customer Order
Co-operated Information System for Global Manufacturing (CIGMA)
Evaporator Subassembly Line
Central Stores
Evaporator
Central Stores
Heater
Final Heater Assembly Line
Fan and Motor
Heater Core
Heater Cases
Order flow
Main assembly flow
Sub assembly flow
Synchronized information flow
Central Stores
Fan & Motor Subassembly Line
Central Stores
Heater Core Subassembly Line
Central Stores
Moulding Subassembly Line

Figure 7.10: Production Process at 11 Station Heater Assembly Line

Raw materials and parts for all stations are served by the central warehouse, where as the first and fourth stations are additionally served by an external sub-assembly line. The eighth station is served by an internal sub-assembly line. Sub-assembly lines that serve components to the main assembly line are mixed model lines. The company uses a *'Co-operated Information system for Global Manufacturing (CIGMA)'* system to send the daily production schedule to the main and sub-assembly lines.

As a manually operated assembly line, raw materials are available at stations and all the required parts and components are pulled as batches from the warehouse and sub-assembly lines while the heater passes through the final assembly line. The configuration is a single piece flow assembly line with provision for a conveyor belt to move products between stations. The company uses kanban and synchronised information system to pass production related information between production lines, cells, the Central Warehouse and the Production Control Department. Kanban is mainly used as a visual record for material handling within the line and with sub-assembly lines. The part picker must keep the withdrawal kanban in the main assembly line withdrawal kanban post and go to the sub-assembly lines with empty trolleys and the production kanban. When he withdraws parts from the sub-assembly line, he must leave the production kanban, which was attached to the empty trolley in the kanban post. Then the trolley is replaced with withdrawal kanban. That production kanban then becomes an order from the internal customer of the sub-assembly line to produce more parts. When a new order begins in the main assembly line, a new production kanban has to be generated.

The CIGMA synchronised information system is used to circulate daily production schedules on the factory floor and to order components from Central Warehouse. The part picker scans the withdrawal kanban to order ancillary parts from the warehouse at regular pre-determined times. Central Warehouse delivers those parts using an automated guided vehicle (AGV) at the next delivery time. During interview sessions, the researcher asked the question, "*Does this production line have steady or sporadic demand for the products?*" The line manager answered "*Sporadic demand*". The conclusion therefore is that the company uses material requirement planning (MRP) to avoid the risk of material and part shortage during the production process. The company allocates 30-40% of the total factory floor for material and parts storage and transportation.

7.5 DETERMINATION OF KEY JIT DRIVERS OF THE ASSEMBLY LINE

The research study used documentation, observation and open ended interviews to determine key JIT drivers and KPIs of the assembly line. Open ended interviews were carried out with four line associates, two process associates, four line managers, two process managers and two top management (Refer to Appendix 1). Data gathered from documents, observations and interviews discuss in the following paragraphs.

The company implements typical JIT techniques such as pull system (kanban), and continuous flow of production and used 'takt time' as a KPI in operational performance measurement in their make-to-order processes. DMUK emphasises visual quality control in order to minimise all kinds of waste on the factory floor. The company has implemented line-balancing techniques, set-up time elimination plans, level schedules, group technology and cellular manufacturing in most of the production areas. However, the company uses few ad-hoc performance measures and does not have a proper performance measurement system to measure process performance quantitatively. To the question of, "*what are the performance or productivity measures you have used in your plant?*", the production manager answered, "*We use performance measures such as hourly output, output per operator/line, frequency of customer complaints, lead time, scrap/defects and safety marks/accident*".

Case study findings show that the company implements selected JIT techniques based on managers' past experience and tacit knowledge and used few ad-hoc KPIs to measure operational performance of the plant.

However, the company still faced problems due to delay of final product delivery to the customers for various reasons, and therefore always tried to keep buffer stock to avoid late deliveries. According to the Production Manager, DMUK suffers from the risk of paying high penalties to customers due to delivery delays and could incur costs of up to £15,000 per minute. The main reasons behind any delay are the long lead-time and process time due to the lack of supplier and customer integration in the production process, improper line balancing, lack of multifunctional employees and complex production and quality control processes. The company is concerned about fairly low productivity, multifunctional ability and innovations in their manufacturing processes. In addition, managers believe that the existing factory floor layout, working hours and legislation, regulations and policies are barriers to successful implementation of JIT. Figure 7.11 depicts detailed possible causes for the long process and takt times. The cause and effect diagram helps to identify the major/main and minor/sub causes for a specific problem. As shown in Figure 7.11, nine major factors affected process and takt times. These are machine breakdown, number of stations, complex quality control process, labour idle time, delivery delays from supplier, lack of automation, unrealistic customer demand, assembly task distribution, and repairs, rejects and returns. These are the critical factors determining the success or failure of DMUK JIT philosophy and if not properly monitored could affect process and takt times negatively.

Having determined the major causes, the next step involves a proper screening to identify the key factors affecting process and takt times. A relations diagram (Figure 7.12) is therefore used to identify the key drivers for process and takt times.

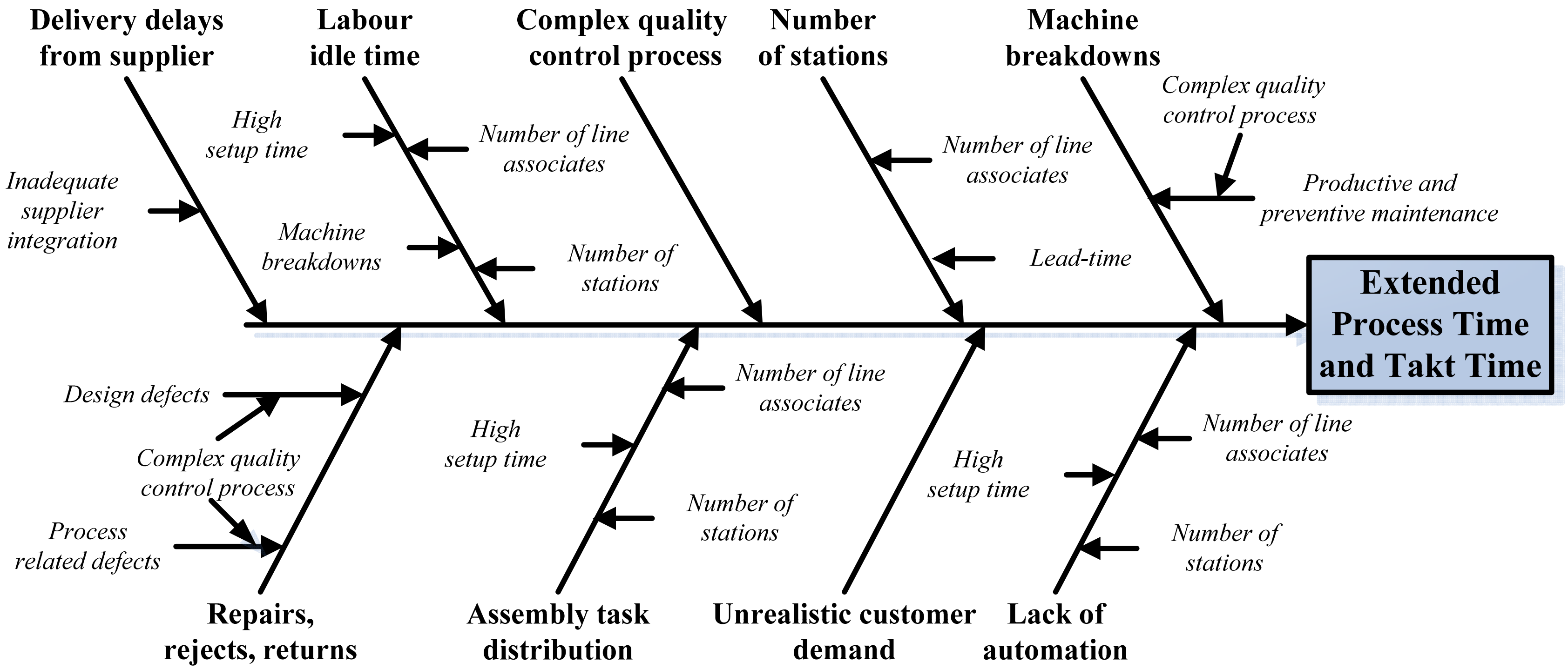

Delivery delays from supplier
Inadequate supplier integration
Labour idle time
High setup time
Number of line associates
Machine breakdowns
Number of stations
Complex quality control process
Number of stations
Number of line associates
Lead-time
Machine breakdowns
Complex quality control process
Productive and preventive maintenance
Extended Process Time and Takt Time
Design defects
Complex quality control process
Process related defects
Repairs, rejects, returns
High setup time
Number of line associates
Number of stations
Assembly task distribution
High setup time
Unrealistic customer demand
Number of line associates
Number of stations
Lack of automation

Figure 7.11: Cause and Effect Diagram Analysis for Process and Takt Times for DMUK

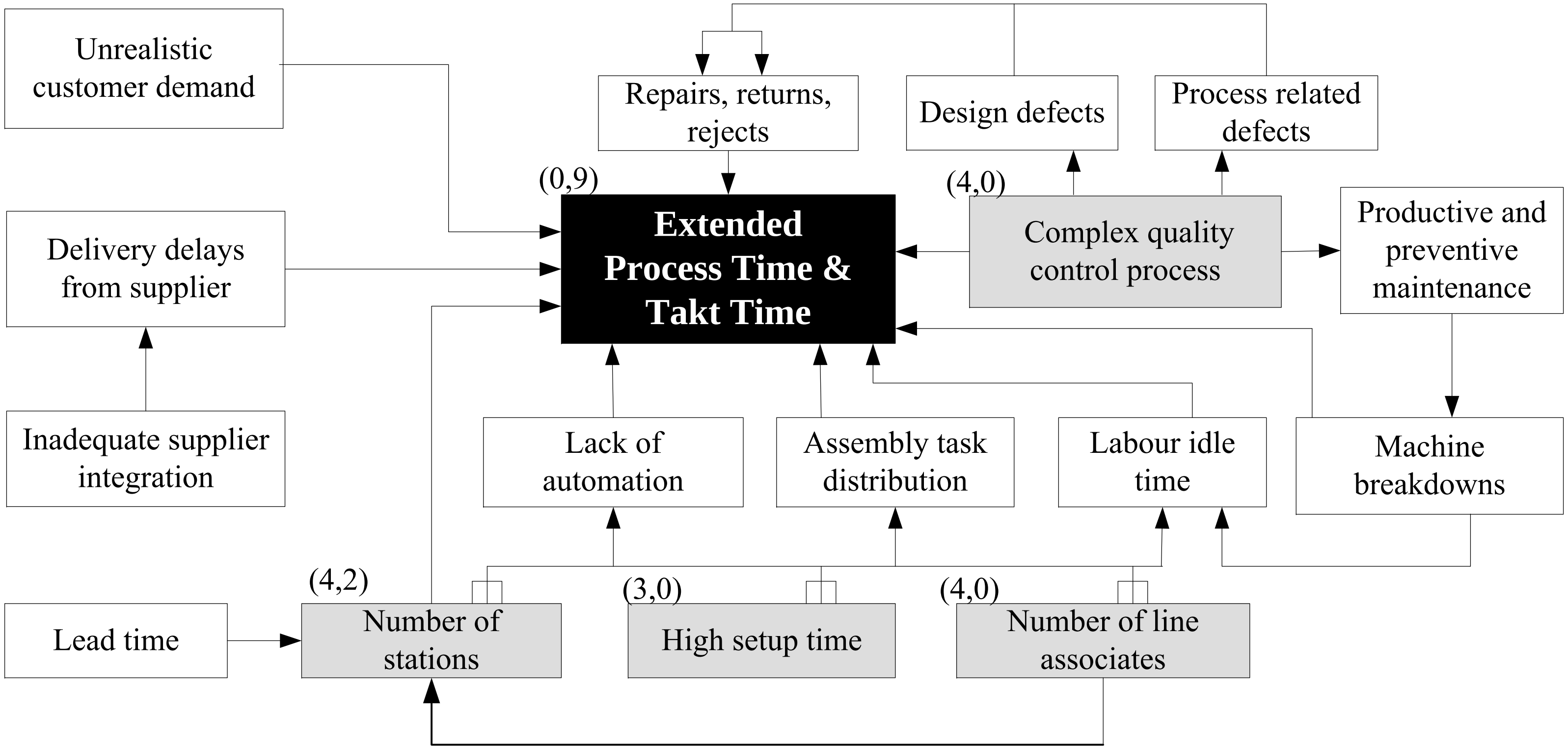

Unrealistic customer demand
Repairs, returns, rejects
Design defects
Process related defects
(0,9)
Extended Process Time & Takt Time
(4,0)
Complex quality control process
Productive and preventive maintenance
Delivery delays from supplier
Inadequate supplier integration
Lack of automation
Assembly task distribution
Labour idle time
Machine breakdowns
(4,2)
Lead time
Number of stations
(3,0)
High setup time
(4,0)
Number of line associates

Figure 7.12: Relations Diagram Analysis for Identification of Key Variables Affecting Process and Takt Times for DMUK

According to the relations diagram for DMUK, "extended process and takt times" were major concerns with nine causes (nine incoming arrows) and zero effects (zero out going arrows) (0 , 9). Using this tool, "complex quality control (QC) process", "number of line associates", "number of stations" and "high setup time" were identified as factors that were key to JIT and which consequently would impact on process and takt times. Their values (number of outgoing and incoming arrows) were (4 , 0), (4 , 0), (4 , 2) and (3 , 0) respectively. (Refer to Section 6.3.1 for theoretical explanations for the cause and effect and relations diagram analysis tools.)

The next logical step is to identify the key JIT drivers behind those variables. Both literature (refer to Chapter 2) and informal discussions with production and line managers were used to identify these key JIT drivers and variables to represent the aforementioned four factors in the simulation model. Visual quality control is a major quality control activity. In multifunctional teams, employees are expected to perform more than one task, so that idle time can be reduced. Thus, the number of multifunctional skills depend on the number of employees available at the production line. Furthermore, one of the key inputs of most algorithms for assembly line balancing is the number of stations (Bukchin, 1998). Moreover, setup time is the key determinant of the efficiency of setup time elimination plans. Therefore, these four key JIT drivers are summarised in Table 7.1.

Table 7.1: DMUK's Key JIT Drivers Applied in Simulation Model

Key Cause	JIT Driver	Variable
Number of stations	Line balancing	Number of stations
Number of line associates	Multifunction employees	Number of line associates
High setup time	Setup time elimination plans	Setup time
Complex quality control process	Quality control activities (QC)	Time spent on quality control activities

The conclusion, therefore, is that these four JIT techniques are the major drivers affecting process and takt times and are now integrated into the customised performance measurement model (Figure 7.13) for further investigation.

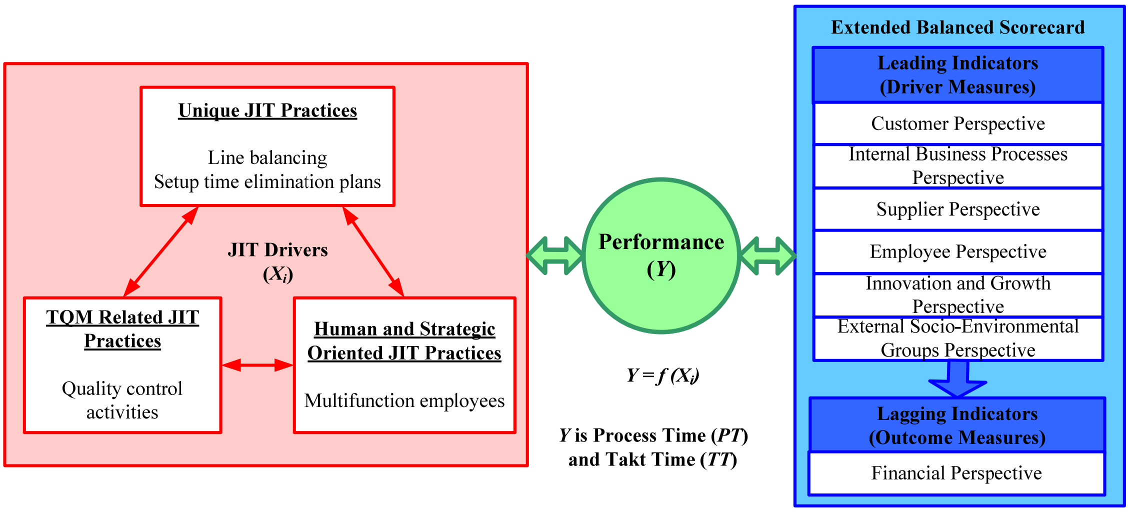

Unique JIT Practices
Line balancing
Setup time elimination plans
JIT Drivers
(X_i)
TQM Related JIT Practices
Quality control activities
Human and Strategic Oriented JIT Practices
Multifunction employees
Performance
(Y)
$Y = f(X_i)$
Y is Process Time (PT) and Takt Time (TT)
Extended Balanced Scorecard
Leading Indicators (Driver Measures)
Customer Perspective
Internal Business Processes Perspective
Supplier Perspective
Employee Perspective
Innovation and Growth Perspective
External Socio-Environmental Groups Perspective
Lagging Indicators (Outcome Measures)
Financial Perspective

Figure 7.13: Customised Performance Measurement Model for DMUK

The customised performance measurement model will now be tested and validated by conducting simulation experiments and AHP analysis to understand the effect of JIT techniques on operational and overall performance of DMUK.

7.6 EXPERIMENTAL DESIGN FOR PERFORMANCE OPTIMISATION OF HEATER ASSEMBLY LINE 3

Process and takt times are the most suitable and relevant KPIs and the best objective functions to measure operational performance, in order to optimise line performance in a JIT environment. Line balancing, setup time elimination plans, quality control activities and multifunction employees are identified as the key JIT drivers, which influence process and takt times. Both literature and case study now confirm that the number of stations, setup time, time spent on quality control activities and number of associates are key variables affecting process and takt times.

In order to understand the effect of JIT drivers on line performance, several different experiments have to be carried out. The experiment is designed to identify and estimate the influence of the four key JIT drivers on line performance. In the simulation experiments, process and takt times are calculated and evaluated. Though there are four JIT drivers identified from the relations diagram (refer to Figure 7.12), the variables are limited to three in the mathematical model, as described in

Section 7.6.2. A three factor mathematical model developed in this study is expressed as (Eq: 7.1):

$$Y = a_0 + a_1A + a_2B + a_3C + a_4AB + a_5AC + a_6BC + a_7ABC + \varepsilon \quad \text{……… Eq: 7.1}$$

Where: Y is Process time (PT) or Takt time (TT)

a_0 is intercept coefficient

a_1 to a_3 are main effect coefficients

a_4 to a_7 are interaction coefficients

ε is Error term

A, B and C are JIT drivers as shown in Table 7.2

A two level, three factor full factorial design consists of 2^3 experiments. Each experimental factor has two levels in two-level full factorial design. Table 7.2 shows a listing of different factors and the allowed values for DoE.

Table 7.2: Factors and Levels for the Experimental Design

Factor	Description	JIT Driver	Lower Value (L)	Higher Value (H)
A	Number of Stations or Number of Line Associates	Line Balancing or Multifunction Employees	11 Stations (14 Line Associates)	13 Stations (16 Line Associates)
B	Time Spent on Quality Controlling	Quality Control Activities	Without Quality Assurance (0 Seconds)	With Quality Assurance (5 Seconds at Each Station)
C	Setup Time	Setup Time Elimination Plans	10 Minutes	20 Minutes

The next sections discuss the aforementioned input factors and reasons for the selected lower and upper values in the experimental design.

7.6.1 Line Balancing

Line balancing involves the assignment of elemental tasks equally to all assembly line workstations in order to optimise the number of stations (APICS, 1992). For assembly line 3, the lower number of stations (11 stations) is defined when the line is balanced to a lower number of stations due to low demand or non-urgent products, while the upper value (13 stations) is defined for high demand or urgent products.

7.6.2 Multifunction Employees

To achieve flexibility, the employee should be able to move to different plants, work sites, workstations or functions according to the demand and type of product in a JIT environment. In an ideal JIT environment, the machine layout has to be arranged in a manner where operators can handle several machines at the same time. Obviously, training the individual worker to become a multifunction employee is an important part of achieving flexibility. The 11 station assembly line consists of 3 off-line associates (team leader, setter and part picker) and 11 on-line associates. The number of stations increase up to 13 in critical work conditions, when two other associates join the main assembly line. In this study, the lower number of line associates is defined as 14 (3 off-line and 11 on-line associates) and the upper value is defined as 16 (3 off-line, 11 on-line and 2 internal sub-assembly line associates). The number of stations and line associates are equal in heater assembly line 3 (refer to Figure 7.9) and these two JIT drivers are therefore considered as one factor.

7.6.3 Quality Control Activities (QC)

It is no longer suitable to think of quality as conformance to specification. Quality has a far broader meaning in today's marketplace. Quality means translating the "voice of the customer" into appropriate company requirements at each stage from product/service concept to delivery. The focus is on prevention, detection and elimination of sources of defects (APICS, 1992). When the researcher asked "*is quality circles implemented in your plant?*" the answer from the Production Manager was "*…currently not at DMUK. But we have implemented Quality Assurance network, 100% visual quality check. We use andon light and unique audible note to indicate quality problems*".

Time spent on quality control activities affects process completion time. In this study, time spent on quality control activities is defined in terms of with and without the quality assurance (QA) network, where QA is defined as 100% visual quality check at each assembly station. Associates on the average spend about 5 seconds per product for quality control activities at every assembly station. This is done in addition to the formal visual and mechanical quality checking at the final stages.

7.6.4 Setup Time Elimination Plans

It is preferable to reduce or eliminate the time lag required for a machine or production line to convert from the production of one product to those of another. Changeovers should be done in minutes rather than hours or even eliminated completely through modern technology or proper planning of the next setup while the machine is still running (McLachlin, 1997). To shorten the setup time, it is important to identify internal and external setup times. Internal setup can be done while the assembly line or machine is running whereas the assembly line or machine has to be stopped for external setups.

In heater assembly line 3, setup time occurs in between two batches of same product family or different product families. For an example, with reference to Figure 7.14, setup time first occurs at the beginning of 200 NCC(L) units and then during the change over to 100 MCC units. DMUK managers have selected setup time as a JIT technique affecting takt time. However, takt time is the time difference between completion of two successive end products. According to this definition, setup time does not have any impact on takt time and hence it is not considered as a JIT driver of takt time in experimental design.

In this study, the lower setup time identified was 10 minutes (setup time between production of two batches of same product family. e.g. from left hand NCC to right hand NCC heater) while the upper value is identified as 20 minutes (setup time between production of two batches of two product families. e.g. from left hand NCC to MCC heater).

7.6.5 Process Time (*PT*) and Takt Time (*TT*)

One of the key competitiveness factors for the company in today's global manufacturing environment is time. Literature review, informal interviews and the case study reveal that Process Time (*PT*) and Takt Time (*TT*) are the best performance measures and objective functions to measure line performance in a JIT environment. *PT* and *TT* play a vital role in on-time delivery of finished products to the final customers. *PT* is comprised of setup time, run time and inspection time, which is the total time taken to complete one or more assembly schedule/s. Figure 7.14 illustrates the *PT* calculation for batch production on assembly line 3.

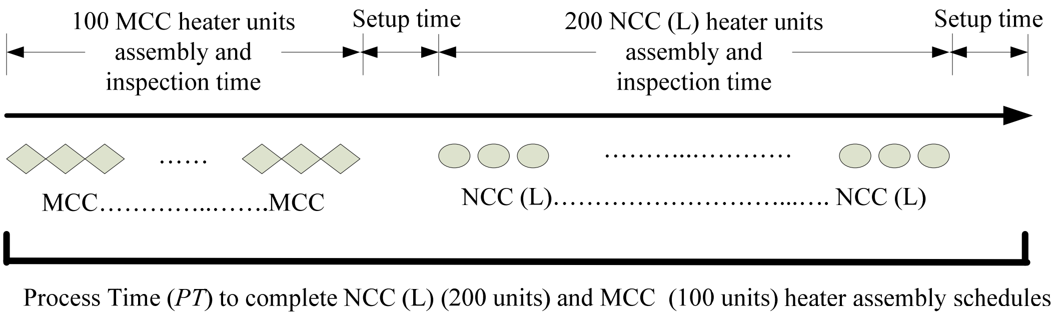

100 MCC heater units assembly and inspection time
Setup time
200 NCC (L) heater units assembly and inspection time
Setup time
MCC…………...…….MCC
NCC (L)……………………….....…. NCC (L)
Process Time (*PT*) to complete NCC (L) (200 units) and MCC (100 units) heater assembly schedules

Figure 7.14: Process Time Illustration

Takt time (TT) is defined as the time difference between completion of two successive units of end products. Figure 7.15 illustrates the *TT* time calculation for an NCC batch production.

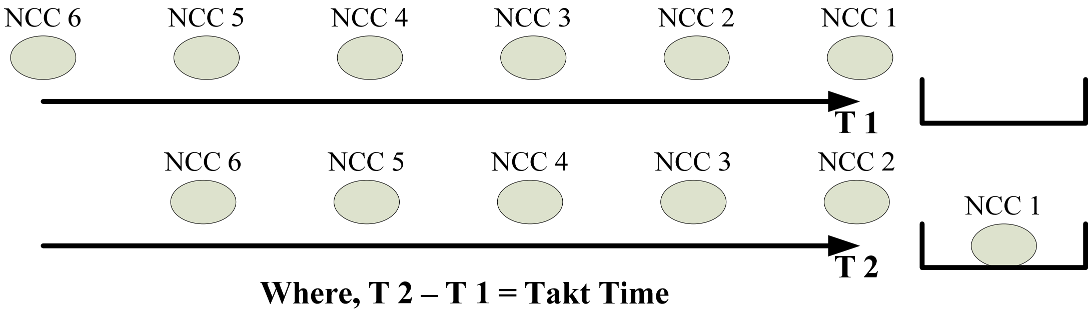
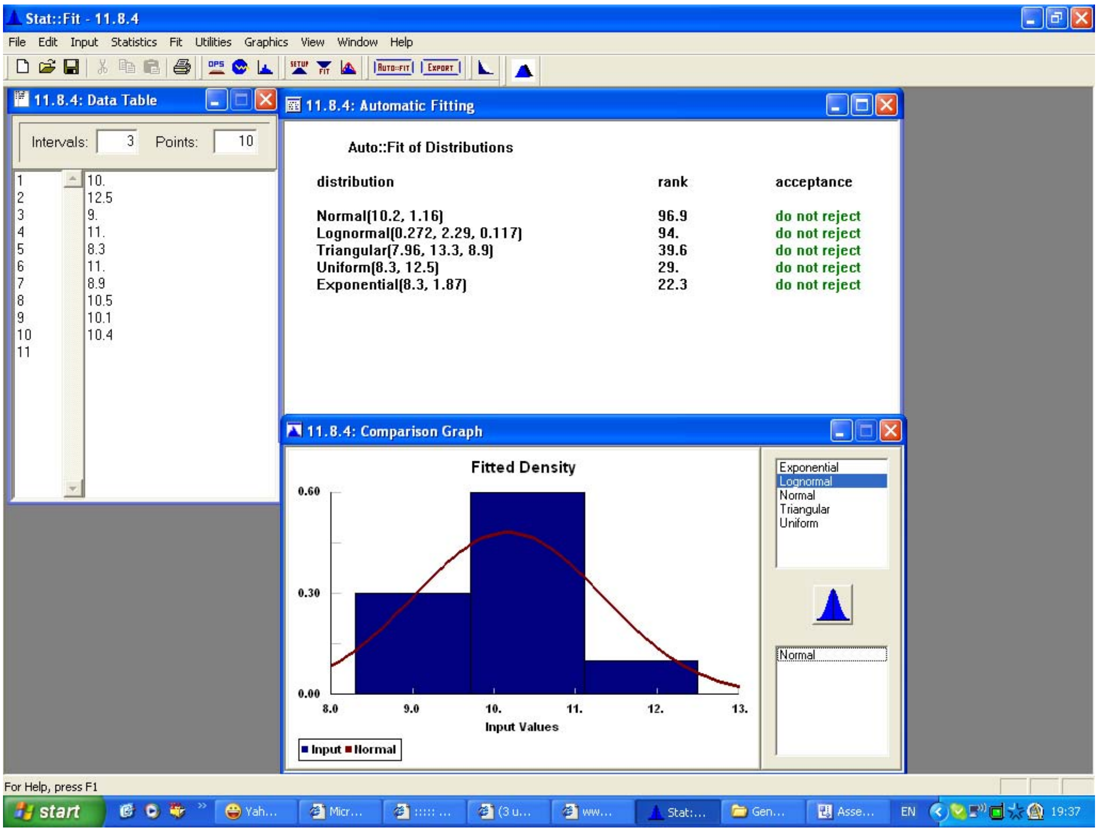


Figure 7.15: Takt Time (*TT*) Illustration

The assembly time at each station was determined using a stopwatch. The average of ten stopwatch readings was taken as an assembly time for each activity. The Auto::Fit function of the Stat::Fit software is used to calculate the appropriate continuous or discrete distributions to fit the input data. The software tests the results for goodness of fit and displays the distributions in the order of their relative ranking. Figure 7.16 is a screen shot of Stat::Fit analysis for activity four at assembly station 8 in the 11 station assembly line. The same procedure is repeated to determine goodness of fit for each activity.



```
Intervals: 3   Points: 10

1    10.
2    12.5
3    9.
4    11.
5    8.3
6    11.
7    8.9
8    10.5
9    10.1
10   10.4
11
```

```
Auto::Fit of Distributions

distribution                        rank    acceptance

Normal(10.2, 1.16)                  96.9    do not reject
Lognormal(0.272, 2.29, 0.117)       94.     do not reject
Triangular(7.96, 13.3, 8.9)         39.6    do not reject
Uniform(8.3, 12.5)                  29.     do not reject
Exponential(8.3, 1.87)              22.3    do not reject
```

Figure 7.16: Stat::Fit Analysis

All input data series scored over ‘80’ relative ranking for normal distribution. Hence, the normal distribution of assembly time input data is used in the simulation experiments.

Table 7.3(a) contains the observations of assembly time at every workstation for an 11 station assembly line.

According to heater assembly line 3, takt time is the longest time at any one station and it dictates the beat of the production line. According to Table 7.3(a), the longest operation occurs at the seventh station, which takes 79 seconds (including five seconds quality inspection time) and therefore takt time reduces to 74 seconds without the QA network.

Table 7.3 (a): Assembly Time for 11 Station Assembly Line

Car Model and Part Number		NCC – MF443110 - 7936	Assembly Time (Seconds)										Normal Distribution (Mean, Standard Deviation)
Station No.	**Activity No.**	**Elemental Operation**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	
1	**1**	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Fetch cases & attach labels	00:08.5	00:11.6	00:09.0	00:07.8	00:09.6	00:09.3	00:08.8	00:09.8	00:10.5	00:07.9	N(9.28, 1.11)
	3	Add bush	00:06.4	00:09.9	00:07.8	00:07.9	00:07.2	00:06.8	00:08.2	00:07.8	00:08.9	00:07.1	N(7.8, 0.98)
	4	Grease & locate doors (3)	00:18.8	00:18.3	00:18.9	00:21.2	00:20.5	00:20.2	00:20.1	00:18.5	00:19.2	00:19.7	N(19.5, 0.902)
	5	Fetch & insert evaporator	00:11.0	00:06.2	00:07.5	00:07.6	00:07.8	00:07.3	00:08.2	00:09.1	00:08.6	00:06.6	N(7.99, 1.29)
Total Assembly Time (Min : Sec) at Station 1 based on Average Assembly Time													**00:49.6**
2	**1**	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Attach cases	00:22.7	00:24.5	00:17.2	00:20.8	00:23.5	00:21.9	00:21.7	00:21.5	00:23.1	00:19.8	N(21.7, 1.971)
	3	Insert screws (6)	00:20.1	00:19.1	00:24.7	00:22.0	00:28.5	00:23.4	00:25.2	00:24.5	00:21.7	00:20.1	N(22.9, 2.74)
Total Assembly Time (Min : Sec) at Station 2 based on Average Assembly Time													**00:49.6**
3	**1**	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Insert grommets & attach lower case	00:22.9	00:21.6	00:22.8	00:20.1	00:21.4	00:21.2	00:22.6	00:21.3	00:21.6	00:22.2	N(21.8, 0.821)
	3	Attach clips (4) & screw (1)	00:23.2	00:20.4	00:22.7	00:22.6	00:21.6	00:22.8	00:21.0	00:21.9	00:22.1	00:22.7	N(22.1, 0.84)
	4	Attach lower case packing (2)	00:10.7	00:11.0	00:10.9	00:10.5	00:10.8	00:10.8	00:11.0	00:10.6	00:10.7	00:10.6	N(10.8, 0.162)
Total Assembly Time (Min : Sec) at Station 3 based on Average Assembly Time													**00:59.6**
4	**1**	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Insert heater core	00:05.2	00:05.5	00:06.3	00:05.1	00:05.3	00:05.1	00:05.2	00:05.1	00:05.8	00:05.8	N(5.44, 0.385)
	3	Grease boss fit leavers (2) & add screw	00:11.0	00:12.7	00:11.7	00:11.9	00:11.8	00:11.5	00:11.9	00:12.2	00:11.9	00:11.5	N(11.8, 0.428)
	4	Fit heater core in to jig & fit clamp to pipe	00:16.2	00:16.9	00:16.1	00:16.3	00:16.5	00:16.8	00:16.6	00:16.1	00:16.3	00:16.5	N(16.4, 0.265)
	5	Fit O'ring to pipes (3) & place pipe on line	00:11.9	00:09.6	00:10.2	00:08.7	00:08.7	00:09.2	00:09.7	00:10.2	00:10.5	00:09.7	N(9.84, 0.897)
Total Assembly Time (Min : Sec) at Station 4 based on Average Assembly Time													**00:48.5**
5	**1**	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Place unit on to jig	00:04.2	00:03.5	00:02.9	00:03.7	00:02.5	00:02.8	00:03.4	00:03.8	00:03.3	00:03.7	N(3.38, 0.492)
	3	Fit 1^{st} pipe to core & fit C' clamp	00:13.9	00:13.9	00:14.3	00:14.4	00:14.2	00:14.2	00:14.3	00:13.9	00:14.0	00:14.4	N(14.2, 0.196)
	4	Fit 2^{nd} pipe to core & fit C' clamp	00:11.6	00:12.0	00:12.7	00:10.5	00:10.9	00:11.0	00:11.8	00:12.1	00:11.4	00:10.8	N(11.5, 0.652)
	5	Attach plate	00:03.5	00:05.1	00:03.1	00:03.9	00:03.5	00:04.6	00:04.7	00:03.7	00:04.5	00:03.8	N(4.04, 0.612)
	6	Fit lever to servo & fit screws (3)	00:12.9	00:13.5	00:13.9	00:13.2	00:13.7	00:13.2	00:13.5	00:13.8	00:13.1	00:13.4	N(13.4, 0.306)
Total Assembly Time (Min : Sec) at Station 5 based on Average Assembly Time													**00:51.5**
6	**1**	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Attach face packing	00:17.7	00:18.1	00:17.3	00:17.3	00:18.6	00:17.5	00:17.9	00:18.4	00:17.8	00:17.7	N(17.8, 0.412)
	3	Grease & fit levers (3)	00:13.2	00:12.8	00:13.7	00:14.3	00:12.4	00:12.8	00:13.1	00:13.8	00:12.9	00:13.5	N(13.3, 0.543)
	4	Attach pipe bracket & screw (1)	00:15.8	00:11.4	00:13.0	00:11.3	00:12.7	00:11.8	00:12.2	00:14.1	00:13.4	00:12.6	N(12.8, 1.29)
Total Assembly Time (Min : Sec) at Station 6 based on Average Assembly Time													**00:48.9**
7	**1**	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Attach face packing	00:18.9	00:18.4	00:19.0	00:16.2	00:19.5	00:17.8	00:19.2	00:17.9	00:18.8	00:18.0	N(18.4, 0.907)
	3	Place unit on jig, attach thermister & resistor	00:13.0	00:13.7	00:10.7	00:12.0	00:13.3	00:12.1	00:13.2	00:12.5	00:11.8	00:12.4	N(12.5, 0.834)
	4	Start & conduct both tests	00:25.1	00:25.9	00:25.5	00:25.6	00:24.5	00:25.8	00:24.7	00:24.9	00:25.3	00:25.2	N(25.3, 0.439)
	5	Stamp, remove unit from jig & place on line	00:17.5	00:18.0	00:19.4	00:18.0	00:16.4	00:16.8	00:17.4	00:18.3	00:18.5	00:18.4	N(17.9, 0.831)
Total Assembly Time (Min : Sec) at Station 7 based on Average Assembly Time													**01:19.0**
8	**1**	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Fit motor / fan & secure with bolt (3)	00:17.7	00:18.3	00:15.6	00:12.5	00:13.6	00:14.3	00:15.1	00:16.4	00:16.8	00:15.0	N(15.5, 1.72)
	3	Place unit on to jig	00:05.6	00:06.3	00:05.1	00:05.1	00:05.7	00:05.2	00:05.5	00:06.1	00:05.9	00:05.6	N(5.6, 0.39)
	4	Scan label & test unit	00:10.0	00:12.5	00:09.0	00:11.0	00:08.3	00:11.0	00:08.9	00:10.5	00:10.1	00:10.4	N(10.2, 1.16)
	5	Stamp & remove unit from jig & place on line	00:09.7	00:09.5	00:09.6	00:10.0	00:09.7	00:09.8	00:09.7	00:09.9	00:09.8	00:09.5	N(9.72, 0.154)
Total Assembly Time (Min : Sec) at Station 8 based on Average Assembly Time													**00:46.0**
9	**1**	Place unit on vibration table & test	00:10.4	00:08.3	00:12.8	00:08.8	00:11.0	00:11.7	00:10.6	00:11.2	00:09.4	00:08.5	N(10.3, 1.41)
	2	Inspect the unit	00:48.2	00:46.7	00:47.2	00:46.5	00:44.4	00:47.8	00:47.1	00:46.9	00:46.4	00:45.2	N(46.6, 1.07)
Total Assembly Time (Min : Sec) at Station 9 based on Average Assembly Time													**00:56.9**
10	**1**	QA inspection & all tests	00:52.5	00:43.6	00:48.5	00:44.5	00:55.4	00:53.4	00:46.2	00:52.1	00:47.9	00:44.9	N(48.9, 3.97)
Total Assembly Time (Min : Sec) at Station 10 based on Average Assembly Time													**00:48.9**
11	**1**	Prepare box of 6 units for finished goods (F/G)	00:38.0	00:38.8	00:26.2	00:24.2	00:24.0	00:24.8	00:30.9	00:34.5	00:33.0	00:27.7	N(30.2, 5.36)
	2	Scan label & place unit in box	00:16.5	00:10.7	00:13.6	00:09.4	00:14.4	00:10.8	00:11.4	00:12.9	00:13.8	00:15.1	N(12.9, 2.12)
	3	Tighten straps (6)	01:07.0	01:01.2	01:02.1	01:09.8	00:58.9	00:59.8	01:06.8	01:02.8	00:59.9	01:04.7	N(63.3, 3.46)
	4	Prepare Kanban (6)	00:19.4	00:21.6	00:11.7	00:14.0	00:10.6	00:12.1	00:17.1	00:17.3	00:16.5	00:16.1	N(15.6, 3.34)
	5	Move F/G to internal stores (2 Boxes/12 units)	00:06.8	00:03.7	00:05.3	00:04.6	00:05.8	00:04.5	00:05.1	00:06.2	00:04.3	00:06.3	N(5.26, 0.95)
Total Assembly Time (Min : Sec) at Station 11 based on Average Assembly Time													**00:36.3**
TOTAL ASSEMBLY TIME PER UNIT (Based on average assembly time)													**09:34.9**

Table 7.3(b) contains an assembly time breakdown for the 13 station assembly line based on the activity times measured on the 11 station assembly line (refer to Table 7.3(a)). The elemental operations of 11 station assembly line given in Table 7.3(a) are distributed among 13 stations in order to minimise assembly associate's idle times. Redistribution of assembly tasks is done by the researcher with the help of line manager and team leader. The rescheduled assembly line is given in Table 7.3(b).

Table 7.3 (b): Assembly Time for 13 Station Assembly Line

Car Model and Part Number		NCC – MF443110 - 7936	Assembly Time (Seconds)										Normal Distribution (Mean, Standard Deviation)
Station No.	Activity No.	Elemental Operation	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	
1	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Fetch cases & attach labels	00:08.5	00:11.6	00:09.0	00:07.8	00:09.6	00:09.3	00:08.8	00:09.8	00:10.5	00:07.9	N(9.28, 1.11)
	3	Add bush	00:06.4	00:09.9	00:07.8	00:07.9	00:07.2	00:06.8	00:08.2	00:07.8	00:08.9	00:07.1	N(7.8, 0.98)
	4	Grease & locate doors (3)	00:18.8	00:18.3	00:18.9	00:21.2	00:20.5	00:20.2	00:20.1	00:18.5	00:19.2	00:19.7	N(19.5, 0.902)
	5	Fetch & insert evaporator	00:11.0	00:06.2	00:07.5	00:07.6	00:07.8	00:07.3	00:08.2	00:09.1	00:08.6	00:06.6	N(7.99, 1.29)
Total Assembly Time (Min : Sec) at Station 1 based on Average Assembly Time													**00:49.6**
2	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Attach cases	00:22.7	00:24.5	00:17.2	00:20.8	00:23.5	00:21.9	00:21.7	00:21.5	00:23.1	00:19.8	N(21.7, 1.971)
	3	Insert screws (6)	00:20.1	00:19.1	00:24.7	00:22.0	00:28.5	00:23.4	00:25.2	00:24.5	00:21.7	00:20.1	N(22.9, 2.74)
Total Assembly Time (Min : Sec) at Station 2 based on Average Assembly Time													**00:49.6**
3	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Insert grommets & attach lower case	00:22.9	00:21.6	00:22.8	00:20.1	00:21.4	00:21.2	00:22.6	00:21.3	00:21.6	00:22.2	N(21.8, 0.821)
	3	Attach clips (4) & screw (1)	00:23.2	00:20.4	00:22.7	00:22.6	00:21.6	00:22.8	00:21.0	00:21.9	00:22.1	00:22.7	N(22.1, 0.84)
Total Assembly Time (Min : Sec) at Station 3 based on Average Assembly Time													**00:48.9**
4	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Attach lower case packing (2)	00:10.7	00:11.0	00:10.9	00:10.5	00:10.8	00:10.8	00:11.0	00:10.6	00:10.7	00:10.6	N(10.8, 0.162)
	3	Insert heater core	00:05.2	00:05.5	00:06.3	00:05.1	00:05.3	00:05.1	00:05.2	00:05.1	00:05.8	00:05.8	N(5.44, 0.385)
	4	Grease boss fit leavers (2) & add screw	00:11.0	00:12.7	00:11.7	00:11.9	00:11.8	00:11.5	00:11.9	00:12.2	00:11.9	00:11.5	N(11.8, 0.428)
	5	Fit heater core in to jig & fit clamp to pipe	00:16.2	00:16.9	00:16.1	00:16.3	00:16.5	00:16.8	00:16.6	00:16.1	00:16.3	00:16.5	N(16.4, 0.265)
Total Assembly Time (Min : Sec) at Station 4 based on Average Assembly Time													**00:49.4**
5	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Fit O'ring to pipes (3) & place pipe on line	00:11.9	00:09.6	00:10.2	00:08.7	00:08.7	00:09.2	00:09.7	00:10.2	00:10.5	00:09.7	N(9.84, 0.897)
	3	Place unit on to jig	00:04.2	00:03.5	00:02.9	00:03.7	00:02.5	00:02.8	00:03.4	00:03.8	00:03.3	00:03.7	N(3.38, 0.492)
	4	Fit 1st pipe to core & fit C' clamp	00:13.9	00:13.9	00:14.3	00:14.4	00:14.2	00:14.2	00:14.3	00:13.9	00:14.0	00:14.4	N(14.2, 0.196)
	5	Fit 2nd pipe to core & fit C' clamp	00:11.6	00:12.0	00:12.7	00:10.5	00:10.9	00:11.0	00:11.8	00:12.1	00:11.4	00:10.8	N(11.5, 0.652)
	6	Attach plate	00:03.5	00:05.1	00:03.1	00:03.9	00:03.5	00:04.6	00:04.7	00:03.7	00:04.5	00:03.8	N(4.04, 0.612)
Total Assembly Time (Min : Sec) at Station 5 based on Average Assembly Time													**00:47.9**
6	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Attach face packing	00:17.7	00:18.1	00:17.3	00:17.3	00:18.6	00:17.5	00:17.9	00:18.4	00:17.8	00:17.7	N(17.8, 0.412)
	3	Fit lever to servo & fit screws (3)	00:12.9	00:13.5	00:13.9	00:13.2	00:13.7	00:13.2	00:13.5	00:13.8	00:13.1	00:13.4	N(13.4, 0.306)
	4	Grease & fit levers (3)	00:13.2	00:12.8	00:13.7	00:14.3	00:12.4	00:12.8	00:13.1	00:13.8	00:12.9	00:13.5	N(13.3, 0.543)
Total Assembly Time (Min : Sec) at Station 6 based on Average Assembly Time													**00:49.5**
7	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Attach pipe bracket & screw (1)	00:15.8	00:11.4	00:13.0	00:11.3	00:12.7	00:11.8	00:12.2	00:14.1	00:13.4	00:12.6	N(12.8, 1.29)
	3	Attach face packing	00:18.9	00:18.4	00:19.0	00:16.2	00:19.5	00:17.8	00:19.2	00:17.9	00:18.8	00:18.0	N(18.4, 0.907)
Total Assembly Time (Min : Sec) at Station 7 based on Average Assembly Time													**00:36.2**
8	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	3	Place unit on jig, attach thermister & resistor	00:13.0	00:13.7	00:10.7	00:12.0	00:13.3	00:12.1	00:13.2	00:12.5	00:11.8	00:12.4	N(12.5, 0.834)
	3	Start & conduct both tests	00:25.1	00:25.9	00:25.5	00:25.6	00:24.5	00:25.8	00:24.7	00:24.9	00:25.3	00:25.2	N(25.3, 0.439)
Total Assembly Time (Min : Sec) at Station 8 based on Average Assembly Time													**00:42.7**
9	1	Stamp, remove unit from jig & place on line	00:17.5	00:18.0	00:19.4	00:18.0	00:16.4	00:16.8	00:17.4	00:18.3	00:18.5	00:18.4	N(17.9, 0.831)
	2	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	3	Fit motor / fan & secure with bolt (3)	00:17.7	00:18.3	00:15.6	00:12.5	00:13.6	00:14.3	00:15.1	00:16.4	00:16.8	00:15.0	N(15.5, 1.72)
Total Assembly Time (Min : Sec) at Station 9 based on Average Assembly Time													**00:38.4**
10	1	QA network	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	00:05.0	
	2	Place unit on to jig	00:05.6	00:06.3	00:05.1	00:05.1	00:05.7	00:05.2	00:05.5	00:06.1	00:05.9	00:05.6	N(5.6, 0.39)
	3	Scan label & test unit	00:10.0	00:12.5	00:09.0	00:11.0	00:08.3	00:11.0	00:08.9	00:10.5	00:10.1	00:10.4	N(10.2, 1.16)
	4	Stamp & remove unit from jig & place on line	00:09.7	00:09.5	00:09.6	00:10.0	00:09.7	00:09.8	00:09.7	00:09.9	00:09.8	00:09.5	N(9.72, 0.154)
	5	Place unit on vibration table & test	00:10.4	00:08.3	00:12.8	00:08.8	00:11.0	00:11.7	00:10.6	00:11.2	00:09.4	00:08.5	N(10.3, 1.41)
Total Assembly Time (Min : Sec) at Station 10 based on Average Assembly Time													**00:40.8**
11	1	Inspect the unit	00:48.2	00:46.7	00:47.2	00:46.5	00:44.4	00:47.8	00:47.1	00:46.9	00:46.4	00:45.2	N(46.6, 1.07)
Total Assembly Time (Min : Sec) at Station 11 based on Average Assembly Time													**00:46.6**
12	1	QA inspection & all tests	00:52.5	00:43.6	00:48.5	00:44.5	00:55.4	00:53.4	00:46.2	00:52.1	00:47.9	00:44.9	N(48.9, 3.97)
Total Assembly Time (Min : Sec) at Station 12 based on Average Assembly Time													**00:48.9**
13	1	Prepare box of 6 units for finished goods (F/G)	00:38.0	00:38.8	00:26.2	00:24.2	00:24.0	00:24.8	00:30.9	00:34.5	00:33.0	00:27.7	N(30.2, 5.36)
	2	Scan label & place unit in box	00:16.5	00:10.7	00:13.6	00:09.4	00:14.4	00:10.8	00:11.4	00:12.9	00:13.8	00:15.1	N(12.9, 2.12)
	3	Tighten straps (6)	01:07.0	01:01.2	01:02.1	01:09.8	00:58.9	00:59.8	01:06.8	01:02.8	00:59.9	01:04.7	N(63.3, 3.46)
	4	Prepare Kanban (6)	00:19.4	00:21.6	00:11.7	00:14.0	00:10.6	00:12.1	00:17.1	00:17.3	00:16.5	00:16.1	N(15.6, 3.34)
	5	Move F/G to internal stores (2 Boxes/12 units)	00:06.8	00:03.7	00:05.3	00:04.6	00:05.8	00:04.5	00:05.1	00:06.2	00:04.3	00:06.3	N(5.26, 0.95)
Total Assembly Time (Min : Sec) at Station 13 based on Average Assembly Time													**00:36.3**
TOTAL ASSEMBLY TIME PER UNIT (Based on average assembly time)													**09:44.9**

According to table 7.3(b), the longest operation time, which is 49.6 seconds takes place at both first and second stations. This longest operation time includes five seconds quality inspection time. However, in the situation where there is no QA network, the longest process time shifts to the twelfth station. Accordingly, takt time without five seconds quality inspection is 48.9 seconds, which is marginally less than 49.6 seconds.

Figure 7.17 (a) and (b) show the takt time comparisons between 11 and 13 station assembly lines respectively.

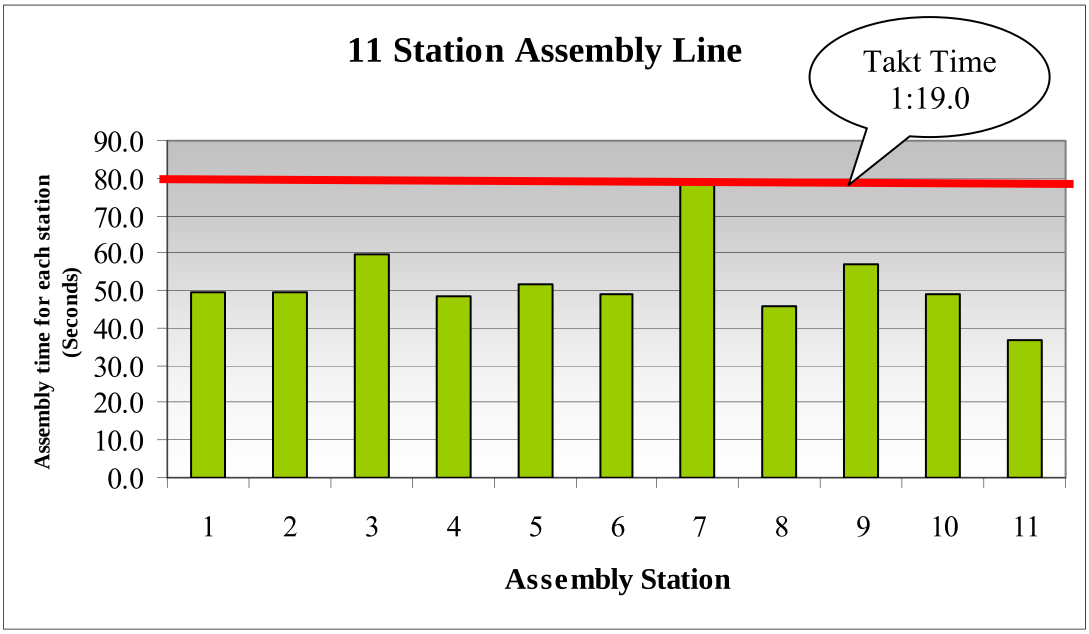


Figure 7.17 (a): Assembly Time and Takt Time for 11 Station Assembly Line

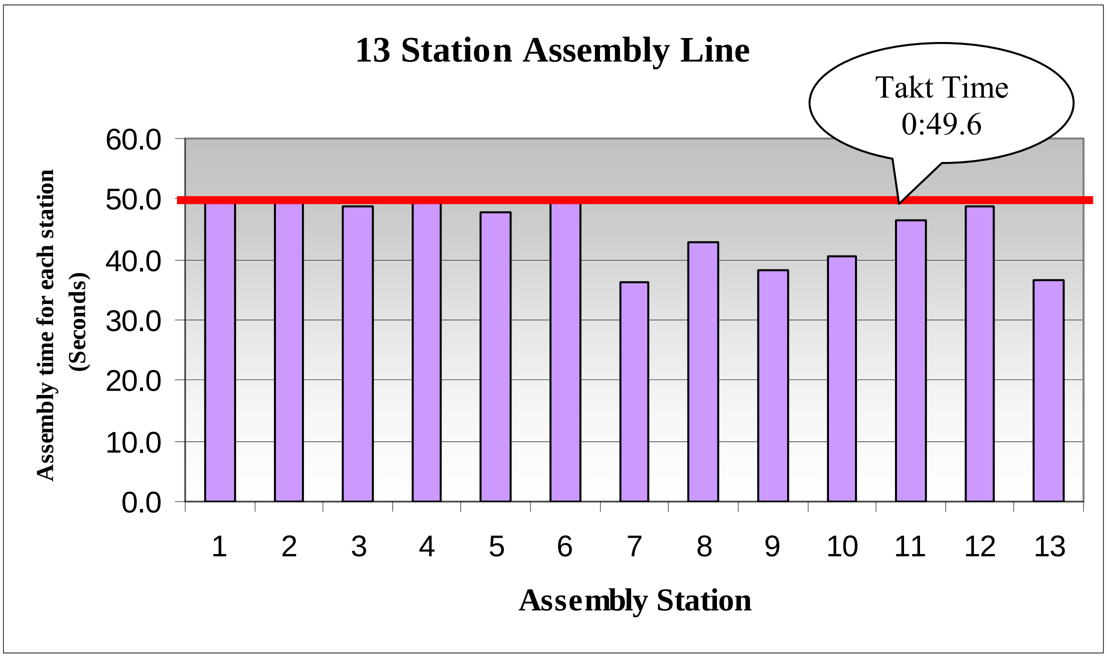


Figure 7.17 (b): Assembly Time and Takt Time for 13 Station Assembly Line

According to Figure 7.17 (a) and (b), the 13 station assembly line is more balanced and has a lower takt time than the 11 station assembly line. However, the 13 station assembly line has employed 2 more line associates than the 11 station assembly line (the extra assembly stations can be manned by internal sub-assembly line associates). It can be concluded therefore that the aforementioned key JIT drivers have impact on process and takt times.

7.7 MODELLING AND SIMULATION OF EXPERIMENTS

7.7.1 Assumptions and Constraints in Simulation Modelling

Most simulation models are constrained by a set of assumptions, which define the limit or scope of the simulation model and the level of detail involved. The following assumptions and limitations were imposed on the simulation modelling experiments reported here:

- raw materials and parts are always available at stations
- the assembly line is flexible and new assembly stations can be introduced according to demand
- the model incorporates a 100% quality check where there is a 1% chance that a part will be found defective, which is considered to be acceptable
- setup times are assumed to be constant at each station, but, however, depend on the product type
- no line stoppage occurs during production and it is expected that both upstream and downstream worker/s, the team leader and the setter will help associates at critical workstations
- no allowance is made for machine breakdowns and repair times in the model; preventive maintenance is assumed to be performed during non-productive time
- first-in-first-out (FIFO) rule applies for parts assembly
- the assembly line works under ideal JIT conditions

Data obtained from plant observations and information obtained from managers were used to develop simulation models using the ProModel simulation software, with the establishment of a relationship between JIT drivers and line performance using mathematical models.

7.7.2 Modelling Assembly Line using ProModel Simulation Software

A system is assumed to consist of entities, activities, resources and controls (Harrell *et al.*, 2003) and decisions about the correct model scope and level of details are key elements in modelling (Robinson, 1994 and Banks and Gibson, 1996). The model developed here is applicable to the operation of heater assembly line 3.

Simulation modelling was started with assembly line background design; the ‘import graphic’ function of the ‘background graphic’ module was used to import the design of the assembly line layout to the simulation model. Model elements such as ‘locations’, ‘entities’, ‘path networks’, ‘resources’, ‘processing’ and ‘arrivals’ were defined during the next step. Please refer to Appendix 3 for the simulation programming for all eight experiments

Locations

‘Locations’ represent fixed places in the system where entities (heater units) are routed for processing, storing or making some decision about further routing (Harrel and Tumay, 1992). The simulation model included locations for the assembly stations, conveyor belt and raw materials, components and final product storage points. The conveyor dialog box allows for specification of conveyor length and speed. For instance, in ProModel, an accumulating conveyor section must end at the point where the parts are permitted to accumulate or process. The conveyor, therefore, is divided into sections and each section is located in between assembly stations. The conveyor speed is 1.25 meters per minute and all locations are assigned by first-in-first-out (FIFO) input-output rule.

Entities

‘Entities’ can be human/animate (customers), inanimate (parts, documents) or intangible (calls, e-mails) (Harrell *et al.*, 2003). The simulation model includes entities such as NCC (L), NCC (R) and MCC components and finished heater boxes. It is assumed that the first batch of entities includes 200 heater units and the second batch includes 100 units in the simulation modelling.

Path Networks

‘Path networks’ allow dynamic resources to travel between locations. The model developed here has only one path network consisting of two paths and paths are located between the conveyor and the finished product storage points. Movement along the path was defined in terms of distance between locations and the speed of an associate working at the final station.

Resources

‘Resources’ are people or equipment that transport or process entities or perform any other process activities including maintenance. Resources can be human/animate (operators, maintenance personnel), inanimate (equipment, tooling, floor space) or intangible items (information, electrical power) (Harrell *et al.*, 2003). A resource may be dynamic (able to move along a path network) or static (unable to move). In this model, all the line associates are set to be static, except the last associate, who moves along the path network. The team leader, setter and part picker do not play an active role in the production and are therefore not included in the model. Shifts downtime and break periods were ignored in the modelling in order to obtain the total productive operation time. The speed for dynamic resources was defined as 50 meters per minute.

Processing

‘Processing’ defines the route of entities throughout the system and the operations that take place at each location. It defines all the activities from entity arrival to exit including entity processing, entity and resource moving, maintenance and repairs. ProModel provides a fast and user-friendly processing editor to define inputs, locations, operations, outputs and their destinations. Operations are defined using statements and functions. The operation time was defined for this model as a constant or normal distribution function wherever necessary. Statements and functions used in the programming are as follows:

- USE {*resource*} FOR {*time*} – Use resource for the specified period of time
- SEND {*expression/number of entities*} {*entity name*} TO {*destination*} – Send the specified number of a particular entity type to the destination.

- INC {*name of variable*} – Increase value of the variable
- ACCUM {*expression*} – Accumulate, without consolidating, the specified quantity of entities at a location
- GROUP {*expression*} AS {*entity name*} – Temporarily consolidate a specified quantity of entities into a single group shell entity
- FREE {*resource*} – Free resource, which is owned by the current entity
- MOVE WITH {*resource*} FOR {*time*} THEN FREE – Move entity using a designated resource for the specified time and then release resource

Arrivals

'Arrivals' define when and where new entities are introduced to the system. Arrivals include the location of arrival, quantity of the entity, time of the first arrival, total occurrences of the arrival and frequency of the arrival. During modelling, it was assumed that the first batch consisted of 200 NCC (L) heater units and the second batch consisted of 100 NCC (R) or MCC heater units.

Variables

'Variables' are normally used for decision-making or statistical reporting. In modelling, three global variables (i.e. NCC (L), NCC (R) and MCC) were defined as counters for the finished products.

7.7.3 Simulation Experiments with ProModel

ProModel can run simulation models with or without animation. Figure 7.18 is a screenshot of the animation with ProModel when all the factors are set at their upper limits. Please refer to Appendix 3 for the simulation programming and screenshots for all eight experiments.

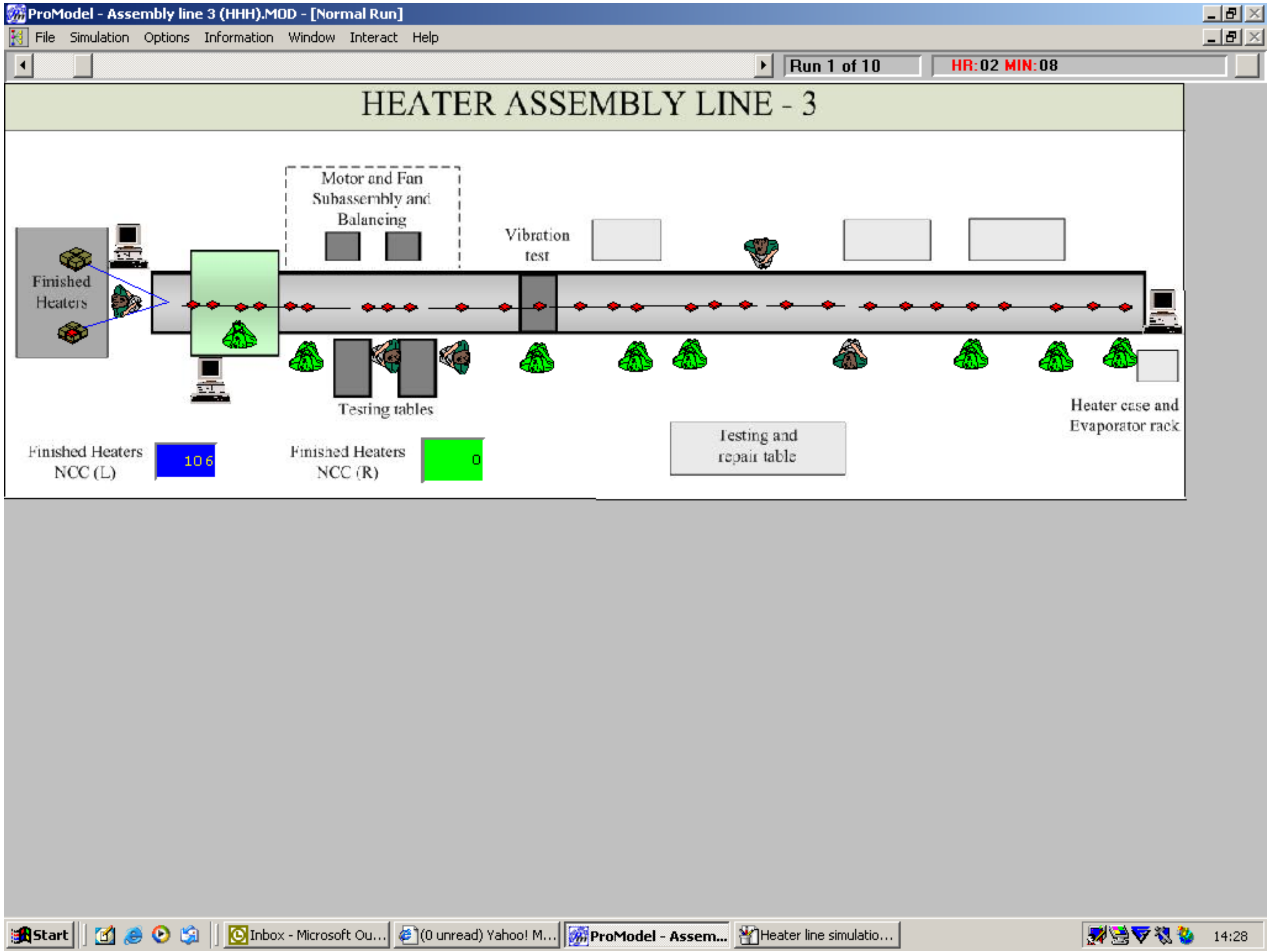
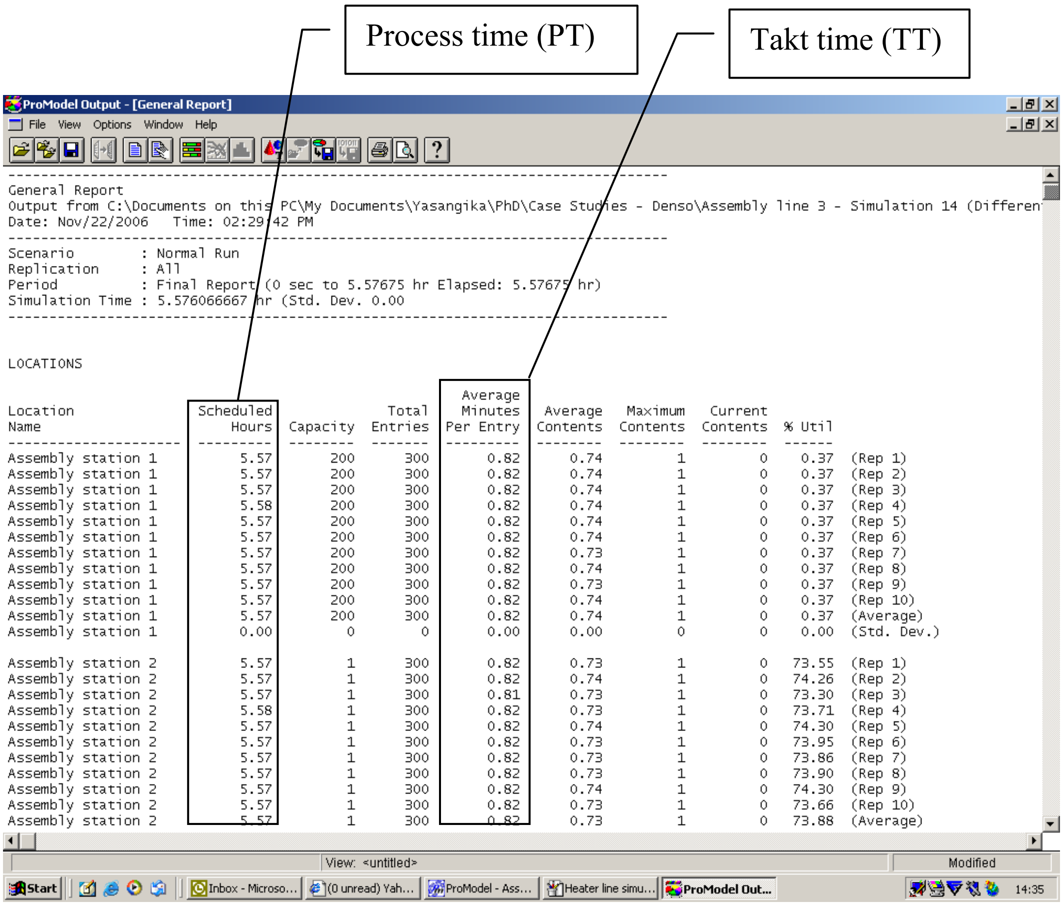


Figure 7.18: Screenshot of Experiment with ProModel when All the Factors were Set at Upper Limit

7.7.4 Simulation Results

Figure 7.19 depicts the screenshot of ProModel output, where all the factors are set at their upper level. Please refer to Appendix 3 for results of all eight experiments.



```
-------------------------------------------------------------------------------
General Report
Output from C:\Documents on this PC\My Documents\Yasangika\PhD\Case Studies - Denso\Assembly line 3 - Simulation 14 (Differen
Date: Nov/22/2006   Time: 02:29:42 PM
-------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 5.57675 hr Elapsed: 5.57675 hr)
Simulation Time : 5.576066667 hr (Std. Dev. 0.00
-------------------------------------------------------------------------------


LOCATIONS

                                                     Average
Location               Scheduled                     Minutes   Average   Maximum   Current
Name                       Hours  Capacity  Entries  Per Entry Contents  Contents  Contents  % Util
---------------------  ---------  --------  -------  --------- --------  --------  --------  ------
Assembly station 1          5.57       200      300       0.82     0.74         1         0    0.37  (Rep 1)
Assembly station 1          5.57       200      300       0.82     0.74         1         0    0.37  (Rep 2)
Assembly station 1          5.57       200      300       0.82     0.74         1         0    0.37  (Rep 3)
Assembly station 1          5.58       200      300       0.82     0.74         1         0    0.37  (Rep 4)
Assembly station 1          5.57       200      300       0.82     0.74         1         0    0.37  (Rep 5)
Assembly station 1          5.57       200      300       0.82     0.74         1         0    0.37  (Rep 6)
Assembly station 1          5.57       200      300       0.82     0.73         1         0    0.37  (Rep 7)
Assembly station 1          5.57       200      300       0.82     0.74         1         0    0.37  (Rep 8)
Assembly station 1          5.57       200      300       0.82     0.73         1         0    0.37  (Rep 9)
Assembly station 1          5.57       200      300       0.82     0.74         1         0    0.37  (Rep 10)
Assembly station 1          5.57       200      300       0.82     0.74         1         0    0.37  (Average)
Assembly station 1          0.00         0        0       0.00     0.00         0         0    0.00  (Std. Dev.)

Assembly station 2          5.57         1      300       0.82     0.73         1         0   73.55  (Rep 1)
Assembly station 2          5.57         1      300       0.82     0.74         1         0   74.26  (Rep 2)
Assembly station 2          5.57         1      300       0.81     0.73         1         0   73.30  (Rep 3)
Assembly station 2          5.58         1      300       0.82     0.73         1         0   73.71  (Rep 4)
Assembly station 2          5.57         1      300       0.82     0.74         1         0   74.30  (Rep 5)
Assembly station 2          5.57         1      300       0.82     0.73         1         0   73.95  (Rep 6)
Assembly station 2          5.57         1      300       0.82     0.73         1         0   73.86  (Rep 7)
Assembly station 2          5.57         1      300       0.82     0.73         1         0   73.90  (Rep 8)
Assembly station 2          5.57         1      300       0.82     0.74         1         0   74.30  (Rep 9)
Assembly station 2          5.57         1      300       0.82     0.73         1         0   73.66  (Rep 10)
Assembly station 2          5.57         1      300       0.82     0.73         1         0   73.88  (Average)
```

Figure 7.19: ProModel Output when all Factors are set at Upper Level

Each experiment was simulated with ten replications and the maximum and minimum outputs for process and takt times (refer to ‘Scheduled Hours’ and ‘Average Minutes Per Entry’ columns in Figure 7.19) were selected for performance analysis. Tables 7.4 and 7.5 show the combination matrix for full factorial design and replication outputs for *PT* and *TT* respectively in the manually operated mixed model heater assembly line 3. (Refer to Table 7.2 for lower values (L) and higher values (H) of JIT variables).

Table 7.4: Experimental Trials and Results for 2^2 Factorial Design of Takt Time

Response	Line Balancing/ Multifunction Employee (*A*)	Quality Control Activities (*B*)	Takt Time (*TT*) (Seconds)	
			Replication 1	Replication 2
R-TT1	L	L	73.8	73.8
R-TT2	H	L	48.6	49.2
R-TT3	L	H	78.6	78.6
R-TT4	H	H	48.6	49.2

* H – Higher value and L – Lower value

Table 7.5: Experimental Trials and Results for 2^3 Factorial Design of Process Time

Response	Line Balancing/ Multifunction Employee (*A*)	Quality Control Activities (*B*)	Setup Time (*C*)	Process Time (*PT*) (Minutes)	
				Replication 1	Replication 2
R-PT1	L	L	L	396.0	397.8
R-PT2	H	L	L	299.4	299.4
R-PT3	L	H	L	421.8	423.0
R-PT4	H	H	L	330.0	330.6
R-PT5	L	L	H	396.0	397.2
R-PT6	H	L	H	309.6	309.6
R-PT7	L	H	H	421.2	423.6
R-PT8	H	H	H	334.2	334.8

* H – Higher value and L – Lower value

According to simulation results of replication 1 presented in Table 7.4, R-TT1 (i.e. 73.8 seconds) and R-TT2 (48.6 seconds) give takt time for lower (11 station) and higher (13 station) line balancing without QA network respectively. Therefore it is clearly evident that the line balancing has a high impact on takt time. Where there is lower line balancing (R-TT1 and R-TT3), takt time differs by 4.8 seconds, which reflects the minor influence of five seconds quality inspection time on takt time (i.e. from 73.8 to 78.6 seconds). As expected the takt time is essentially the same for both R-TT2 and R-TT4. According to the explanation given under Table 7.3(b), takt time shifts from stations 1 and 2 (with QA network) to station 12 (without QA network). The only difference between assembly times of these two scenarios is approximately 0.7 seconds.

According to heater assembly line 3, it is evident that process time depends on variables such as takt time, setup time, throughput time and the number of units produced in a production schedule. If the process time is assumed as Eq: 7.2,

$$\Pr ocess\ Time = (Takt\ Time \times (No.\ of\ Units\ \Pr oduced - 1)) + Throughput\ Time + Setup\ Time + Unknown\ Factors$$

Eq: 7.2

the experimental results as per the Table 7.5 for R-PT1 and R-PT3 are tallying with the results of Eq: 7.2. The only deference between R-PT1 and R-PT3 is the five seconds inspection time added to several stations, which brings about additional 25 minutes to R-PT3. Further, the process time of R-PT4 and R-PT8 are 330.0 and 334.2 minutes respectively. The only difference between these two experiments is the setup time increasing from 20 (=2*10) minutes to 40 (=2*20) minutes. But as per the above experimental results, the process time difference is only 4.2 minutes. This clearly indicates that setup time is sequential throughout each assembly station rather than the line stopping completely.

However, the formula outcomes of the R-PT2, R-PT5, R-PT6 and R-PT7 compared against the experimental results shows different significant values for the unknown factor given in the Eq:7.2. The reasons for the difference can be speculated as follows:

- Software error / inefficiency
- Formula error
- Conveyor specification error (e.g. speed, length, width, to name a few)
- Entity arrival frequency error

Having considered the above facts, the following section will further analyse simulation experimental results using a statistical tool in order to establish relationships between JIT variables.

7.8 SIMULATION RESULT ANALYSIS AND MATHEMATICAL MODELLING

Simulation experimental results were analysed using MINITAB software (MINITAB version 14). Statistical analysis and factorial fit for the data shown in Tables 7.4 and 7.5 are presented in Table 7.6. Analysis of the main, two-way and three-way interactions obtained at a 0.05 significance level (α) together with the coefficients and *p* values are presented. An effect is deemed significant, if the *p* value is less than or equal to α (Minitab, 2003).

Table 7.6: Factorial Fit for Process and Takt Times

JIT Factor/s	**Process Time (*PT*)**	
	Coefficient	***p* Value**
Intercept	364.01	0.000
A	- 45.56	0.000
B	13.39	0.000
C	1.76	0.000
*A*B*	0.56	0.000
*A*C*	1.84	0.035
*B*C*	- 0.71	0.012
*A*B*C*	- 0.79	0.008

JIT Factor/s	**Takt Time (*TT*)**	
	Coefficient	***p* Value**
Intercept	62.48	0.000
A	- 13.72	0.000
B	1.12	0.000
*A*B*	- 1.27	0.000

A: Line balancing (multifunction employees)
B: Quality control activities
C: Setup time elimination plans

According to Table 7.6, *p* values for all the effects and interactions on *PT* are less than 0.05 (α). Therefore, all effects and interactions on *PT* and *TT* are deemed statistically significant. In this study, the coefficient of line balancing (multifunction employees) shows the highest impact on both process time and takt time compared to the other JIT drivers. The same explanation goes for their two and three-way interactions. Process and takt times therefore decrease when the number of stations (number of employees) change from lower to upper values. In this instance, management can decrease *PT* and *TT* by introducing more assembly stations (more employees) with better line balancing (improved multifunctional ability). Process time is found to increase when setup time and time spent on quality control activities change from the lower to the upper values. The impact of quality control activities on process time is greater than those for setup time but lower than for line balancing (multifunction employees).

7.8.1 Factorial Plots

(a) Effect Plot

The main effect plot shows the major effects of key JIT drivers on process and takt times and helps to compare the relative strengths of the effects (refer to Section 6.3.4). The following conclusions can be drawn from the main effect plot (Figure 7.20):

- process time decreases with increase in number of stations (associates)
- process time increases marginally with increase in setup time
- process time increases with increase in time spent on quality control activities

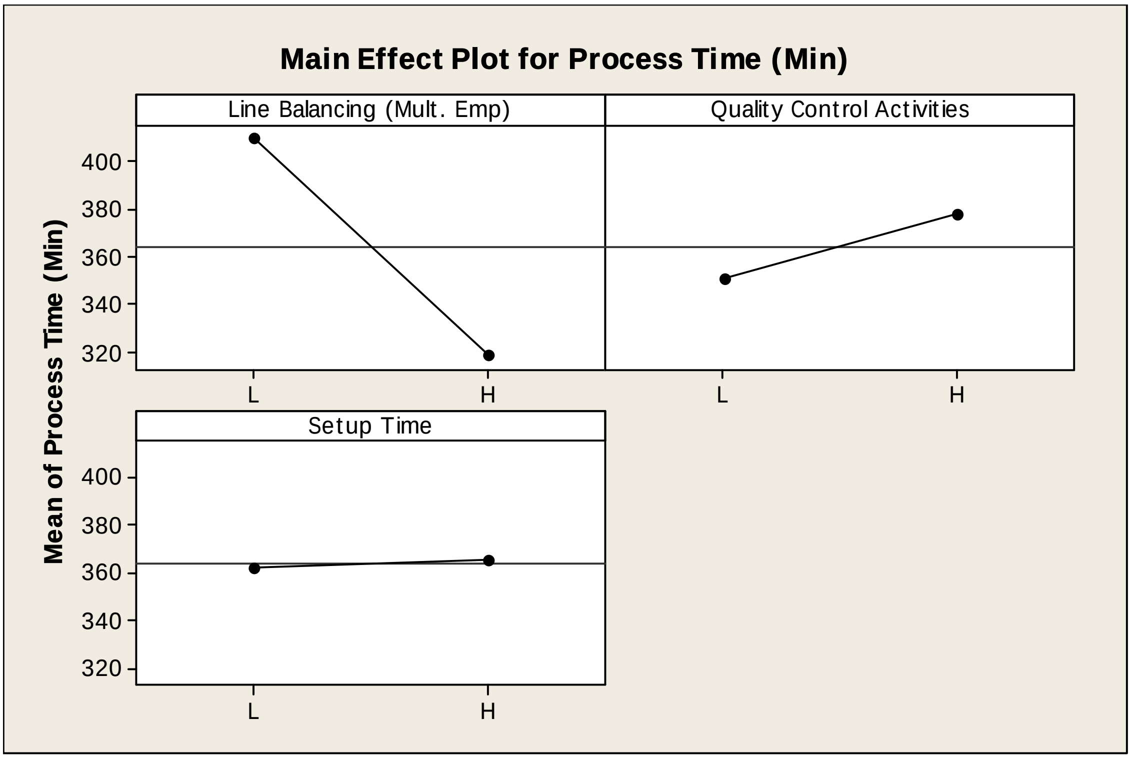


Figure 7.20: Plot of the Main Effect of JIT Drivers on Process Time

Figure 7.21 depicts the plot of the main effects of the selected JIT drivers on takt time and following conclusions can be drawn:

- takt time decreases with increase in number of stations (number of associates)
- effect of quality control activities on takt time is not highly significant compared to line balancing (multifunction employee); however, takt time increases with increase in time spent on quality control activities

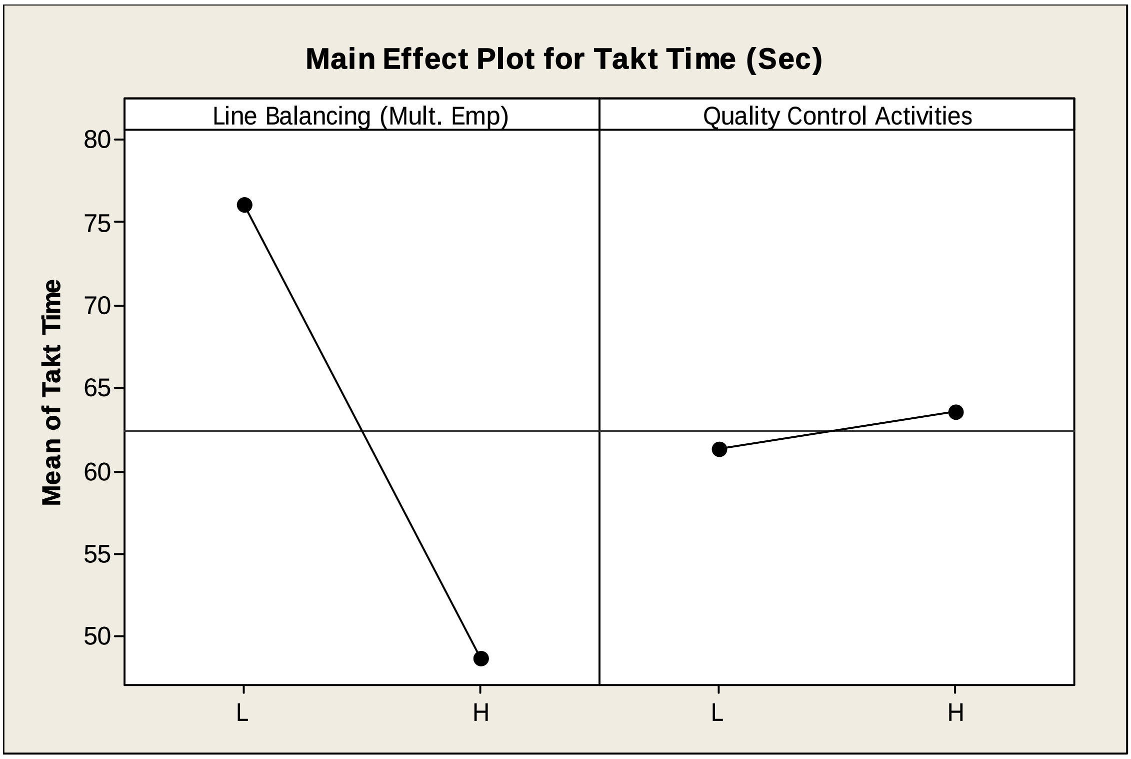


Figure 7.21: Plot of the Main Effect of JIT Drivers on Takt Time

(b) Interaction Plots

The interaction plot illustrates the impact of interactions of three key JIT drivers on takt time and compares the relative strength of their interactions (refer to Section 6.3.4).

Figure 7.22 (a) and (b) show the interactions between JIT drivers and their relative impact on the process and takt times respectively. Interactions between key JIT drivers in Figure 7.22 (a) and (b) are difficult to recognise in the interaction plots, although statistically significant interactions exist according to the factorial fit table (refer to Table 7.6).

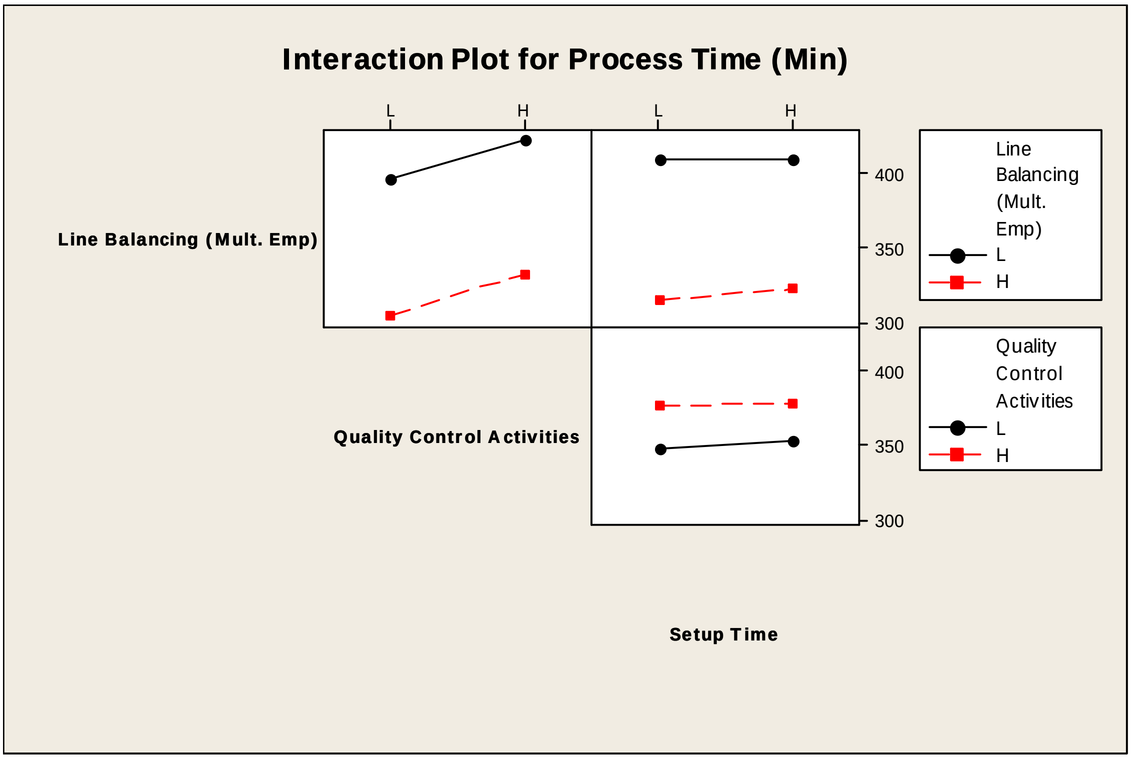


Figure 7.22 (a): Interaction Plot for Process Time

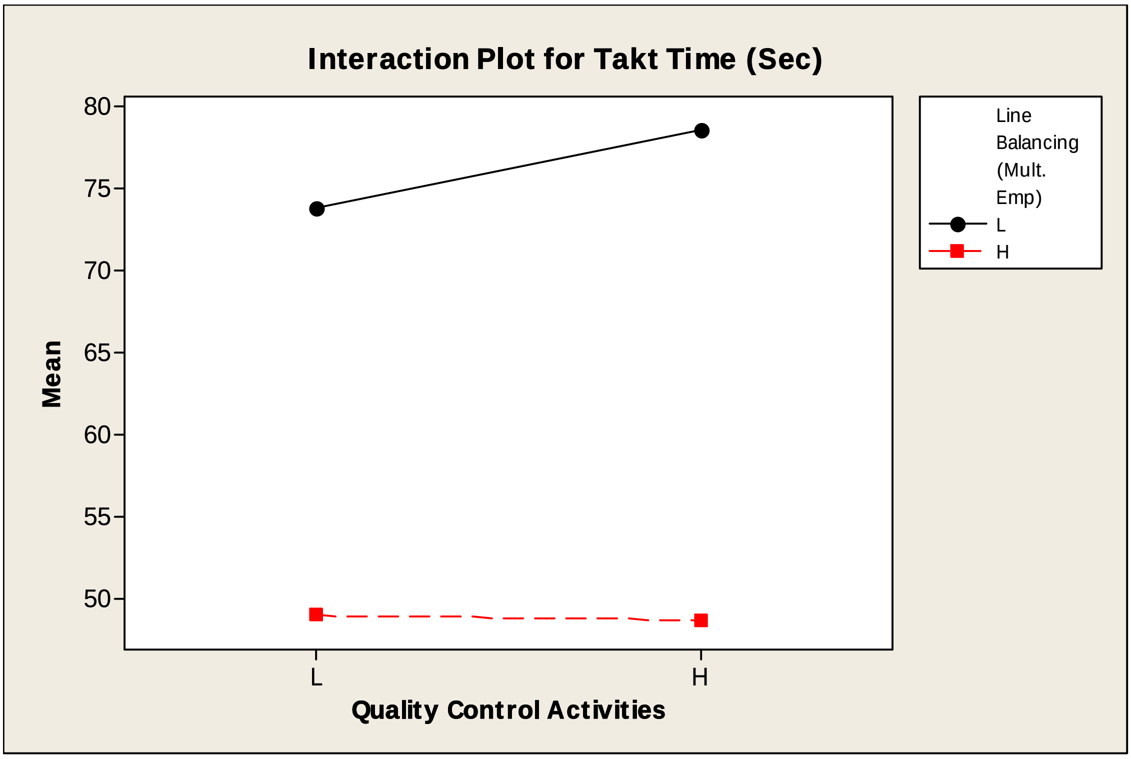


Figure 7.22 (b): Interaction Plot for Takt Time

(c) Normal Probability Plots

The normal probability plot compares the relative magnitudes and statistical significance of main and interaction effects of three key JIT drivers on process and takt times (refer to Section 6.3.4). Figure 7.23 shows the normal probability plot of the effect on process time when α is 0.05. According to Figure 7.23, the effects of all the factors and their interaction effects on process time are important and significant. Line balancing/multifunction employees (*A*) is the most significant factor followed by quality control activities (*B*). All the other main and interaction effects (*C, AB, AC, BC* and *ABC*) are deemed marginally significant.

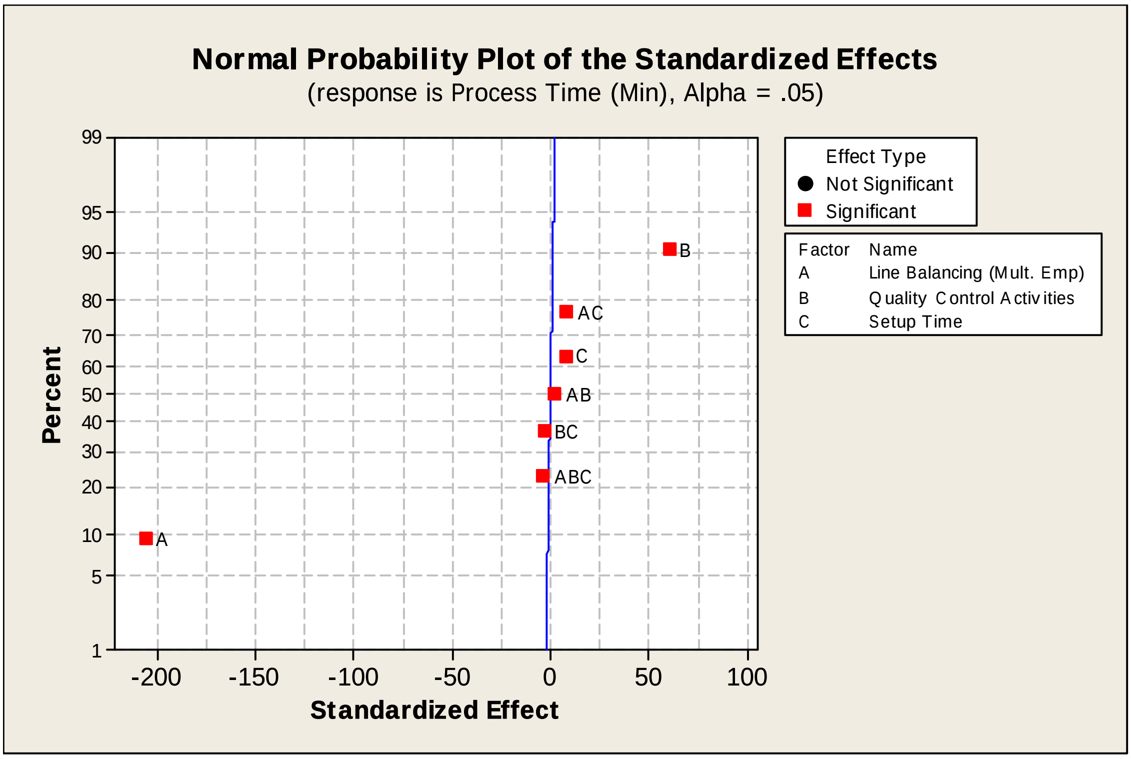


Figure 7.23: Normal Probability Plot for the Standardised Effect on Process Time

According to the normal probability plot for takt time (Figure 7.24) and similar to *PT*, line balancing/multifunction employees (*A*) is the most significant factor. Quality control activities (*B*) also depict high impact on the value of takt time. The impact of interaction between line balancing/multifunction employees and quality control activities (*AB*) on takt time is deemed marginally high.

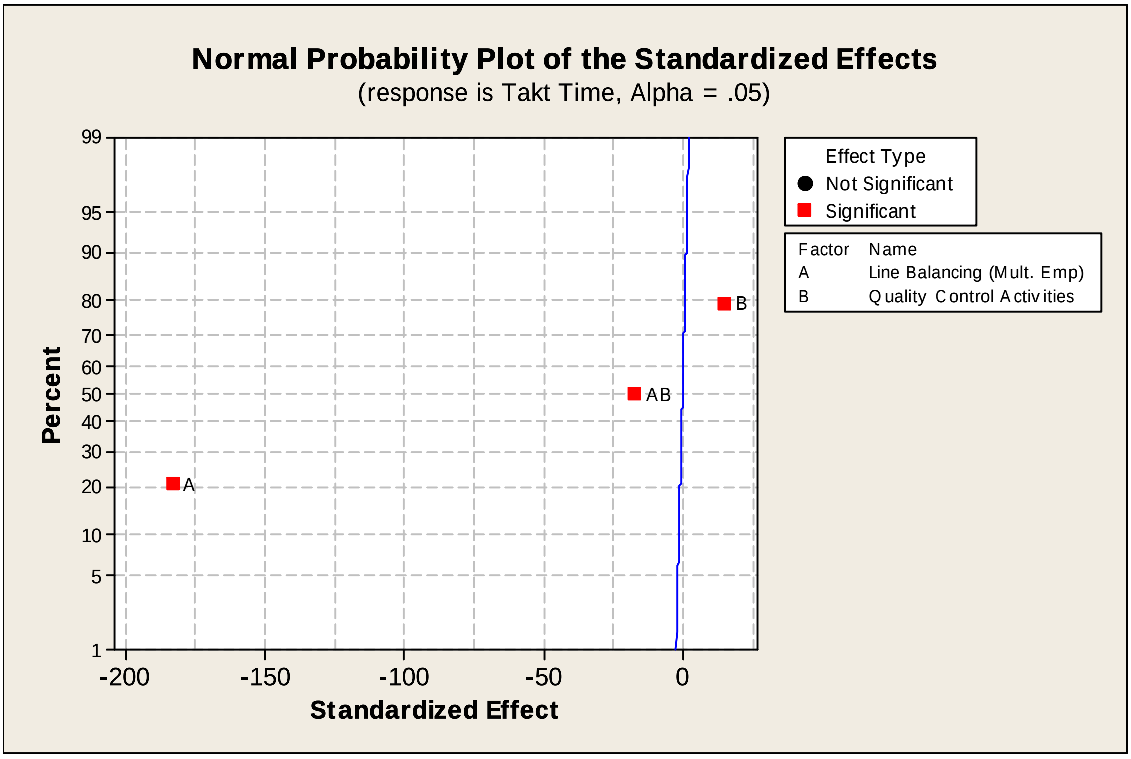


Figure 7.24: Normal Probability Plot for the Standardised Effect on Takt Time

Based on Table 7.6, the following regression equations were derived for process time (*PT*) (Eq: 7.3) and takt time (*TT*) (Eq: 7.4):

$PT = 364.01 - 45.56A + 13.39B + 1.76C + 0.56AB + 1.84AC - 0.71BC - 0.79ABC$ ……. **Eq: 7.3**

$TT = 62.48 - 13.72A + 1.12B - 1.27AB$ ………………………………………….. **Eq: 7.4**

Where, A : Line balancing (multifunction employees)

B : Quality control activities

C : Setup time

The above equations are limited to the specific factor values given in Table 7.2 and therefore Eqs: 7.3 and 7.4 are not universal. The company can use the mathematical models to predict process and takt times by assigning upper ('+') and lower ('-') values for the aforementioned factors to similar assembly setting. Assignment of values will depend on the specifications for line associates, customer demand for shorter lead-times, scrap and defect levels, and quality requirements.

7.9 DETERMINATION OF DMUK'S COMPETITIVE PRIORITIES

7.9.1 Development of Performance Hierarchy

As a first step in the AHP analysis, the performance measurement hierarchy was developed with the following overall objective, measurement criteria and decision alternatives:

- Overall objective – Improved overall performance of the company
- Measurement criteria – Extended BSC perspectives
- Decision alternatives – Key JIT drivers needed to compare, quantify and optimise

Figure 7.25 shows the customised performance measurement hierarchy developed for DMUK.

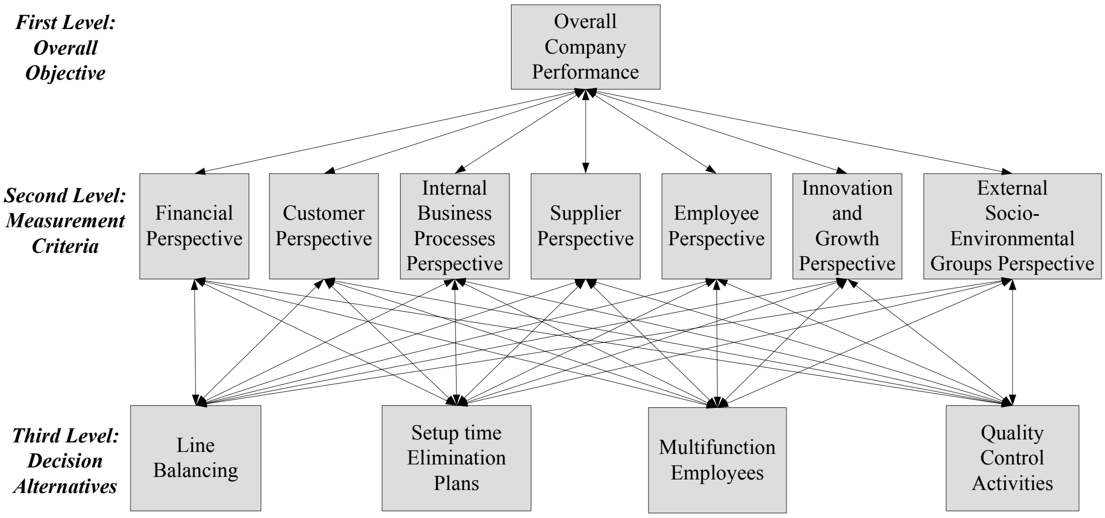

First Level: Overall Objective
Overall Company Performance
Second Level: Measurement Criteria
Financial Perspective
Customer Perspective
Internal Business Processes Perspective
Supplier Perspective
Employee Perspective
Innovation and Growth Perspective
External Socio-Environmental Groups Perspective
Third Level: Decision Alternatives
Line Balancing
Setup time Elimination Plans
Multifunction Employees
Quality Control Activities

Figure 7.25: Customised Performance Measurement Hierarchy for DMUK

7.9.2 Questionnaire Design and Survey

A series of focused and structured interviews were carried out with top managers, executive staff members and line managers (Refer to Table 7.8). The purpose of these interviews was to gain the opinion and views of the managers about DMUK's competitive priorities, and the impact of JIT manufacturing techniques on extended

BSC perspectives and overall performance of the company. Appendix 2 shows the survey instrument (questionnaire) used to collect data during interviews with Senior Managers at DMUK. The questionnaire consisted of two parts. Part I was used to identify DMUK's competitive priorities and to quantify the impact of seven extended BSC perspectives on overall performance of the company, while Part II was used to assess the influence of selected key JIT drivers on each BSC perspective. Participants were further encouraged to brainstorm, use their experience and tacit knowledge to answer three major questions about the BSC perspectives relevant to their job functions. Typical questions were:

- What does your company think about the customer perspective?
- Did you consider the customer perspective in the mission and vision statements?
- What are the key performance indicators you have considered and performance targets set in performance measurement of the customer perspective?
- What are the factors affecting customer perspective?

These questions were repeated for the remaining extended BSC perspectives namely, financial, internal business processes, employees, suppliers, innovation and growth, and external socio-environmental groups.

The respondents were further asked to give their individual opinion and indicate the magnitude of importance placed on selected key JIT factors for each BSC perspective. The participants were finally asked to state the reasons for their decisions.

Respondents from the different departments participated and the number of participants from each department are shown in Table 7.7.

Table 7.7: Composition of Participants from each Department

Department	Number of Participants
Production Control Department	5
Finance Department	4
Human Resource Department	7
Purchasing Department	3
Environmental Department	1
TOTAL NUMBER OF PARTICIPANTS	**20**

Most of the survey participants were multi-skilled and multi-professional. Even though the participants were attached to a specific department, they had close relationships with other departments and were involved in their activities. For example, most of the participants from the Human Resource Department were involved with employee training and production process improvement, and were therefore able to comment on employee and internal business processes as well as innovation and growth perspectives. The respondents from Finance Department were managers dealing with financial accounting and customer care. Top managers and line managers from Production Control Department commented on DMUK's internal business processes, employee and customer perspectives. Three members who participated from the Purchasing Department and Central Stores are involved in activities such as purchasing, central store management, part distribution within the floor, finished product delivery to the final customer and supplier selection. They were therefore able to comment on supplier, customer, internal business processes, financial and employee perspectives.

The Environmental Department is a new branch introduced to DMUK in the year 2003, managed and operated by an environment controller/manager involved with the socio-environmental activities, waste segregation and minimisation, recycling and manufacturing process improvement activities. Environmental Department is a newly established branch and consists with a manager and two administrators.

DMUK was unable to arrange discussions with customers and suppliers, hence the case study had to rely on the information given by in-house staff on the customer and supplier perspectives.

The total number of participants interviewed was limited to 20, due to time constraints and busy time schedules for the participants. The company arranged five individual interviews and several group discussions, and allocated 30-45 minute time slots for each interview and discussion sessions.

Table 7.8 shows a correlation of the participant department with the various BSC perspectives for the 20 participants interviewed.

Table 7.8: Participant Responses Matched Against the Different BSC Perspectives

		Participants Department					**Total Responses**
		Production Control Department	Finance Department	Human Resource Department	Purchasing Department	Environmental Department	
Extended BSC Perspectives	Customer Perspective	1	2	-	2	-	5
	Financial Perspective	-	4	-	1	-	5
	Internal Business Processes Perspective	5	-	6	1	-	12
	Employee Perspective	4	3	7	1	-	15
	Supplier Perspective	-	-	-	3	-	3
	Innovation and Growth Perspective	1	-	2	-	-	3
	Environmental Perspective	1	-	-	-	1	2

7.9.3 Summary of Findings from Interviews and AHP Analysis

Table 7.9 presents the summary of findings for the three questions posed for the various perspectives (refer to Section 7.9.2 and Appendix 2) and statements made by participants during the focused interviews. The answers obtained improved the understanding of the extended BSC tool in overall performance measurement of JIT in DMUK. This exercise therefore helped the company to categorise KPIs into the relevant BSC perspectives. The brainstorming sessions were also helpful in assessing the impact of the key JIT drivers on extended BSC perspectives.

Table 7.9: A Summary of Focused Interview Findings in DMUK

Extended BSC Perspective	Question 1 What does your company think about BSC perspective? Did you consider BSC perspective in the mission and vision statements?	Question 2 What are the KPIs you have considered and performance targets set in performance measurement of the BSC perspective?	Question 3 What are the factors affecting BSC perspective?
Customer Perspective	❑ DMUK philosophy is ‘customer first’ ❑ The customer is critical in all decision making processes; customer satisfaction is a key business objective ❑ DMUK’s customers feature strongly in the mission statement	❑ Frequency and number of complaints ❑ Quantity of faulty parts expressed as ‘parts per million’ ❑ Product cost ❑ Warranty cost ❑ On time delivery ❑ Quality ❑ Number of new businesses	❑ Quality ❑ On time delivery ❑ Price of product ❑ Market claim ratio ❑ Customer complaints ratio ❑ Defects of incoming materials ❑ Number of delayed delivery
Financial Perspective	❑ Stakeholders are not considered in the vision or mission statements. It is hidden in the second sentence of the mission statement ❑ Importance of financial stability is indirectly stated as ‘seek continuous growth’, in the company mission statement.	❑ Profitability ❑ Return on investment ❑ Cash flow ❑ Productivity ❑ Sales ❑ Cost reduction	❑ Global market conditions ❑ Increase in price of raw materials such as aluminium and plastics (purchase power) and labour market (head count) ❑ Skill levels ❑ Energy costs ❑ Sales side requests for price reductions ❑ Process, machinery and technology improvements ❑ Poor quality ❑ Mismanagement of company assets such as employees ❑ Inadequate planning ❑ Missed shipments ❑ Production wastes

Contd...

Contd...

Extended BSC Perspective	Question 1 What does your company think about BSC perspective? Did you consider BSC perspective in the mission and vision statements?	Question 2 What are the KPIs you have considered and performance targets set in performance measurement of the BSC perspective?	Question 3 What are the factors affecting BSC perspective?
Internal Business Processes Perspective	❑ Company's philosophy is better productivity and ideology is Toyota production system, reduced lot size and clean manufacturing ❑ Quality and health and safety processes ensured in the business philosophy ❑ Processes are influenced by the mission and vision statement ❑ Internal business processes are very structured and are constantly reviewed. There are procedures for every thing to ensure consistent application. The aim is to try to be consistent in processes across the company ❑ Company received quality awards - ISO14001 and TSI16949	❑ Order lead time ❑ Stock levels ❑ Scrap ratio ❑ Production achievement ratio ❑ Safety mark ❑ Productivity improvement ratio ❑ Added value productivity ❑ Production achievements ❑ Headcount ❑ Overtime	❑ High demand from customer ❑ Drive to become lean ❑ Reduced man power/manning levels ❑ Employee morale, diversity, skills, training, knowledge and recruitment procedures ❑ Machine downtime ❑ Leadership and management styles ❑ External influences (environmental, economic and legislative) ❑ Technology ❑ Communication ❑ Availability of parts
Employee Perspective	❑ Employee perspective is considered in the vision and mission statement ❑ Employees are the most important asset ❑ Employees are at the centre of the all decisions and processes ❑ The revenue per employee per year is about £14,500.00 ❑ The company has implemented working consultation groups and associates meetings to discuss the employee's problems and listen to their suggestions towards performance improvement ❑ The company is conducting training and continuous professional development programmes such as on-job-training, team leader training, induction programmes and people soft skills training as needed ❑ Aims and objectives of these training programmes are to improve task related skills and knowledge, achieve higher anatomy and self-reliance, safe and productive introduction to the role, increase effective communication and working relationships	❑ Attendance ❑ Core competencies ❑ Skill levels and how many skills employees have developed over the time ❑ Length of service ❑ Turnover ❑ Overtime levels ❑ Employee satisfaction survey ❑ Heath survey	❑ Skill competence level ❑ Communication of objectives and needs ❑ Motivation ❑ Language/communication ❑ Time to attend training due to the high demand for production ❑ Quality of supervision/management ❑ Job satisfaction ❑ Working environment ❑ Company culture ❑ Personal factors ❑ Job design and rotation ❑ Recognition ❑ Financial status ❑ Quality pressure

Contd...

Contd...

Extended BSC Perspective	**Question 1** **What does your company think about BSC perspective? Did you consider BSC perspective in the mission and vision statements?**	**Question 2** **What are the KPIs you have considered and performance targets set in performance measurement of the BSC perspective?**	**Question 3** **What are the factors affecting BSC perspective?**
Supplier Perspective	▫ DMUK has internal suppliers (up-stream process lines, who supply WIP parts to the down stream assembly lines) and external suppliers ▫ Suppliers are pillars of the company ▫ Suppliers are not clearly considered in the vision and mission statements ▫ The company uses supplier questionnaire survey to get feedback from supplier ▫ Cost of parts, quality and delivery times are fixed and heavy penalties will be charged for quality defects and delivery delays	▫ Quality ▫ Cost of raw materials/parts supplied by the external suppliers ▫ On time delivery ▫ Supplier questionnaire survey	▫ Cost variations from supplier side ▫ Supplier integration
Innovation and Growth Perspective	▫ DMUK launches new products and introduces major improvements to the existing products and processes whenever a new bid won or model changed ▫ The company launched *"Vision 2010"*, which is a five years plan to be the best and largest HVAC automotive component suppliers in the UK ▫ DMUK's one of the missions is to 'delight the customers through innovation'	▫ Market share by customers ▫ Market share by UK ▫ Market share by Europe	▫ DMUK customer's demands and expectations are high and their demand to reduce cost also high. But material and energy prices are increasing; DMUK is therefore always thinking about Kaizen and investing on continuous innovation and growth
External Socio-Environmental Groups Perspective	▫ DMUK has established a new Environmental Department to take care of all environmental and social issues of the company ▫ The company has developed a new environmental policy ▫ DMUK has obtained ISO 14000 certificate ▫ The company produces noise and nuisance report for the local Council as they request	▫ Noise and nuisance levels ▫ Ordure contamination level ▫ Air emission ▫ Volatile organic compounds ▫ Total particulate matters ▫ Solid waste (target zero land fill) ▫ Recycle, reuse and recovered levels ▫ Spillages ▫ Complaints	▫ There are no financial barriers on implementing environmental and health and safety procedures ▫ Culture is a barrier ▫ Social and environmental policies are legal requirements ▫ Company is currently focusing more on production efficiency than waste minimization

The following conclusions can be drawn from the above findings (refer to Table 7.9):

- DMUK gives due consideration to customer, employee, innovation and growth and external socio-environmental groups perspectives in its mission statements, however financial and internal business processes perspectives are not directly mentioned. Customer satisfaction appears to be the top priority of DMUK business.
- Different production lines and departments appear to use different KPIs to measure performance.
- Quality of products, product delivery schedule, cost of material, labour and energy, leadership and management style, morale, diversity and knowledge all seem to affect DMUK performance.

7.9.4 Analysis of Analytic Hierarchy Process Data

The next step in the multidimensional PMS development process is data analysis using the AHP tool. For all decision alternatives, a geometric mean was calculated from the allocated weights from the participants; the mean for each alternative was considered in the analysis.

AHP analysis with illustrations is given in Sections 7.9.4.1 and 7.9.4.2, and detailed calculations and results of AHP analysis are presented in Appendix 5. Sections 7.9.4.1 to 7.9.4.4 present the conclusions drawn from the AHP analysis.

7.9.4.1 Relative Ranking (1) of BSC Perspectives in terms of Overall Performance

Rationalisation of BSC perspectives with overall performance

The AHP analysis based on Part I of the survey instrument is used to calculate Relative Ranking (1) in order to identify the impact of each extended BSC perspective on overall performance of the company. The performance pairwise comparisons are given in Table 7.10. The weightings of Table 7.10 are then normalised and presented in Table 7.11. The consistency calculations are given in the Table 7.12. The steps of analysis are presented in Appendix 5.

Table 7.10: Pairwise Comparisons of the Extended BSC Perspectives

Step 1.2
Reciprocity Axiom
(1/W_1, e.g: 1/1.825)

Step 1.1
Geometric mean of pairwise
comparison responses (W_1)

Performance Pair-Wise Comparison							
Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective
Customer Perspective	1.000	1.825	2.017	2.067	2.867	1.742	2.325
Financial Perspective	0.548	1.000	1.875	1.917	2.550	1.850	2.550
Internal Business Processes Perspective	0.496	0.533	1.000	1.375	1.908	1.108	1.925
Employee Perspective	0.484	0.522	0.727	1.000	2.117	1.317	1.725
Supplier Perspective	0.349	0.392	0.524	0.472	1.000	0.704	1.208
Innovation and Growth Perspective	0.574	0.541	0.902	0.759	1.420	1.000	1.817
External Environmental Groups Perspective	0.430	0.392	0.519	0.580	0.828	0.550	1.000
SUM	**3.881**	**5.205**	**7.565**	**8.170**	**12.689**	**8.271**	**12.550**

Step 1.3
Sum of the column (S_1)

Table 7.11: Pairwise Normalised Comparisons of the Extended BSC Perspectives

Step 2.1
Matrix element is divided
by its column sum (W_1/S_1)

Step 2.2
Sum of the row
($W_1/S_1 = x_1$)

Step 2.4
An average of row
($x_1/X = Y_1$)

Performance Normalized Comparison									
Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective	SUM	Performance Score
Customer Perspective	0.258	0.351	0.267	0.253	0.226	0.211	0.185	1.750	0.250
Financial Perspective	0.141	0.192	0.248	0.235	0.201	0.224	0.203	1.444	0.206
Internal Business Processes Perspective	0.128	0.102	0.132	0.168	0.150	0.134	0.153	0.969	0.138
Employee Perspective	0.125	0.100	0.096	0.122	0.167	0.159	0.137	0.907	0.130
Supplier Perspective	0.090	0.075	0.069	0.058	0.079	0.085	0.096	0.553	0.079
Innovation and Growth Perspective	0.148	0.104	0.119	0.093	0.112	0.121	0.145	0.842	0.120
External Environmental Groups Perspective	0.111	0.075	0.069	0.071	0.065	0.067	0.080	0.537	0.077
								7.000	

Step 2.3
Sum of the column (X)

RELATIVE RANKING – 1

Table 7.12: Consistency Calculations for Extended BSC Perspectives

Step 3.1
Multiply matrix of comparison by performance score vector to obtain new vector

Step 3.2
Sum of the row (Z_1)

Step 3.3
Ratio between sum of the row and performance score ($Z_1/Y_1=\alpha_1$)

	Performance Normalized Comparison								
Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective	SUM	SUM ÷ Performance Score
Customer Perspective	0.250	0.376	0.279	0.268	0.226	0.209	0.178	1.787	7.150
Financial Perspective	0.137	0.206	0.259	0.248	0.201	0.222	0.196	1.470	7.130
Internal Business Processes Perspective	0.124	0.110	0.138	0.178	0.151	0.133	0.148	0.982	7.098
Employee Perspective	0.121	0.108	0.101	0.130	0.167	0.158	0.132	0.916	7.074
Supplier Perspective	0.087	0.081	0.073	0.061	0.079	0.085	0.093	0.558	7.070
Innovation and Growth Perspective	0.144	0.111	0.125	0.098	0.112	0.120	0.139	0.850	7.070
External Environmental Groups Perspective	0.108	0.081	0.072	0.075	0.065	0.066	0.077	0.544	7.083

The performance score column of Table 7.11 presents the importance of extended BSC perspectives in overall performance measurement. According to the managers' opinions, customer satisfaction (0.250) is the top priority of DMUK. The managers further believe that strong and stable financial status (0.206) is critical for the business to flourish. Internal business processes (0.138), employee (0.130) and innovation and growth (0.120) perspectives have moderate importance levels. Supplier (0.079) and external socio-environmental groups (0.077) perspectives have been given low priorities in the overall performance measurement of the company. Consistency ratio (*CR*) is 0.012 thus lower than the acceptable limit of 0.10 and hence the performance scores are considered as acceptable and consistent.

7.9.4.2 Relative Rankings (2) of Key JIT Drivers in terms of BSC Perspectives

The next step of AHP analysis is the pairwise comparison of key JIT drivers with respect to BSC perspectives. The AHP analysis for customer perspective is presented first with detailed results. The remaining perspectives are discussed here and results are included in Appendix 5.

<u>Rationalisation of key JIT drivers with customer perspective</u>

AHP analysis for the impact of the key JIT drivers on customer satisfaction is given in Tables 7.13, 7.14 and 7.15 respectively. The performance score of Table 7.14 (Relative Ranking (2) for customer perspective) is transferred to the customer perspective row of the overall evaluation table (Table 7.16). The appropriate random index for four alternatives is 0.9 (refer to Table 6.6).

Table 7.13: Pairwise Comparisons of Key JIT Drivers with Respect to the Customer Perspective

Performance Pair-Wise Comparison				
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control Activities
Line Balancing	1.000	2.800	1.500	0.607
Setup Time	0.357	1.000	0.533	0.357
Multifunction Employee	0.667	1.875	1.000	0.473
Quality Control Activities	1.648	2.804	2.113	1.000
SUM	**3.672**	**8.479**	**5.146**	**2.437**

Table 7.14: Pairwise Normalised Comparisons of Key JIT Drivers with Respect to the Customer Perspective

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control Activities	SUM	Performance Score
Line Balancing	0.272	0.330	0.291	0.249	1.143	0.286
Setup Time	0.097	0.118	0.104	0.146	0.465	0.116
Multifunction Employee	0.182	0.221	0.194	0.194	0.791	0.198
Quality Control Activities	0.449	0.331	0.411	0.410	1.600	0.400
					4.000	

RELATIVE RANKING – 2 (For customer perspective)

Table 7.15: Consistency Calculations for Key JIT Drivers with Respect to the Customer Perspective

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control Activities	SUM	SUM ÷ Performance Score
Line Balancing	0.286	0.326	0.297	0.243	1.151	4.027
Setup Time	0.102	0.116	0.106	0.143	0.467	4.012
Multifunction Employee	0.191	0.218	0.198	0.189	0.796	4.023
Quality Control Activities	0.471	0.326	0.418	0.400	1.615	4.037

According to the performance score column of Table 7.14, quality control activities are the most significant factor from the customer perspective. Quality control activities (0.400) are nearly twice as important as multifunctional ability of the associates (0.198) and about 1.5 times as important as line balancing (0.286). The least important JIT technique is setup time elimination plans (0.116). One manager stated, *"Poor quality affects our customers' reputation in the market and also affects sales"*. DMUK has therefore designed a quality assurance process to address the quality related problems. The company has implemented 100% visual and mechanical quality checks and controls in all production lines. As a result, the company spends a lot of time on quality control activities rather than product and process improvement. According to the TQM philosophy, quality should be designed into the product instead of inspected out. Transformation from traditional quality control techniques to a modern TQM philosophy is therefore critical to DMUK in order to reduce time spent on visual quality control. Consistency ratio (*CR*) is 0.009 and hence the performance scores are considered as acceptable and consistent.

Rationalisation of key JIT drivers with financial perspective

During the interviews, one manager from the Purchasing Department mentioned that *"Line balancing is necessary to ensure robust production processes."* A manager from the Finance Department stated, *"Line balancing and multitasking ensure the product gets out quickly with the least amount of disruptions due to breakdowns; job downtimes are reduced, thus reducing costs."* Another manager commented that *"Multifunctional ability reduces workforce and increases productivity and profitability."* According to participants' opinions, improved line balancing and multifunctional ability reduce workforce, operational costs, takt time, increase line productivity and profitability. Line balancing and employee training are investments that will impact positively on long-term return on investment. Quality control, according to a manager will help to improve quality of products, and lead to superior quality products delivered to customers on time. This in turn will increase customer satisfaction, loyalty, sales levels and profit margins. According to participants, line balancing (0.306) is the most important JIT technique from the financial perspective followed by quality control activities (0.286), multifunction employees (0.268) and setup time elimination plans (0.139).

Rationalisation of key JIT drivers with internal business processes perspective

According to performance score, line balancing (0.301) is most influential JIT technique on the internal business processes. The comments and concerns raised during interviews regarding the importance of line balancing are as follows:

- *"Line balancing must be struck between each of the comparators"*
- *"Line balancing is vital to maximise production achievement, reduce waste, maximise efficiency, and work with optimum operator numbers"*
- *"Line balancing improves performance of internal business processes through ensuring the right mix of employees"*

The respondents have given second priority to multifunction employees JIT driver (0.274) for the following reasons:

- *"Having multifunction employees is integral to the performance of any assembly line; line balancing is also vital; if you have a multifunctional team and the correct line balancing, the other factors should follow"*
- *"The employees must know the process and how to do the job; line balancing and quality control will take care of themselves if associates know their jobs"*
- *"Multifunction employees will ensure that quality and setup time are always achieved; poor employees will not produce positive result even if systems are good"*

The respondents have given similar priority to the other two JIT techniques, where they have allocated 0.220 and 0.204 for quality control activities and setup time elimination plans respectively. The company is currently under a quality alert and quality is one of the major driving factors of the business. One manager stated, "*Quality is imperative."* DMUK has recently received TSI 16949 (for the quality standards for automotive industry) accreditations. The company has minimised setup time in most of their process and assembly lines. Setup time therefore has very low impact on the internal business processes perspective.

Rationalisation of key JIT drivers with employee perspective

Multifunctional employee (0.330) is the most important JIT factor with the highest influence on employee perspective. Line balancing (0.305) is also a highly influential JIT technique on the employee perspective. Typical reasons given by the managers for their selected magnitudes are as follows:

- *"Multifunction employees and correct line balancing will address several relevant issues within the production environment"*
- *"Flexible employees who can be rotated in the shop floor will result in the improvement of KPIs"*
- *"Multifunction employees increase performance through increased job satisfaction and motivation and reduced strain and repetitive injuries"*
- *"Employees will perform better if maintenance is carried out on time as their workstation will not breakdown as often. Multifunction employees vary their role, so do not get bored"*

DMUK has sporadic demand for its products. The company has strict production deadlines and therefore has a flexible workforce to achieve those targets. According to the opinions of the respondents, multifunction employees and line balancing are nearly twice as influential as setup time (0.186) and quality control activities (0.178) on the employee perspective. In other words, respondents believe that multifunction employees and line balancing would achieve most of the goals of JIT philosophy.

Rationalisation of key JIT drivers with supplier perspective

From the supplier perspective, quality control is the most critical JIT technique. It generated a performance score of 0.479, which is more than twice that of line balancing (0.219) and multifunction employees (0.212) and more than five times those of setup time (0.089) (Appendix 5). A manager from the Purchasing Department commented that *"From a purchasing point of view, the company needs to know that the suppliers have robust processes, good quality products and employees that can multitask to meet the needs of JIT"*. However, according to most of the top managers, all the external suppliers are dominated by DMUK; product specification, price and delivery times are fixed and heavy penalties will be charged for quality defects and delivery delays. Suppliers have therefore been given very low priority on overall performance measurement. DMUK has over 110 suppliers in the UK and around the world and it was not possible to get comments from external suppliers, since the company was unable to provide any contact details of their external suppliers.

Rationalisation of key JIT drivers with innovation and growth perspective

DMUK has implemented total industrial engineering (TIE) plan (Figure 7.5) in line with the continuous improvement exercise. The company's current innovation and growth priorities are as follows:

- update machinery with modern technology and rearrange assembly lines to reduce takt time, improve line balancing and hence enhance process efficiency
- improve quality of products using innovative concepts and minimise muda
- regular training to improve flexibility and multifunctional ability of associates

It is not surprising that line balancing has been given the highest performance score (0.354) followed by quality control activities (0.311) and multifunction employees (0.222) (Appendix 5). Setup time (0.113) has been assigned the lowest priority from the innovation and growth perspective. During the interview, only one manager rated quality control activities as more important than line balancing. His comment was mainly due to the current high quality alerts set by the company.

Rationalisation of key JIT drivers with external socio-environmental groups perspective of balanced scorecard

DMUK has a good rapport with external socio-environmental groups. The company has developed a new environmental policy and has obtained ISO 14001 (for environmental management systems and standards) accreditation. The participants have therefore given the highest priority to quality control activities (0.469) with respect to the external socio-environmental groups perspective (refer to Appendix 5). This weighting is rated as highly significant compared to line balancing (0.206), multifunction employees (0.170) and setup time elimination plans (0.155).

7.9.4.3 Global Ranking of Key JIT Drivers in terms of Overall Performance

The results of all pairwise matrices were synthesised and yielded the Global Ranking of the key JIT drivers in Table 7.16. The average of each column presents the Global Ranking of the respective JIT driver.

Table 7.16: Overall Evaluation of Key JIT Variables and Extended BSC Perspectives

Overall Evaluation					
Decision Alternatives	Line Balancing	Setup Time Elimination Plans	Multifunction Employees	Quality Control Activities	Weights
Customer Perspective	0.286	0.116	0.198	0.400	0.250
Financial Perspective	0.306	0.139	0.268	0.286	0.206
Internal Business Processes Perspective	0.301	0.204	0.274	0.220	0.138
Employee Perspective	0.305	0.186	0.330	0.178	0.130
Supplier Perspective	0.219	0.089	0.212	0.479	0.079
Innovation and Growth Perspective	0.354	0.113	0.222	0.311	0.120
External Environmental Groups Perspective	0.206	0.155	0.170	0.469	0.077
Overall Priorities for the JIT Variables	**0.292**	**0.143**	**0.242**	**0.324**	

Relative Rankings - 2

Relative Ranking - 1

Global Ranking

According to the global ranking of the JIT variables (Table 7.16), the top priority has been given to quality control activities (QC) (0.324). Though the company's top priority is quality, most of the managers and associates considered it a burden and described it as *"quality pressure"*. According to the analysis, the second most influential JIT technique is line balancing (0.292) followed by multifunction employees (0.242). The least significant factor is setup time elimination plans with an overall weighting of 0.143. These results are discussed in detail in Section 7.10.

7.9.4.4 Consistency of AHP Analysis

The summary of consistency ratios is given in Table 7.17. The appropriate random indexes (RI) for four and seven alternatives (four key JIT drivers and seven balanced scorecard perspectives) are 0.9 and 1.32 respectively (refer to Table 6.6 for RI).

Table 7.17: Summary of Consistency Ratio (CR)

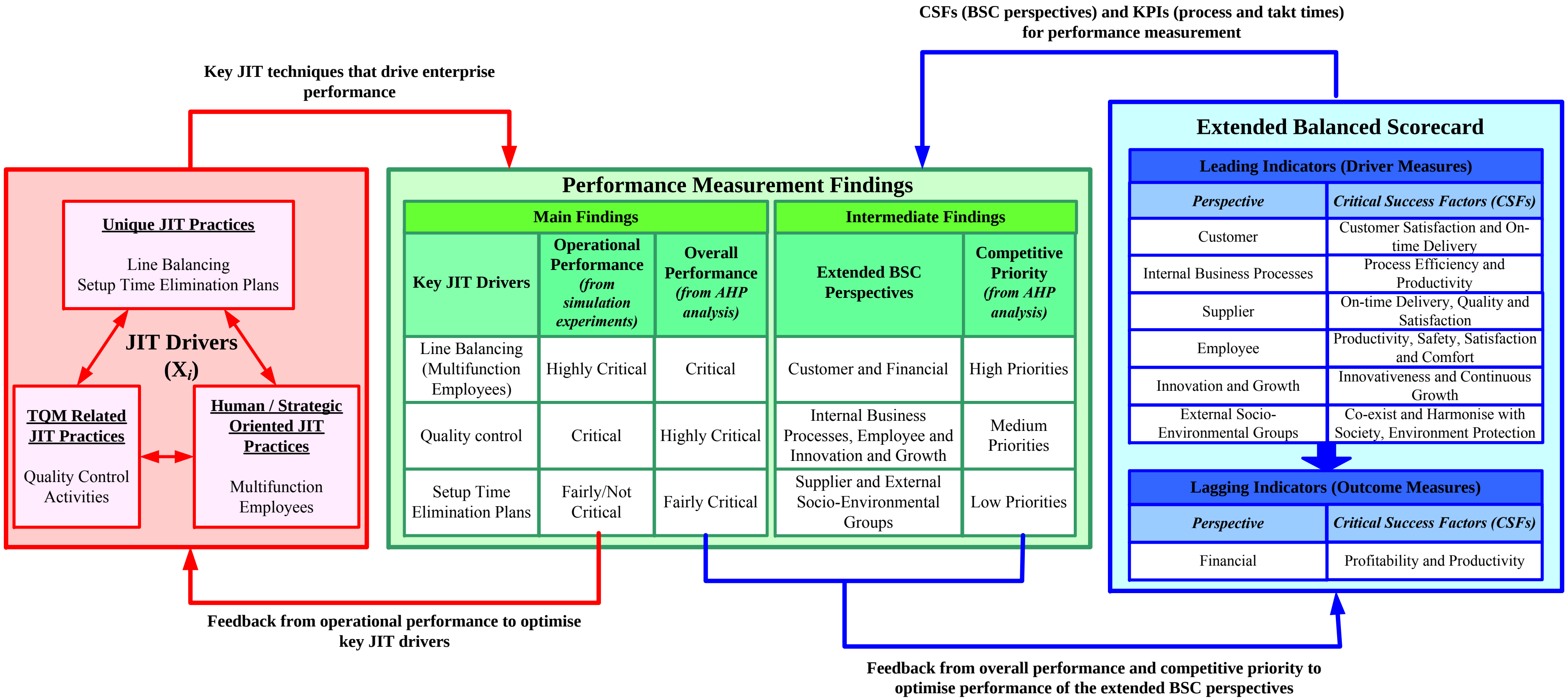
Decision Alternative	Consistency Ratio (CR)
Overall Performance	0.012
Customer Perspective	0.009
Financial Perspective	0.031
Internal Business Processes Perspective	0.013
Employee Perspective	0.016
Supplier Perspective	0.027
Innovation and Growth Perspective	0.014
External Socio-Environmental Groups Perspective	0.020

As can be seen in Table 7.17, the consistency ratios (CR) for all decision alternatives are less than 0.10, which confirms that all performance scores are acceptable and consistent.

7.10 OVERALL ANALYSIS AND RECOMMENDATIONS TO DMUK

It is necessary for DMUK to measure and manage their JIT processes in order to understand and appreciate their operational performance characteristics; to identify key JIT drivers affecting operational performance, assess competitive priorities and goals for future improvements. The customised performance measurement model (refer to Figure 7.13), developed in Section 7.6, was therefore used to identify the most influential JIT techniques affecting operational and overall performance for DMUK. Finally, the customised performance measurement model for DMUK is described in Figure 7.26 and shows identified critical JIT drivers affecting operational performance.

The left side of Figure 7.26 provides the key JIT practices (line balancing, multifunction employees, setup time elimination plans and quality control activities) that drive enterprise performance. The right side shows the extended BSC tool with details of the necessary key performance indicators and critical success factors for performance measurement. The major and intermediate findings of the case study are presented in the middle box. The major findings are broken down into highly, moderately and fairly influential JIT drivers affecting company performance. The intermediate findings present the organisation's competitive priorities based on extended BSC perspectives. The model provides the feedback from operational performance which optimises key JIT drivers. Figure 7.26, further provides feedback from overall performance and competitive priorities which optimise performance of the extended BSC perspectives.


Key JIT techniques that drive enterprise performance
CSFs (BSC perspectives) and KPIs (process and takt times) for performance measurement
Unique JIT Practices
Line Balancing
Setup Time Elimination Plans
JIT Drivers (X_i)
TQM Related JIT Practices
Quality Control Activities
Human / Strategic Oriented JIT Practices
Multifunction Employees
Feedback from operational performance to optimise key JIT drivers
Feedback from overall performance and competitive priority to optimise performance of the extended BSC perspectives

Performance Measurement Findings

Main Findings			Intermediate Findings	
Key JIT Drivers	**Operational Performance** ***(from simulation experiments)***	**Overall Performance** ***(from AHP analysis)***	**Extended BSC Perspectives**	**Competitive Priority** ***(from AHP analysis)***
Line Balancing (Multifunction Employees)	Highly Critical	Critical	Customer and Financial	High Priorities
Quality control	Critical	Highly Critical	Internal Business Processes, Employee and Innovation and Growth	Medium Priorities
Setup Time Elimination Plans	Fairly/Not Critical	Fairly Critical	Supplier and External Socio-Environmental Groups	Low Priorities

Extended Balanced Scorecard

Leading Indicators (Driver Measures)

Perspective	*Critical Success Factors (CSFs)*
Customer	Customer Satisfaction and On-time Delivery
Internal Business Processes	Process Efficiency and Productivity
Supplier	On-time Delivery, Quality and Satisfaction
Employee	Productivity, Safety, Satisfaction and Comfort
Innovation and Growth	Innovativeness and Continuous Growth
External Socio-Environmental Groups	Co-exist and Harmonise with Society, Environment Protection

Lagging Indicators (Outcome Measures)

Perspective	*Critical Success Factors (CSFs)*
Financial	Profitability and Productivity

Figure 7.26: A Summary of Overall Findings from DMUK Case Study

As shown under the main findings in Figure 7.26, line balancing and multifunction employees are the most influential JIT drivers on operational performance of DMUK; quality control activities has medium influence, while setup time elimination plans have marginal influence on operational performance. From Table 7.6, it can be seen that all the main and interaction effects of line balancing (multifunction employees), setup time elimination plans and quality control activities on process time are significant. Line balancing (multifunction employees) affects process and takt times significantly compared to quality control activities.

Feedback received from the managers (Figure 7.26 and Table 7.16) show that quality control activities is the most critical JIT driver in overall business performance for DMUK. Line balancing and multifunction employees have medium significance while setup time elimination plans has low significance on overall company performance. It can also conclude that the customer and financial perspectives are the company's top competitive priorities. It also appears internal business processes, employee and innovation and growth perspectives are medium priorities while supplier and external socio-environmental groups perspectives are low priorities for DMUK.

While shop floor managers try to improve process efficiency, top managers strive to improve quality of products and reduce cost of production in order to compete with rival brands. As a result, all the decisions of top managers are built around quality improvement and cost reduction, rather than process improvement. Production managers insist that all shop floor managers and associates must pay full attention to quality control. In order to satisfy the quality needs of the customers, the company has implemented the quality assurance process; i.e. 100% visual quality control at each assembly or process station along with formal visual and mechanical quality checks at specific stations. This is in stark contrast to the TQM concept, where it is believed that quality should be built in at the front of the process, rather than inspected in after manufacture.

According to intermediate results, financial stability and profitability are secondary priorities for DMUK. The shop floor managers are therefore currently under relentless pressure from the company's financial controllers to reduce waste and number of associates in order to reduce the cost of production. Due to excessive production demand, line managers simply tend to reduce the number of associates (number of work stations), instead of implementing proper line balancing and process improvement tools to make full use of multifunctional skills.

The quality assurance process and reduced number of associates (work stations) could improve the quality of products and profitability respectively. However, this will also eventually increase process time and give rise to a negative impact on the manufacturing process performance. It is therefore essential to strike a balance between both operational and overall competitive priorities in order to optimise the performance levels.

The following recommendations are aimed at improving both process efficiency and overall performance of DMUK:

- Process and takt times can be reduced (according to Tables 7.4 and 7.5, *TT* and *PT* can be reduced by approximately 36% and 22% respectively on heater assembly line 3) by applying optimal line balancing and employing multifunctional associates; therefore, the company can increase production capacity, productivity and hence profitability (assuming the extra assembly stations can be manned by present employees) by introducing more assembly stations or more multifunctional employees
- Process and takt times can be reduced (according to Tables 7.4 and 7.5, *TT* and *PT* can be reduced by approximately 3% and 7% respectively on assembly line 3) by building quality into the product and process rather than inspecting it in
- Process time can be further reduced by reducing setup time

This analysis therefore provides DMUK with enough grounds to undertake strategic investment decisions such as re-arranging the assembly line (e.g. U-shape conveyor arrangement) to optimise performance and developing associates multi functional capabilities to enhance the existing portfolio. Improvement of the main assembly line and the down stream process lines, development of the associate skill levels and implementation of an advanced integrated supplier network will take care of the quality of their products.

In summary, Figure 7.26, Tables 7.6 and 7.16 will facilitate top, middle and floor level managers in collective decision making to optimise the company performance.

7.11 SUMMARY

The aim of Chapter 7 was to test and validate the conceptual model, which was developed during Phase I of this research study by applying it to a leading automotive component manufacturer in the UK (DMUK). From the evidence provided by the study, it was found that, in order to apply the paradigm of JIT manufacturing, components must be well coordinated to enable consistent, constant and uniform assembly times at each station in an ideal JIT environment. However, the study has shown that variables such as inconsistent task distribution, variability of operator performance, misconception of total quality management philosophy and lack of setup time elimination plans disrupted ideal JIT production in this case manufacturing environment. Design of experiments and ProModel simulation software have been used to simulate different experimental scenarios in order to validate the model and to quantify the impact of input key JIT factors (i.e. line balancing, multifunction employees, setup time elimination plans and quality control activities) on objective functions such as process and takt times. Moreover, the AHP tool has been used to identify the key JIT factors affecting the overall business performance and organisational competitive priorities.

In summary, the following conclusions and recommendations are made to help DMUK to improve their competence levels and enhance operational and strategic business performance:

- Line balancing, multifunction employees, setup time elimination plans and quality control activities are the key JIT drivers while process and takt times are the key performance indicators for operational performance of DMUK.
- Line balancing and multifunction employees are the most influential JIT drivers on operational performance, while quality control activities has medium influence.
- All the main and interaction effects of the key JIT drivers on process time are significant; setup time elimination plans and it's interactions with other drivers have very low influence on process time.
- Since the weightings of the performance perspectives are based on a ratio scale, customer and financial perspectives can be interpreted as being almost

twice as important as internal business processes, employee, and innovation and growth perspectives and three times as important as the supplier and external socio environmental groups perspectives of the scorecard.

- Quality control activities and line balancing can be interpreted as more than twice and multifunction employees as more than 1.5 times as important as setup time elimination plans in overall performance measurement.
- Operational performance can be optimised by implementing line balancing techniques, quality control tools, setup time elimination plans coupled with developing multifunctional ability of existing employees.
- It is essential that DMUK reviews its vision, mission strategy and core competencies and incorporate all BSC perspectives in order to achieve a balanced performance scorecard.
- The performance measures summarised in Table 7.9 should be equally measured in every assembly/process line and communicated throughout the company. This will facilitate performance appraisal, benchmarking, rewards and recognitions for improved performance. It will further help in identifying any underperforming production processes and in revising the conceptual performance measurement model in order to identify and improve key JIT drivers affecting system performance in the continuous improvement exercise.

It can also be concluded that the performance measurement model can be used as a tool to optimise JIT manufacturing performance and to generate strategic decisions on investment, process improvement, capability development, diversification with regard to new customers/markets and delivery of innovative products to customers, promote supplier integration and sustainable production.

The conceptual model has now been successfully tested and validated using this case study. The next chapter will apply the performance measurement model to a non-automotive small and medium enterprise.

CHAPTER 8: APPLICATION OF PERFORMANCE MEASUREMENT MODEL IN A NON-AUTOMOTIVE PRODUCTION ENVIRONMENT

8.1 INTRODUCTION

Chapter 8 reports the application of the performance measurement model to a non-automotive JIT enabled manufacturing environment. The company selected for the application is Risane Ltd., a small and medium enterprise (SME) that provides innovative products to the packaging industry. The objective of the second case study, which is based on action research, is to investigate the applicability of the proposed model to a JIT enabled non-automotive, small and medium production environment. Section 8.2 gives an introduction to the company, while Section 8.3 presents the application of the eight-step approach to Risane Ltd. in order to: (i) identify key JIT drivers (X_i) and quantify their impact on operational performance (Y), (ii) assess the strategic influence of key JIT drivers on extended BSC perspectives, business competitive priorities and overall performance, and (iii) compare operational and overall performance results and provide recommendations to Risane Ltd. for process management and performance optimisation.

8.2 INTRODUCTION TO THE COMPANY: RISANE LTD.

Risane Ltd. is a solutions company, which was founded in 2003 as a small and medium enterprise (SME) with the simple objective of providing innovative solutions to the packaging industry. The company’s core skills are built around material science and design process engineering, and its vision is *“to continuously improve our individual and combined performances so that, as a team, working smarter, we can delight our customers, in a safe and profitable manner, keeping Risane Ltd. ahead of the competition”*. The company’s aim is to listen to the needs of the customers and work as fast as possible to develop innovative solutions in an efficient and cost-effective manner. Risane Ltd. has about 200 active customers in Belgium, Denmark, Finland, France, Ireland, Poland, Portugal, Spain and the UK and has sales offices in Poland, Spain and South Africa.

Risane Ltd. is a fast growing company with 80 employees and it achieved a turnover of £3.7 million in the year 2006. The company is continuously changing and improving products and production processes according to their customers' requirements and has increased turnover by a factor of 51 over the last four years. The company is managed by shared culture and not by command or control.

Risane Ltd. manufactures a range of packaging and other products including absorbents, bio-degradable, bio-compostable, microwaveable and ovenable and protective materials for a number of food and other applications such as boneguard products and dental and medical products. The manufacturing plant is scattered over three different building units within one site as shown in Figure 8.1.

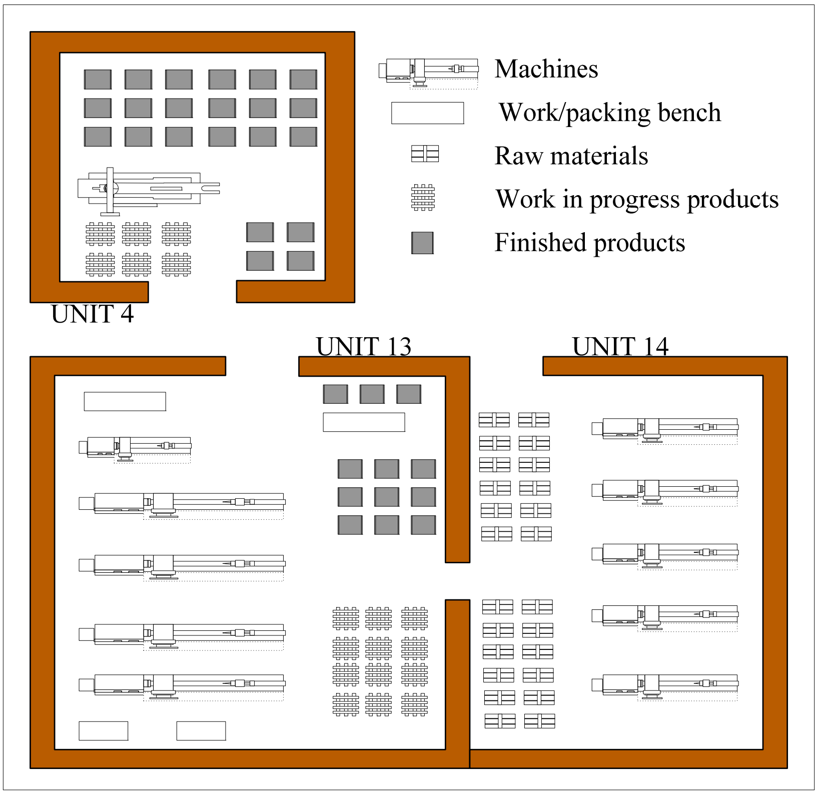


Figure 8.1: Plant Layout of Risane Ltd.

Some products are only processed by one machine before being sent to a final customer, while the other products are processed by one machine and then sent to another machine or to an outsourced company for further processing before going on to the customer.

The company's manufacturing and development operations have implemented some JIT techniques, and lean and flexible manufacturing principles to produce high quality products within a short lead-time to provide an exceptional service to the customer. The production processes have implemented typical tools and techniques such as line balancing, setup time elimination plans, quality control, group technology, total productive maintenance, multifunction employee, integrated product and process design, and innovation and investment plans. However, the production processes still faced problems due to extended process times and lead times for various unknown reasons.

The performance measurement model is applied to Kepak Rustler Inserts packaging material production process. The manually operated production process consists of three machine operators, two other workers at a packing bench and a supervisor. This mixed model manufacturing process produces three types of products namely, long, square and speedy inserts. The machines are located in three different building units and products are moved using pump trucks. The company does not have an in-house printing facility and hence printing is currently outsourced to an outside organisation. The Kepak Rustler inserts production process layout (with photographs) and flowchart are shown in Figures 8.2 and 8.3 respectively. One batch of products is 3,135,000 units of Kepak Rustler inserts made up of 38 reels each of 2500m length boards and suscepters.

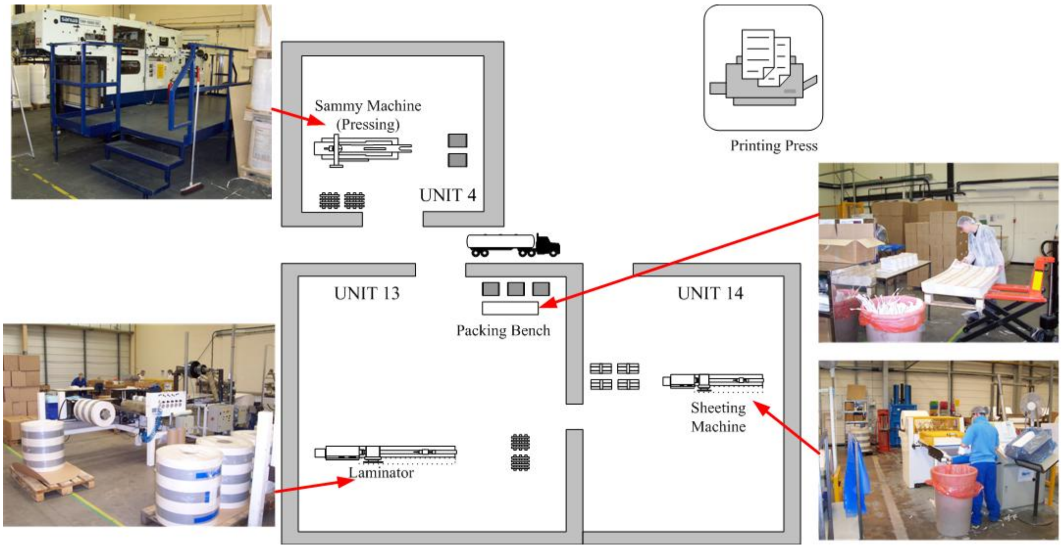


Figure 8.2: Kepak Rustler Inserts Production Process Layout

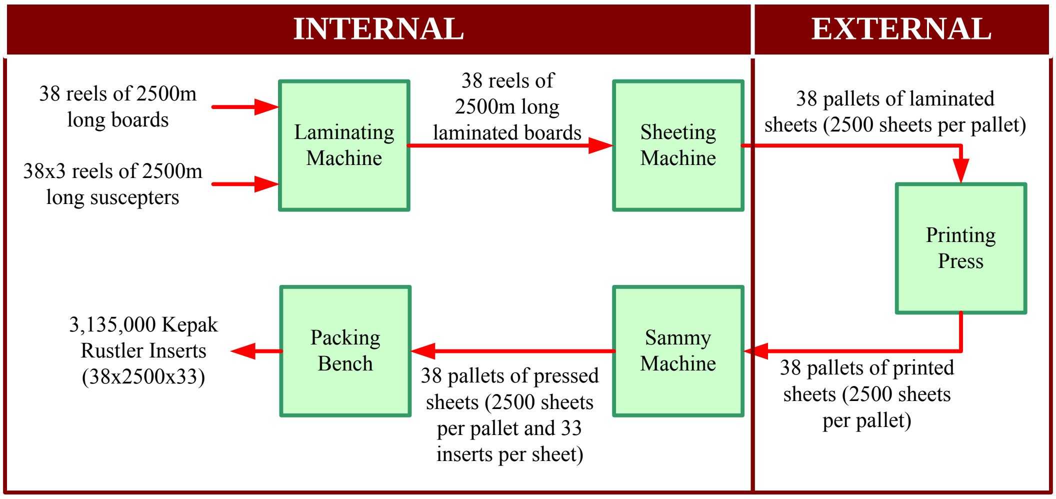

INTERNAL
EXTERNAL
38 reels of 2500m long boards
38x3 reels of 2500m long suscepters
Laminating Machine
38 reels of 2500m long laminated boards
Sheeting Machine
38 pallets of laminated sheets (2500 sheets per pallet)
Printing Press
38 pallets of printed sheets (2500 sheets per pallet)
Sammy Machine
38 pallets of pressed sheets (2500 sheets per pallet and 33 inserts per sheet)
Packing Bench
3,135,000 Kepak Rustler Inserts (38x2500x33)

Figure 8.3: Kepak Rustler Inserts Production Process Flowchart for One Batch

The following section presents the application of the performance measurement model implementation procedure to the Kepak Rustler inserts production process.

8.3 APPLICATION OF MULTIDIMENSIONAL PMS DEVELOPMENT PROCESS TO RISANE LTD.

8.3.1 Determination of Key JIT Drivers and KPIs of the Kepak Rustler Inserts Production Process

Risane Ltd. has experienced long production process times for various reasons and Figure 8.4 depicts the detailed possible causes for this problem. Ten major factors were identified using documents, observations and open-ended interviews with managers and operators (Appendix 7 presents a typical informal interview / discussion transcription). The critical factors affecting process time are positioning of machinery, machine idle time, high setup time, inadequate machine integration, high labour idle time, unrealistic customer demand, inefficient line balancing, large batch size, lack of automation and outsource printing.

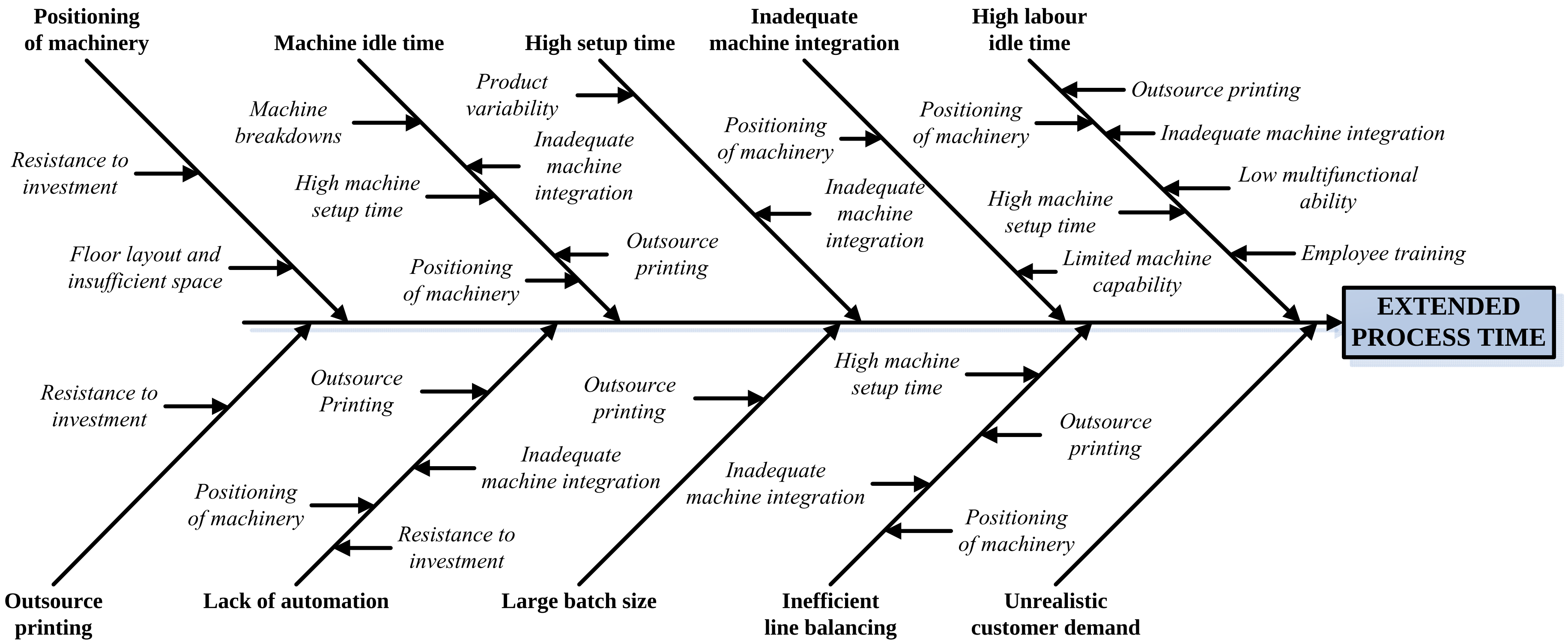


Figure 8.4: Cause and Effect Diagram Analysis for Process Time for Risane Ltd.

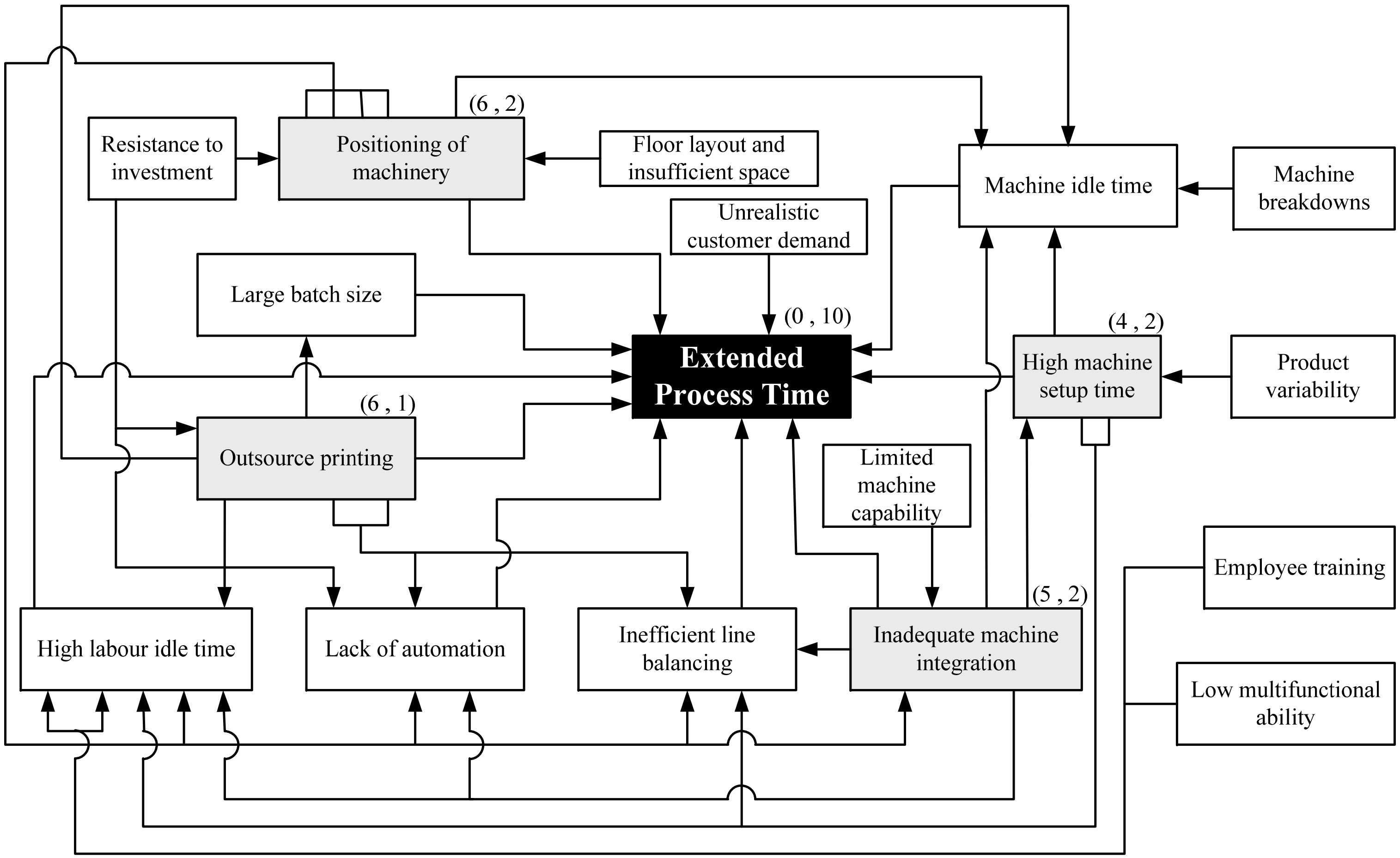


Figure 8.5: Relations Diagram Analysis for Identification of Key Factors Affecting Process Time for Risane Ltd.

Relations diagram analysis was subsequently carried out to identify key drivers for the process time (Figure 8.5). According to the relations diagram for Risane Ltd., "extended process time" was a major concern (key performance indicator) with ten causes (0, 10); "positioning of machinery", "outsource printing", "inadequate machine integration" and "high machine setup time" were identified as key causes with values (6, 2), (6, 1), (5, 2) and (4, 2) respectively. Both literature (refer to Chapter 2) and informal discussions with managers were used to identify key JIT drivers and relevant variables to represent the aforementioned four factors in the simulation model. The key JIT drivers and variables for Risane Ltd. are summarised in Table 8.1.

Table 8.1: Key JIT Drivers and Variables Affecting Process Performance

Factor	Key Cause of Extended Process Time	Key JIT Driver of Process Time	Variable
A	High machine setup time	Setup time elimination plans	Setup time
B	Inadequate machine integration	Group technology – 1	Number of workstations
C	Outsource printing	Innovation and investment plans	Printing option
D	Positioning of machinery	Group technology – 2	Location of workstation/ machinery

These four key JIT drivers were then integrated into the customised performance measurement model (Figure 8.6) for further investigation.

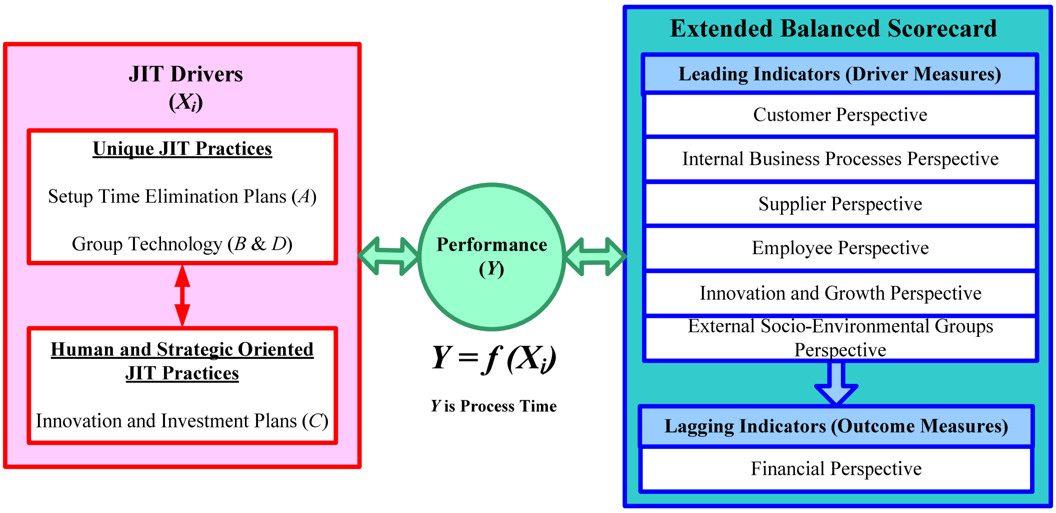

JIT Drivers
(X_i)
Unique JIT Practices
Setup Time Elimination Plans (A)
Group Technology (B & D)
Human and Strategic Oriented JIT Practices
Innovation and Investment Plans (C)
Performance
(Y)
$Y = f(X_i)$
Y is Process Time
Extended Balanced Scorecard
Leading Indicators (Driver Measures)
Customer Perspective
Internal Business Processes Perspective
Supplier Perspective
Employee Perspective
Innovation and Growth Perspective
External Socio-Environmental Groups Perspective
Lagging Indicators (Outcome Measures)
Financial Perspective

Figure 8.6: Customised Performance Measurement Model for Risane Ltd.

8.3.2 Experimental Design and Linear Mathematical Modelling

The customised performance measurement model was then applied to the Kepak Rustler inserts production process to assess the impact of key JIT drivers (Table 8.1) on process time. The four factor linear mathematical model developed for Risane is as follows:

$$Y = a_0 + a_1A + a_2B + a_3C + a_4D + a_5AB + a_6AC + a_7AD + a_8BC + a_9BD + a_{10}CD + a_{11}ABC + a_{12}ABD + a_{13}ACD + a_{14}BCD + a_{15}ABCD + \varepsilon \quad \text{… Eq: 8.1}$$

Where, Y: process time (KPI)

a_0: intercept coefficient

a_1 to a_4: main effect coefficients

a_5 to a_{10}: two way interaction coefficients

a_{11} to a_{14}: three way interaction coefficients

a_{15}: four way interaction coefficient

A, B, C and D: JIT drivers (variables) (refer to Table 8.2)

ε: error term

A two level full factorial design was developed and the number of simulation experiments was determined as $2^4 = 16$. Table 8.2 shows the factors considered for experimental design as well as the levels at which the experiments were run.

Table 8.2: Factors and Levels for Experimental Design

Factor	Variable	Lower Value (L)	Upper Value (H)
A	Setup time	Ten minutes	One hour
B	Number of work stations	Three work stations	Four work stations
C	Printing option	In-house printing	Outsource printing
D	Location of workstation/ machinery	Single location	Several locations

The following subsections describe the reasons for selecting these lower and upper values in the experimental design.

8.3.2.1 Setup Time Elimination Plans (Setup Time)

The lower setup time is defined as ten minutes when there is a change between two batches of a similar product family. The upper value is defined as one hour when there is a change between two batches of distinct families.

8.3.2.2 Group Technology – 1 (Number of Workstations/Machinery)

The Rustler inserts production process currently consists of three flexible process machines (laminator, sheeting machine and Sammy machine) and a packing bench. The upper number of workstations was therefore defined as four. During discussions with the Managing Director (Innovations), the researcher identified the possibility of merging the laminator and sheeting machines. The lower value was defined as three workstations, where there are two process machines (integrated machine and Sammy machine) and a packing bench.

8.3.2.3 Innovation and Investment Plans (Printing Option)

Risane Ltd. currently outsources printing to an external printing company. The Managing Director (Operations and Sales) expressed willingness to invest in new printing facilities during the interview sessions. Thus the upper value was defined as outsource printing, while the lower value was defined as in-house printing.

8.3.2.4 Group Technology – 2 (Location of Workstation)

The machines are currently located in three different buildings. Managers suggested that all machines could be positioned in one location. Hence, the upper value was defined as several locations and the lower value as a single location.

8.3.2.5 Process Time

Process time is the total time taken to produce one assembly schedule. It is comprised of setup time, in-house activity time, move time within factory floor, loading/unloading time, transport time to/from printing press, printing time and inspection time. The number of product units in one assembly schedule is:

$$\begin{aligned} \text{One assembly schedule} &= 38 \ \text{pallets} \times 2500 \ \text{sheets per pallet} \times 33 \ \text{inserts per sheet} \\ &= \underline{\underline{3{,}135{,}000 \ \text{Inserts}}} \end{aligned}$$

8.3.3 Modelling and Simulation

ProModel simulation software was applied to Risane Ltd. to optimise process time and the following assumptions were incorporated into the simulation model:

- raw materials are always available at the raw material storage point
- machine failure and repair times are ignored, while preventive maintenance is carried out during non-productive hours
- the model includes quality inspection, where there is a one percent chance that a part will be found to be defective, which is acceptable
- waiting time at the outsource company is ignored
- the first come first served (first-in-first-out) rule is applied
- the production process works under ideal JIT conditions

Simulation experiments started with determination of setup times, activity times for the in-house production processes, loading/unloading times and inspection times at each workstation; data were collected using a stopwatch. Delivery times between Risane Ltd. and the printing company were taken from transport logbooks. An average of ten stopwatch readings was taken for the process time for each activity. According to printing company information, the printing rate is approximately 7000 sheets per hour.

Table 8.3 contains the activity time breakdown and Stat::Fit analysis data for the Kepak Rustler inserts production process.

Table 8.3: Activity Time Breakdown and Stat::Fit Analysis Results

Product: Kepak Rustler Inserts		Activity Time for each Operation (Minutes)										Normal Distribution (Mean, Standard Deviation)
Location	**Elemental Operation**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	
Laminator	Laminating 2500m board and suscepters	245	260	255	265	270	255	260	245	265	240	N(256, 9.43)
Sheeting Machine	Sheeting 2500m laminated board	114	112	116	118	124	120	117	113	119	115	N(117, 3.43)
Loading/ Unloading Bay	Loading/unloading of 38 pallets	55	60	70	58	63	46	73	62	58	67	N(61.2, 7.39)
From Risane Ltd. to Printing Press	Delivery time	145	160	150	135	170	165	150	130	155	165	N(153, 12.5)
Printing Press	Printing time for 2500 laminated sheets	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5
Sammy Machine	Pressing time for 2500 printed sheets	42	40	45	41	42	43	44	42	43	40	N(42.2, 1.54)
Packing Bench	Packing time for 33*2500 inserts	170	165	162	179	164	172	169	167	174	168	N(169, 4.8)

The Stat::Fit data summarised in Table 8.3 was used to develop simulation models and to establish the relationship between JIT drivers and line performance. The production process background was then designed and model elements such as locations, entities, path networks, resources, processing and arrivals were defined. The following is a brief description of each model element:

- ***Location*** – Locations were included for all raw materials, work in progress and finished products storage points, machinery, printing press, packing bench, loading and unloading bays. All locations were assigned by first-in-first-out input-output rule and the capacity of the product storage locations was defined as 38 units.
- ***Entities*** – The simulation model included three entities: raw materials (reels), work in progress (reels/sheets) and finished inserts. One batch size of finished inserts was set to 3,135,000 inserts.
- ***Path Networks*** – Paths were positioned between all locations. '*Distance*' was selected as the basis for measuring movement time along the path networks within Risane Ltd. '*Time*' was selected as the basis for measuring transport time between Risane Ltd. and the printing company.
- ***Resources*** – The simulation model included two dynamic resources: machine operators and a truck. The speed of an operator was defined as 50 metres per minute.
- ***Processing*** – The following statements and functions were used for the process programming:
    - WAIT {*time expression*} – Delays further processing of the entity until the specified time has elapsed
    - MOVE WITH {*resource*} FOR {*time*} THEN FREE – Used to move an entity using a designated resource
    - ACCUM {*expression*} – Accumulates, without consolidating, the specified quantity of entities at a location
    - GROUP {*expression*} AS {*entity name*} – Temporarily consolidates a specified quantity of entities into a single group shell entity
    - UNGROUP – Separates entities that were grouped with the GROUP statement (ProModel, 2003)

- ***Arrivals*** – Arrivals were defined for two batches of Kepak Rustler inserts products (two batches of the same or distinct families). The number of occurrences was defined as 38 and setup time was defined under '*offset*'.

Simulation experiments were conducted for two batches of 3,135,000 inserts; 16 experiments were simulated, each with ten replications. Figure 8.7 presents a typical screenshot of experiment with ProModel. Please refer to Appendix 4 for typical programming and results of experiments.

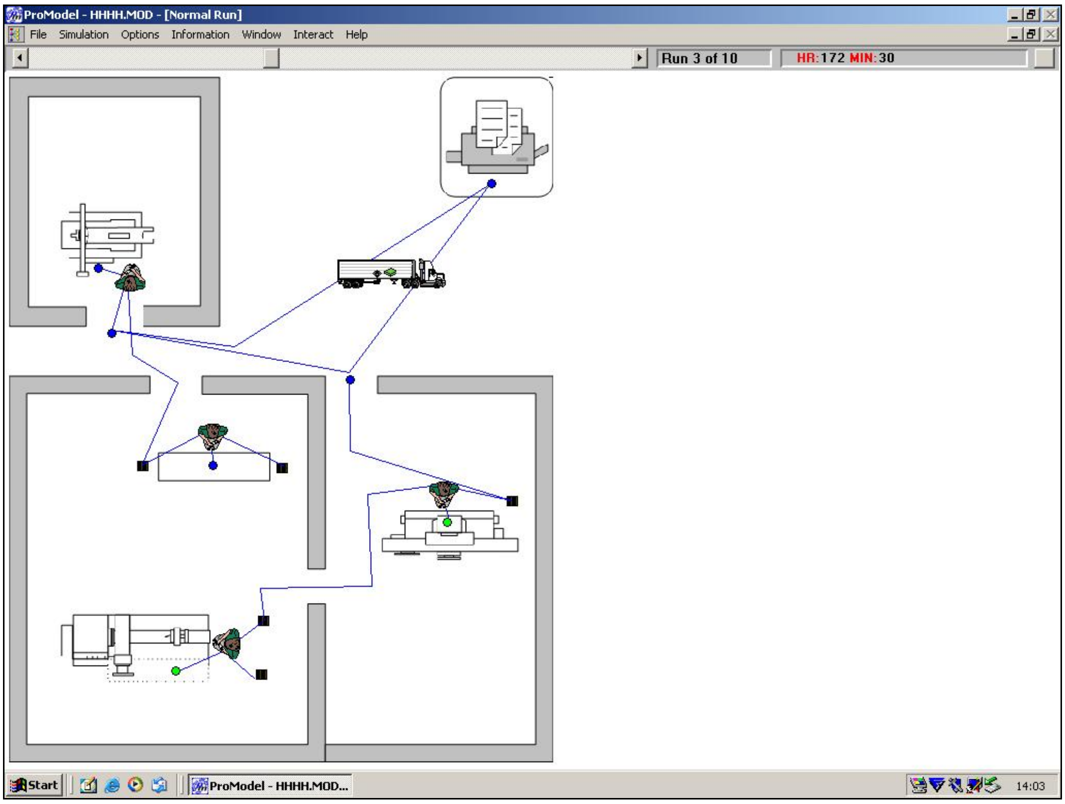


Figure 8.7: Typical Screenshot of Experiments with ProModel

8.3.4 Simulation Results Analysis and Mathematical Modelling

In this study, each experiment was simulated with ten replications and the minimum and maximum results were selected for performance analysis. Table 8.4 shows the combination matrix for 2^4 full factorial design with output as process time, for two replications each in a Kepak Rustler inserts production process.

Table 8.4: Experimental Trials and Results for 2^4 Full Factorial Design

Response	Setup time elimination plans (*A*)	Group technology – 1 (*B*)	Innovation and investment plans (*C*)	Group technology – 2 (*D*)	Process time (Hours)	
					Replication 1	Replication 2
R1	H	H	H	H	460.13	463.82
R2	H	H	H	L	460.33	464.95
R3	H	H	L	H	334.02	338.07
R4	H	H	L	L	333.61	337.13
R5	H	L	H	H	460.17	461.49
R6	H	L	H	L	459.05	461.63
R7	H	L	L	H	333.50	333.74
R8	H	L	L	L	332.70	333.45
R9	L	H	H	H	459.30	462.98
R10	L	H	H	L	459.79	461.65
R11	L	H	L	H	333.18	337.23
R12	L	H	L	L	332.76	336.29
R13	L	L	H	H	459.34	460.65
R14	L	L	H	L	458.21	460.80
R15	L	L	L	H	328.47	332.67
R16	L	L	L	L	331.86	332.62

According to Table 8.4, the average difference between process times from R1 to R8 and from R9 to R16 respectively is less than an hour, which is due to the setup time (*A*) applicable to experiments from R1 to R8. Further, the average change in the process time responses to JIT variable group technology-1 (*B*) from its higher value to lower value while holding the other factors fixed is slightly higher than an hour. Therefore it can be concluded that simple replacement of laminator rewind time with sheeting time will not generate a significant impact on the process time. If the formula defined under Eq:7.2 is applied with the data given in Table 8.3 to calculate the impact of innovation and investment plans (*C*), the process time is as follows;

For higher value,

To produce 38 pallets of laminated sheets ≈ *(256 X 37) + 373*
≈ *9845 Minutes*
For outsourced printing of 38 pallets ≈ *(61.2 X 4) + (153 X 2) + (21.5 X 38)*
≈ *1367.8 Minutes*
*To produce 33*2500 inserts* ≈ *(169 X 37) + 211.2*
≈ *6464.2 Minutes*
∴Total PT of two sequential batches ≈ *((9845 X 1) + 17677 + 10)/60 Hours*
≈ *458.9 Hours*

For lower value,

Total PT of two sequential batches ≈ *((256X37)+(256+117+21.5+42.2+169)+10)X2*

≈ *20175.4/60 Hours*

≈ *336.3 Hours*

The above values are in line with the results of Table 8.4. Therefore it is evident that the innovation and investment plans (*C*) has a significant impact on process time. The difference between the process time of upper and lower value of group technology-2 (*D*) hardly shows any change. This reflects that the movement time (in minutes) of WIP between process machines is negligible compared against the overall process time, which is in hours.

Having observed very high influence of innovation and investment plans on process time, a fresh set of experiments were carried out by ignoring outsourced printing (i.e. transportation between Risane and printing press and loading/unloading time) and analysed the impact of other three variables. These experimental results were also very much closer to the results of Table 8.4.

Statistical analysis and factorial fit for the above experiments are presented in Table 8.5. Analysis of main effect, and two-way, three-way and four-way interactions were obtained at a 0.05 significance level (α).

Table 8.5: Factorial Fit for Process Time

Key JIT Drivers and Interactions *(A: Setup time elimination plans, B: Group technology – 1, C: Innovation and investment plans, and D: Group technology – 2)*	**Process Time (Hours)**	
	Coefficient	***p* Value**
Intercept	397.362	0.000
A	0.625	0.117
B	1.090	0.011
C	63.531	0.000
D	0.060	0.875
AB	- 0.070	0.856
AC	- 0.072	0.852
AD	0.070	0.854
BC	- 0.365	0.347
BD	0.078	0.838
CD	0.032	0.934
ABC	0.205	0.593
ABD	- 0.207	0.591
ACD	- 0.206	0.592
BCD	- 0.232	0.547
ABCD	0.071	0.853

According to Table 8.5, p values for main effects of group technology – 1 (B), and innovation and investment plans (C) on process time are both less than 0.05 (α). These two factors are therefore deemed statistically significant. All the other main and interaction effects are not statistically significant. For the case company, the effect coefficient of innovation and investment plans show the highest statistical significance and it has the greatest impact on process time. Moreover, process time decreased slightly when laminator and sheeting machines were grouped together. Although setup time (A) and group technology – 2 (D) are not statistically significant, process time reduces when setup time and location of machinery change from their upper to lower values. The aforementioned statistically significant factors are then built into the regression equation.

Based on the factorial fit analysis for the process time (Table 8.5), the following regression equation (Eq: 8.2) was derived:

$$\boldsymbol{Process\ Time = 397.362 + 1.09B + 63.531C} \quad \text{..................................} \quad \textbf{Eq: 8.2}$$

Where, B: Group technology-1 (number of work stations)
C: Innovation and investment plans (printing option)

The main effects, interactions and normal probability plots, for α = 0.05 are shown graphically in Figures 8.8 (a), (b) and (c) respectively.

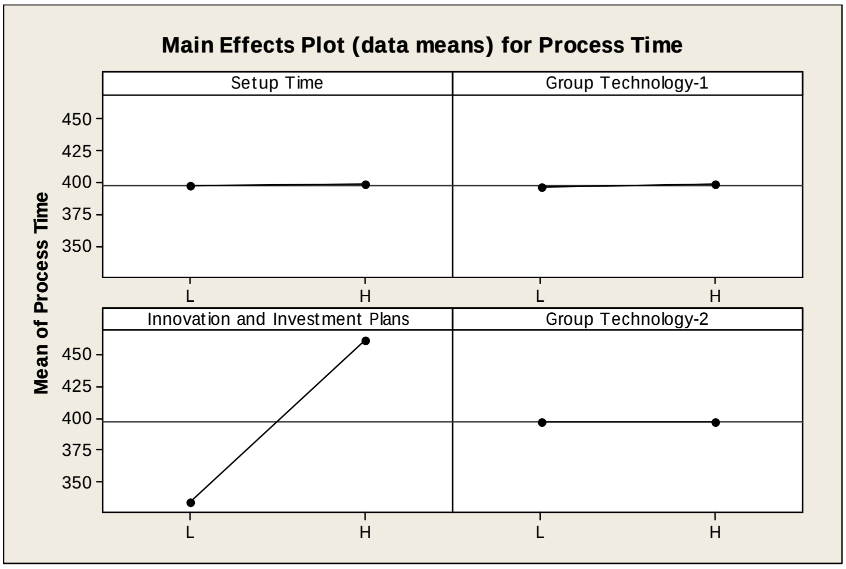


Figure 8.8 (a): Main Effects of Key JIT Drivers on Process Time

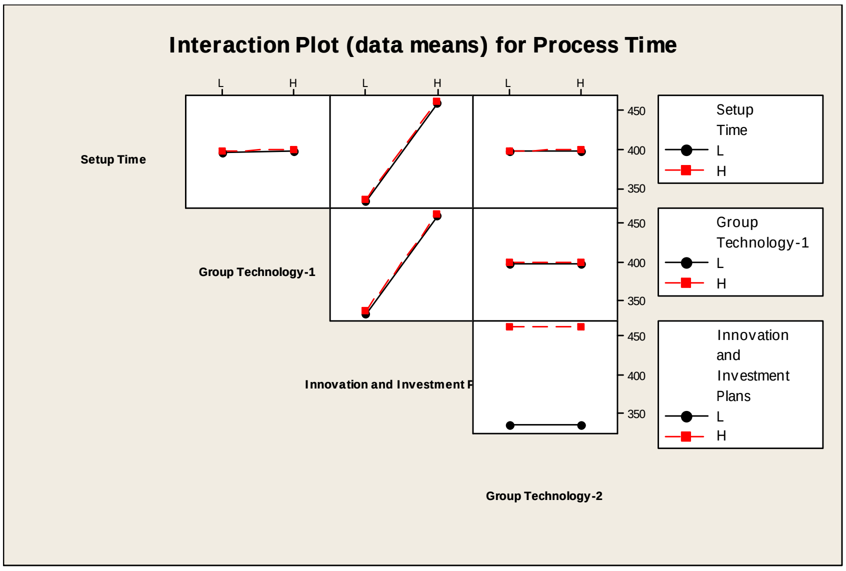


Figure 8.8 (b): Plot of Interactions of Key JIT Drivers on Process Time

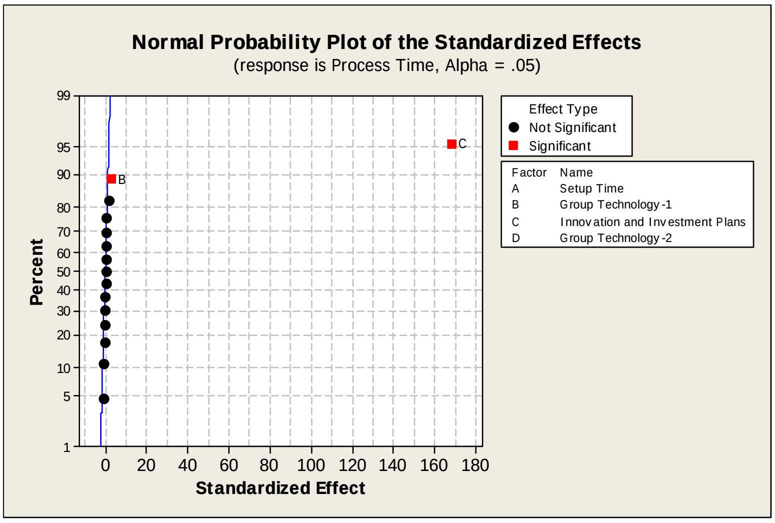


Figure 8.8 (c): Normal Probability Plot for the Standardised Effects on Process Time

Based on Table 8.5 and Figures 8.8 (a), (b) and (c) above, the following conclusions can be drawn:

- Figure 8.8 (a) confirms that the main effect of innovation and investment plans (printing option) on process time is highly statistically significant and the main effects of the other factors are not statistically significant. Subcontracted printing led to higher process time than in-house printing.

- According to Figure 8.8 (b), there are no statistically significant interactions between key JIT drivers.
- Figure 8.8 (c) confirms the results of Table 8.5, and shows two statistically significant effects. Innovation and investment plans (printing option) has the highest significance on process time while group technology-1 (number of work stations) is a slightly less significant factor.
- Process time can be reduced by approximately 27% through in-house printing (Table 8.5). Process time, therefore, can be optimised by investing on in-house printing facilities. Installation of in-house printing facilities may require high initial investment, but can yield considerable long-term benefits such as smoother production line, reduced process time, lot size, scrap and waste, and improved quality, productivity and profitability.
- Process time can also be minimised by integrating laminator and sheeting machines. It is therefore recommended that laminator rewind time is replaced with sheeting time; hence, the activity time of the new integrated machine is equal to the activity time of the laminator.
- Process time can be further reduced by minimising or completely eliminating setup time.
- Moreover, process time can be optimised by positioning all in-house machinery in a single location and forming manufacturing cells.

8.3.5 Development of Performance Hierarchy for Analytic Hierarchy Process Analysis

In order to determine the most important performance perspectives and JIT techniques, a three level hierarchical model (Figure 8.9) was developed. The first level shows the overall objective, which is improved overall performance of the company. The overall objective is divided into seven performance criteria based on extended BSC perspectives. The third level consists of four key JIT drivers that managers can use to optimise the organisational performance.

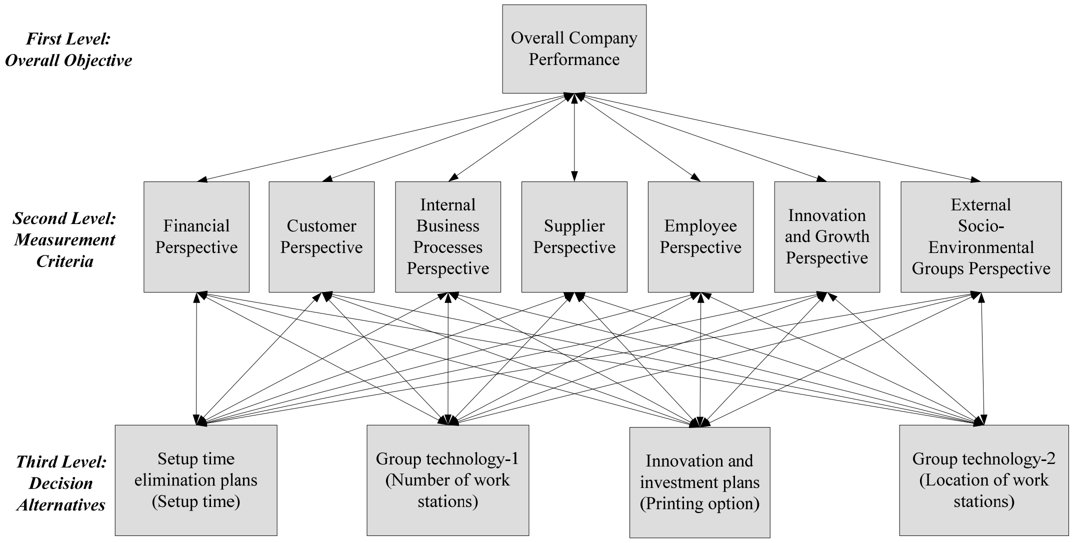

First Level: Overall Objective
Overall Company Performance
Second Level: Measurement Criteria
Financial Perspective
Customer Perspective
Internal Business Processes Perspective
Supplier Perspective
Employee Perspective
Innovation and Growth Perspective
External Socio-Environmental Groups Perspective
Third Level: Decision Alternatives
Setup time elimination plans (Setup time)
Group technology-1 (Number of work stations)
Innovation and investment plans (Printing option)
Group technology-2 (Location of work stations)

Figure 8.9: Performance Hierarchy for Risane Ltd.

8.3.6 Design Questionnaire and Conduct Survey for Risane Ltd.

During this stage, a customised questionnaire for Risane Ltd. was developed (the survey instrument for DMUK given in Appendix 2 was amended with the relevant key JIT drivers for Risane Ltd.) and a series of focused and structured interviews were carried out with the Managing Directors and the other managers of the company. Respondents were first asked to give their opinion on the relevance of extended BSC perspectives in performance measurement of the company. They were asked to categorise all KPIs of the company into extended BSC perspectives and further requested to suggest the factors affecting performance for each perspective. The respondents were finally asked to indicate the magnitude of importance of selected key JIT factors on each perspective.

Since Risane Ltd. is an SME, the number of participants was limited to six; most of the participants are multi-skilled managers and were therefore able to answer on more than one extended BSC perspective. The composition of participants and their respective response perspectives are given in Table 8.6.

Table 8.6: The Participants and their Contributing Perspectives

	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Socio-Environmental Group Perspective
Managing Director (Operations and Sales)	✓	✓			✓		✓
Managing Director (Innovations)						✓	
Financial Controller		✓					
Production Manager			✓	✓			
Hygiene and Quality Controller / Training Manager				✓			✓
Manufacturing Manager			✓			✓	
Total Responses	**1**	**2**	**2**	**2**	**1**	**2**	**2**

The Managing Director (Operations and Sales) allocated 30-60 minute time slots for interview and discussion sessions. Some of which were audio recorded. The company was unable to arrange interviews with customers, suppliers and external socio-environmental groups, hence, the researcher had to rely on the information given by in-house managers.

8.3.7 Interview Data Analysis for Overall Performance Optimisation

8.3.7.1 Summary of Findings from Interviews

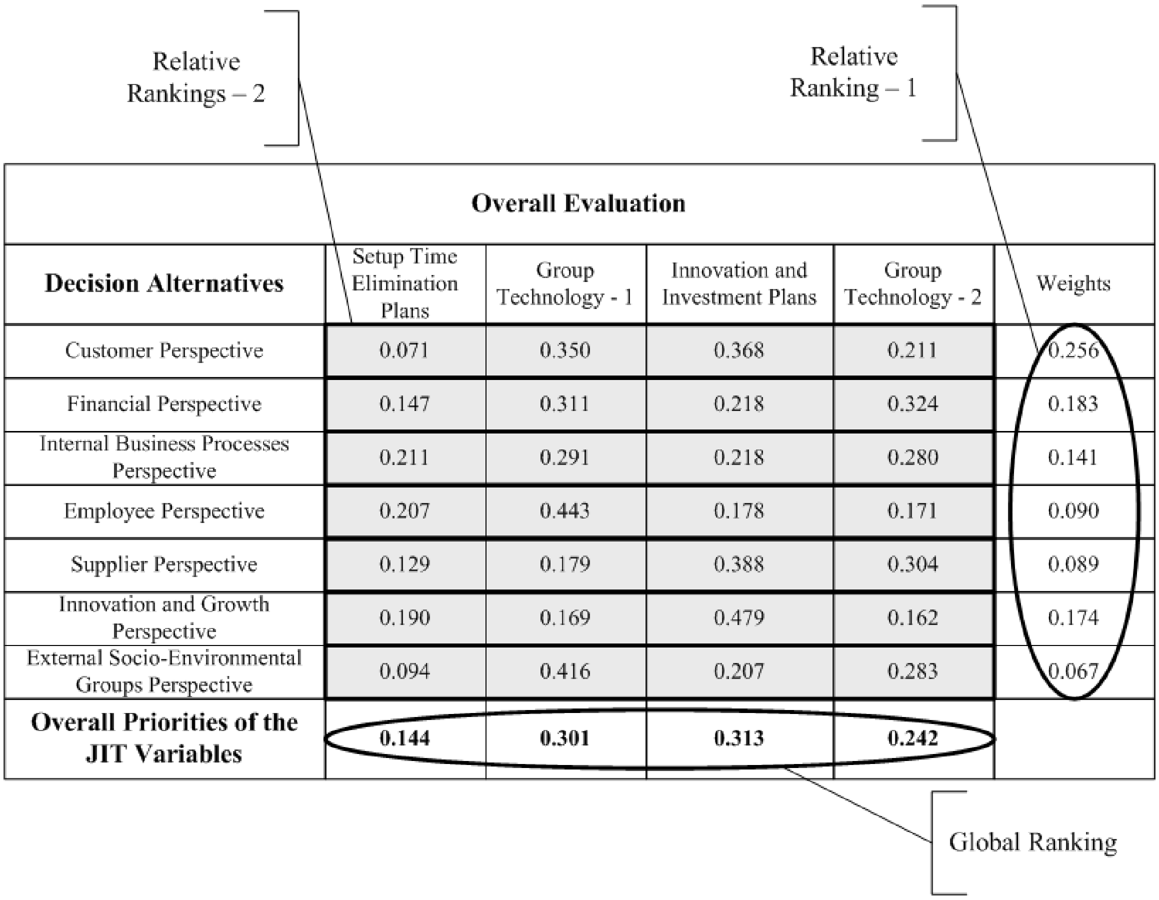
The focused interviews were conducted in order to understand the managers' opinion of the relevance of extended BSC perspectives on overall performance measurement. This exercise helped the company to categorise KPIs into relevant perspectives. The researcher and the managers were able to gain deeper insights into the factors affecting the performance of each perspective. These brainstorming interviews were helpful in assessing the impact of key JIT drivers on the extended BSC perspectives. Appendix 8 presents the findings of the focused interviews.

In summary, the following conclusions can be drawn from the analysis presented in Appendix 8:

- Risane Ltd. included all the extended BSC perspectives except supplier perspective in the vision statement. Customer satisfaction is the utmost priority and the second priority is innovation and growth with an objective of providing innovative solutions to the packaging industry. The company has a fairly hard view about suppliers and has not considered them in the vision and mission statements.
- Risane Ltd., as a recently established and fast growing organisation, does not have a proper performance measurement system. The company is using performance measures (KPIs) ad hoc to quantify performance levels. The company has recently recruited a Manufacturing Manager to implement new production procedures, policies and performance appraisal system for the company. Risane Ltd. has also recently recruited an in-house financial controller to take care of financial aspects of the company.
- The number of innovative products, delivery procedures, product quality, sales growth, production and running costs, competitors, manufacturing performance, waste, machine capabilities and breakdowns, floor space, supplier issues, manpower, training, understanding, culture and communication are the common factors affecting performance of the organisation.

8.3.7.2 Questionnaire Analysis using Analytic Hierarchy Process Tool

The next step in the PMS development process was data analysis using the AHP tool. The geometric mean of weights assigned by the participants is considered in AHP analysis. The overall evaluation of the AHP analysis is given in Table 8.7 and detailed calculations are presented in Appendix 6.


Relative Rankings – 2
Relative Ranking – 1
Global Ranking

Overall Evaluation					
Decision Alternatives	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	Weights
Customer Perspective	0.071	0.350	0.368	0.211	0.256
Financial Perspective	0.147	0.311	0.218	0.324	0.183
Internal Business Processes Perspective	0.211	0.291	0.218	0.280	0.141
Employee Perspective	0.207	0.443	0.178	0.171	0.090
Supplier Perspective	0.129	0.179	0.388	0.304	0.089
Innovation and Growth Perspective	0.190	0.169	0.479	0.162	0.174
External Socio-Environmental Groups Perspective	0.094	0.416	0.207	0.283	0.067
Overall Priorities of the JIT Variables	**0.144**	**0.301**	**0.313**	**0.242**	

Table 8.7: Overall Evaluation of AHP Analysis

The following conclusions can be drawn from the above AHP analysis.

Relative Ranking (1) of BSC Perspectives in terms of Overall Performance

- The weights column of Table 8.7 reflects the managers' opinion about the importance of extended BSC perspectives in overall performance measurement. According to managers, customer satisfaction (0.256) is top priority for their business. They further believe that financial stability (0.183) is essential for the steady growth of the business. Having an objective of "providing innovative solutions to the packaging industry", innovation and growth is the next important perspective (0.174) in terms of overall performance measurement. Other perspectives seem to be of minor importance to the organisation

Relative Rankings (2) of Key JIT Drivers in terms of BSC Perspectives

- According to the performance score row, innovation and investment plans (0.368) and group technology – 1 (0.350) are highly significant JIT drivers from the customer perspective. These two decision alternatives are more than five times important as setup time elimination plans (0.071). Group technology – 2 (0.211) has moderate importance. The managers believe that process time, defects and waste can be reduced by installing new in-house printing capability, grouping the laminator and sheeting machines together and installing all machinery in a single location, with a consequence of improvement on on-time delivery, quality and customer satisfaction.

- Managers have given the highest priority to group technology – 2 (0.324) followed by group technology – 1 (0.311) and innovation and investment plans (0.218) from the financial perspective as drivers of performance. The lowest priority was given to setup time elimination plans (0.147). The Financial Controller thinks that the company can save floor space and hence cost of space by locating machines in a single place and integrating two machines. There are conflicting views between the Managing Directors and Financial Controller on whether or not to continue to outsource printing or to purchase printing equipment. The Financial Controller believes it is more economical to outsource printing.

- The participants have given similar priority to group technology – 1 (0.291) and 2 (0.280) followed by innovation and investment plans (0.218) and setup time elimination plans (0.211) from the internal business processes perspective. The top managers are certain that cell manufacturing and machine integration have high impact on operational performance. As a fast growing company, it is believed that proper implementation of all four key JIT drivers will be critical in improving production process efficiency.

- From the employee perspective, group technology – 1 (0.443) is the most significant JIT driver. The participants have allocated 0.207, 0.178 and 0.171 for setup time elimination plans, innovation and investment plans, and group technology – 2 respectively. The company cites multitask machining as a factor in reducing labour. However, labour reduction or even the anticipation of it can have a dramatic influence on employee motivation and productivity. Moreover, machine operators have to work efficiently in the improved production environment (reduced setup time with in-house printing in cellular manufacturing environment) to avoid downstream machine idle times.

- The company can reduce inventory levels by implementing in-house printing and cell manufacturing. Thus, suppliers will have to deliver raw materials more frequently than previously. The respondents have therefore given high priority to innovation and investment plans (0.388) and group technology – 2 (0.304) with respect to supplier perspective. Other factors were rated of relatively low significance.
- Risane Ltd. was founded with the simple objective of providing innovative solutions to the packaging industry. It is not surprising that innovation and investment plans driver was given the highest performance score (0.479) in terms of innovation and growth perspective. Other factors were rated of relatively low significance.
- Risane Ltd. has their own environmental policy; i.e. the protection of the environment, prevention of pollution and waste, encouragement of recycling and minimisation of material and energy. According to the ranking given by the participants, group technology – 1 (0.416) is the most important JIT technique followed by group technology – 2 (0.283) with reference to the external socio-environmental groups perspective. Innovation and investment plans (0.207) and setup time elimination plans (0.094) are ranked in third and last positions respectively. The managers believe that energy usage, waste from defects, delays, excess inventory, unnecessary processing and motion can be reduced by integrating machines and arranging them in a cell. They considered the environmental consequences (defects, energy usage and emissions) of transportation between the company and the printing press in assigning performance priorities. However, the impact of setup time elimination plans based on scrap and energy usage on the environmental perspective has been ignored.

Global Ranking of JIT Drivers in terms of Overall Performance

- According to the global ranking row (Table 8.7), identical priorities have been given to both innovation and investment plans (0.313) and group technology – 1 (0.301). The third most influential JIT driver is group technology – 2 (0.283) while the least significant factor is setup time elimination plans (0.144). The company's objective is to deliver best quality product within the shortest lead-time to the final customer. Hence, from the managers' perception, the JIT techniques that drive reduced lead-time and improved quality are the most significant factors for their business.

Consistency of AHP Analysis

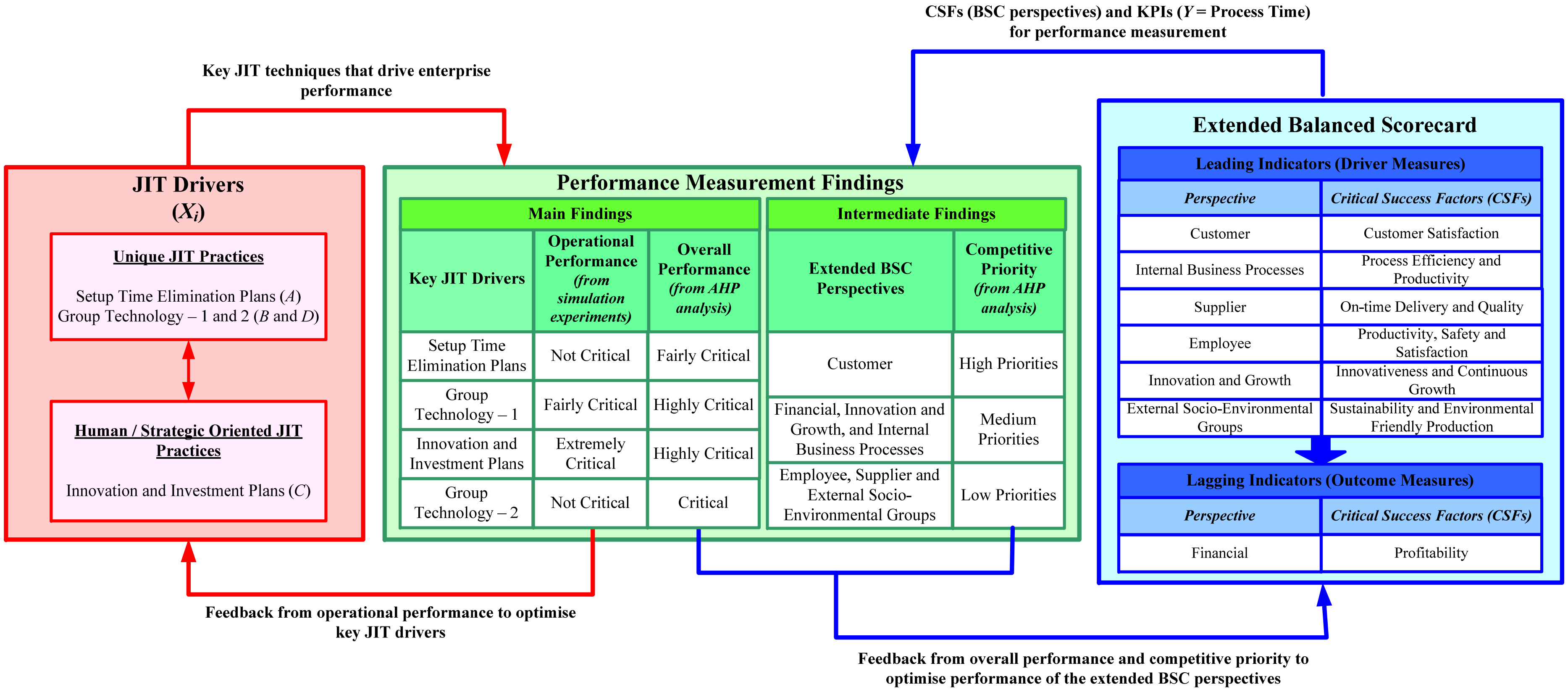
The summary of consistency ratios (CRs) is given in Table 8.8 and the appropriate random indexes (RIs) for four JIT drivers and seven BSC perspectives are 0.9 and 1.32 respectively (refer to Table 6.6 for RI). According to Table 8.8, the consistency ratios for all decision alternatives are less than 0.10 and hence, it can be concluded that all performance scores are consistent.

Table 8.8: Summary of Consistency Ratio (CR)

Decision Alternative	Consistency Ratio (CR)
Overall Performance	0.031
Customer Perspective	0.018
Financial Perspective	0.043
Internal Business Processes Perspective	0.074
Employee Perspective	0.077
Supplier Perspective	0.057
Innovation and Growth Perspective	0.062
External Socio-Environmental Groups Perspective	0.034

8.3.8 Overall Analysis and Recommendations to Risane Ltd.

The summary of overall findings from the case study is presented in Figure 8.10. It displays the key JIT techniques that drive enterprise performance and the extended BSC outlining the necessary KPIs and CSFs for performance measurement. The main and intermediate findings are shown in the middle box.


CSFs (BSC perspectives) and KPIs (Y = Process Time)
for performance measurement
Key JIT techniques that drive enterprise
performance
JIT Drivers
(X_i)
Unique JIT Practices
Setup Time Elimination Plans (A)
Group Technology – 1 and 2 (B and D)
Human / Strategic Oriented JIT Practices
Innovation and Investment Plans (C)
Performance Measurement Findings
Main Findings
Intermediate Findings
Extended Balanced Scorecard
Leading Indicators (Driver Measures)
Lagging Indicators (Outcome Measures)
Feedback from operational performance to optimise
key JIT drivers
Feedback from overall performance and competitive priority to
optimise performance of the extended BSC perspectives

Main Findings

Key JIT Drivers	Operational Performance *(from simulation experiments)*	Overall Performance *(from AHP analysis)*
Setup Time Elimination Plans	Not Critical	Fairly Critical
Group Technology – 1	Fairly Critical	Highly Critical
Innovation and Investment Plans	Extremely Critical	Highly Critical
Group Technology – 2	Not Critical	Critical

Intermediate Findings

Extended BSC Perspectives	Competitive Priority *(from AHP analysis)*
Customer	High Priorities
Financial, Innovation and Growth, and Internal Business Processes	Medium Priorities
Employee, Supplier and External Socio-Environmental Groups	Low Priorities

Leading Indicators (Driver Measures)

Perspective	*Critical Success Factors (CSFs)*
Customer	Customer Satisfaction
Internal Business Processes	Process Efficiency and Productivity
Supplier	On-time Delivery and Quality
Employee	Productivity, Safety and Satisfaction
Innovation and Growth	Innovativeness and Continuous Growth
External Socio-Environmental Groups	Sustainability and Environmental Friendly Production

Lagging Indicators (Outcome Measures)

Perspective	*Critical Success Factors (CSFs)*
Financial	Profitability

Figure 8.10: A Summary of Overall Findings from Risane Ltd. Case Study

The following conclusions and recommendations are aimed at improving both process efficiency and overall performance of the company (refer to Figure 8.10):

- Group technology, setup time elimination plans, and innovation and investment plans are key JIT drivers while process time is the KPI of the operational performance for Risane Ltd. (Figure 8.5 and Table 8.1).

- From the simulation studies, innovation and investment plans (printing facility) is identified as an extremely significant JIT driver and group technology – 1 (machine integration) is recognised as a fairly influential driver on operational performance. There are no interactions between key JIT drivers under the current manufacturing environment (Table 8.5).

- Customer perspective is thought to be the company's top competitive priority, while financial, innovation and growth, and internal business processes perspectives are of medium priorities (Table 8.7).

- According to AHP analysis, innovation and investment plans (printing facility) and group technology – 1 (machine integration) are the most critical JIT drivers for overall performance. Group technology – 2 (cellular manufacturing) has a medium impact on overall performance. These three JIT drivers can be interpreted as being almost twice as important as setup time elimination plans (Table 8.7).

- The operational performance priorities are similar, to a certain extent, to the managers' overall competitive priorities (Figure 8.10).

- Operational performance can be improved (for example, process time can be reduced by approximately 27% on the Kepak Rustlers inserts production process) by installing an in-house printing machine.

- Process time can be further reduced by integrating machines, providing the new integrated machine will be operating at a similar or higher process rate compared to the maximum rate of the individual machines. The researcher proposes that the laminator and sheeting machine are grouped together in order to eliminate unnecessary processing and motion times, and to reduce scrap, energy and labour costs. Initially, the company had planned to merge the two machines with simple modifications to eliminate the setup time for the sheeting machine. However, from simulation experiments and results analysis, the researcher realised that this modification could increase process time. Then the laminator rewind time has been replaced with sheeting time. The development process of the integrated machine is depicted in Figure 8.11.

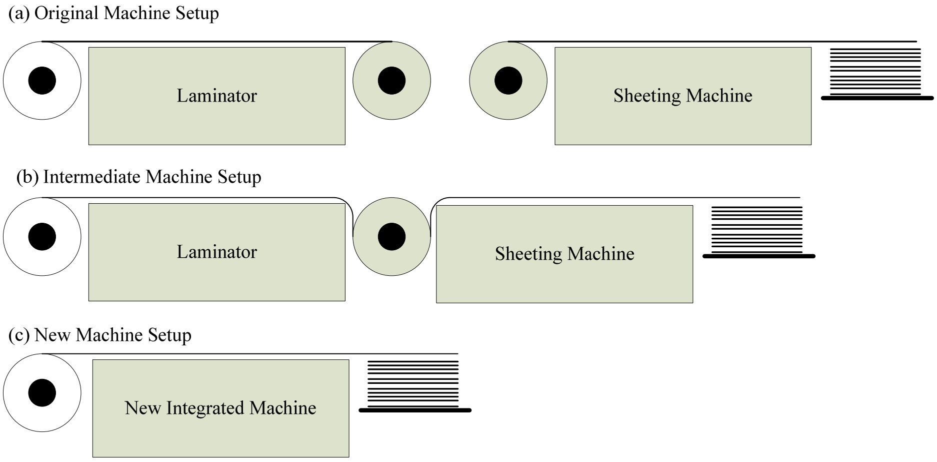


Figure 8.11: Evolution of Integrated Machine

The company has now been able to improve the laminator (laminator + sheeting machine) while reducing labour cost, factory floor space (occupied by sheeting machine and material storage), unnecessary motion time, waste and defects by integrating machines.

- Operational performance can be further optimised by placing machinery in a single location and arranging them in a work cell. Hence, part movement and waiting time between operations, and work in progress inventory can be reduced. This will allow the company to achieve cost savings and quality improvements. However, it is difficult to achieve the desired benefits using cellular manufacturing with the current speed and efficiency of the existing machines. The company can also reduce the number of employees by one, by arranging a work cell as shown in Figure 8.12. The three machine operators are supposed to work in the packing area during the machine operating time and hence labour idle time can be minimised.

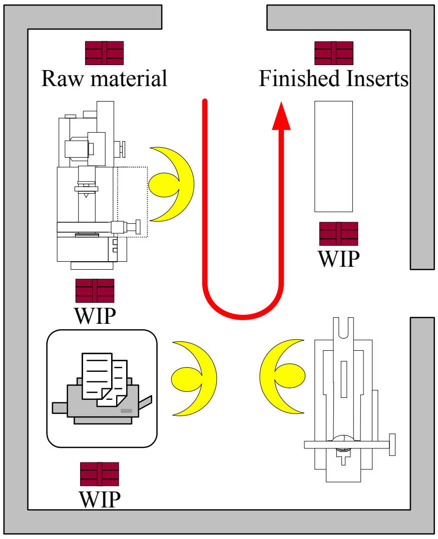


Figure 8.12: The Proposed Cell Structure

- The existing machine setup times are high; however, the impact of setup time is hidden due to the high activity time at the laminator. Improving the laminator will reduce setup time between two different products by 85%.

8.4 COMPARISON OF DMUK AND RISANE CASE STUDIES

A comparison of two case study findings is presented in Table 8.9.

Table 8.9: Comparison of Case Study Findings

	DMUK	**Risane Ltd.**
Industry	Automotive	Packaging
Size of the organization	Large enterprise	Small and medium enterprise
Culture of the organization	Japanese and Western culture	Western culture
Key JIT drivers	Line balancing Setup time elimination plans Multifunction employee Total quality control	Group technology Setup time elimination plans Innovation and investment plans
KPI/s	Process time Takt time	Process time
Impact of key JIT drivers on operational performance	Line balancing – high Setup time elimination plans – very low/no Multifunction employee – high Total quality control – fairly high	Group technology – fairly high Setup time elimination plans – no Innovation and investment plans – extremely high
Impact of key JIT drivers on organization competitive priorities and overall performance	Line balancing – high Setup time elimination plans – fairly hign Multifunction employee – high Total quality control – Very high	Group technology – very high Setup time elimination plans – fairly high Innovation and investment plans – very high
Major competitive priorities	Customer perspective Financial perspective	Customer perspective

The key JIT drivers and KPIs identified and analysed in this case study are different from the DMUK case study (refer to Table 8.9). This confirms the finding of literature (Voss and Robinson, 1987, Clode, 1993 and Funk, 1995) and preliminary interviews (refer to Section 4.2.2) that the key JIT drivers and KPIs are varying from organisation to organisation, industry to industry and even from culture to culture. Hence, a performance measurement system with generic JIT techniques and performance measures are not suitable for performance measurement in JIT enabled production environment.

The aforementioned two case studies confirmed the findings of CIMA (1993 cited in Abdel-Maksoud, 2005) that "performance measures appear to change as the company is influenced by different factors, some to do with innovations in manufacturing technology and factory organisation (e.g. Risane Ltd.) and others entailing the imposition of particular standards such as quality, by a customer (e.g. DMUK)".

The both studies further strengthen the Kaplan and Nortons balanced scorecard concept, that the operational measures of customer satisfaction, efficiency of internal business processes, employee efficiency, supplier efficiency, innovativeness and sustainability are the drivers of future financial performance.

The multidimensional performance measurement model developed in this study therefore identifies the key JIT drivers relevant to the implemented manufacturing setting and measures the impact of those drivers on both operational and overall performance in order to propose recommendations for performance deficiencies and further improvements.

8.5 SUMMARY

Chapter 8 has presented the application of the performance measurement model to a different JIT manufacturing environment. The company studied here is an SME producing packaging products for local and export markets. This study applied the eight-step approach to identify and assess the impact of key JIT drivers (innovation and investment plans, group technology and setup time elimination plans) on performance of the Kepak Rustler inserts production process. Customer perspective was identified as the organisations' major competitive priority; and innovation and investment plans was recognised as a key JIT driver affecting both operational and overall performance of the company. It was recommended that Risane Ltd. should reduce process time, improve the quality of their products and hence, improve operational and overall performance of the company by: (i) investing in new in-house printing facilities, (ii) integrating laminator and sheeting machine (iii) improving the new machine's process capability, (iv) arranging machines in a cell format, and (v) reducing setup time of machinery.

The case studies presented in Chapter 7 and 8 affirm that the performance measurement model proposed in Chapter 4, which provides JIT techniques and multidimensional performance measurement system, can be adapted to JIT enabled production environments (regardless of type of industry or size of the company) with customised key JIT variables and performance measures. It can therefore be concluded that the performance measurement model can be suitably amended for application in JIT enabled manufacturing environments.

The next chapter will provide an overview of the research study, summarise conclusions and finally present recommendations for practitioners and further research.

CHAPTER 9: CONCLUSIONS

9.1 INTRODUCTION

This chapter provides a summary of the conclusions drawn from the research study including a brief review of the aim and objectives, research approach, performance measurement model and implementation procedure, strengths and weaknesses of model and the key findings. Finally, the original contribution to knowledge and recommendations made for practitioners and future researchers are given at the end of the chapter.

9.2 OVERVIEW OF RESEARCH AND CONCLUSIONS DRAWN FROM STUDY

There has been a remarkable increase in intensity of research activities in the area of just-in-time (JIT) manufacturing, which recently has become one of the major operations management philosophies in Western manufacturing industries. Previous studies on JIT have always been limited to a few selected JIT techniques and performance measures, and were lacking in depth in terms of the inter-relationships of techniques and their effects on production performance. The leading researchers in the field of JIT manufacturing as well as practitioners in the manufacturing industry affirmed the need to study and understand the applicability of key JIT drivers/variables. Most of the past literature state that the conservative financial performance measurement systems are both insufficient and inadequate for the assessment of JIT production practice due to their backward looking approach, lack of strategic focus, negligence of individual performance, continuous improvement, innovation and growth, and failure to recognise operational performance and customer needs. Financial measures tend to ignore competitiveness and environmental consequences and focus only on middle and top management decision-making. The research question therefore is, *"in the present day manufacturing setting, is there a generic performance measurement system suitable for the evaluation and assessment of just-in-time enabled processes?"* There is no evidence in the literature of a robust performance measurement model and implementation procedure to quantitatively relate the JIT techniques and practices relevant to a given organisation and its production processes with measurable performance in the present day manufacturing environment.

The main aim of the research study carried out here therefore, was to develop a robust performance measurement model to identify and capture the influence of JIT practices on the performance of manufacturing enterprises. A three-phase approach was adopted for the study in order to fulfil the aim and objectives mentioned in Section 1.3.

The Phase I of the study employed an extensive literature review followed by informal interviews with various experts in three manufacturing companies in the West Midlands. This phase reviewed existing literature to appreciate the scope of JIT techniques, multidimensional performance measurement systems and performance measurement in JIT environments (objective 1). Chapter 2 presented the literature review relating to the JIT concept in manufacturing environments and concluded that misunderstanding of the philosophy was highly critical and implementation issues remained unclear. A major characteristic to a generic JIT implementation is that there are no universally accepted JIT techniques, as they seemed to vary from organisation to organisation, from one industry to another industry, and also from culture to culture. In this research study, 20 JIT techniques satisfying the underlying philosophy of JIT, i.e. continuous improvement by implementing pull production and eliminating all kinds of waste, were identified and assembled through an extensive literature review. Literature review suggests that kanban and pull system, multifunction employee, group technology, quality control activities, setup time elimination plans, TPM, quality circles and level schedules are the most frequently addressed JIT techniques. According to the review, techniques such as focused factory, employee training, integrated product and process design, line balancing, JIT purchasing, supplier integration, work place organisation plans, effective communication and inventory transportation systems are moderately reviewed whereas innovation and investment plans, value added analysis and other control techniques are less frequently reported JIT techniques.

Chapter 3 presented an extensive literature review on performance measurement systems, highlighting the inadequacy of financial performance measurement systems in the present day manufacturing scenarios and emphasising the need for a multidimensional PMS, which integrates both financial and operational measures in order to facilitate robust decision-making. Most of the well-known and better-structured integrated PMSs provide broad and non-perspective templates, where managers can develop their own measures to assess performance. However, the lack of a mechanism to identify key performance indicators is one of the major weaknesses of well-known PMSs. Having considered the strengths and weaknesses of eight fairly applied multidimensional PMSs in relation to the research context, Kaplan and Norton's BSC was selected as a suitable tool for further exploration for study. By focusing not only on the financial perspective but also on drivers of financial performance, such as customer, internal business processes, and innovation and growth perspectives, the BSC provides a more comprehensive view of a business performance. Although, BSC appears more acceptable than other integrated PMSs available in the research literature, it still fails to highlight other relevant performance dimensions such as employee and supplier contribution as well as the influence of environmental and socio-cultural groups on the performance of JIT enabled manufacturing settings. This study therefore has developed and applied a restructured extended balanced scorecard concept, capable of assessing performance not only from the financial point of view but also from customer, employee, supplier, internal business processes, innovation and growth, and external socio-environmental groups perspectives.

The role of performance measurement in JIT enabled production environments was the next focus of the study and three organisations were approached for interview (objective 2). Preliminary findings showed that all three case companies used in the study (Denso Manufacturing (UK) Ltd., Metsec Plc. and Bemason Ltd.) implemented selected JIT techniques based on management past experience and tacit knowledge, and only used few KPIs to measure performance of the plant as there was no comprehensive PMS in place (Section 4.2.2). Previous studies concluded that unique, TQM related and human/strategic oriented JIT practices were the three major inter-related categories and internally consistent JIT concepts. An integrated framework of JIT practices was therefore introduced in the study, which considered JIT techniques and their relationships in a modern manufacturing setting.

The integrated framework of JIT practices and an extended BSC tool were then used in developing a suitable conceptual performance measurement model for JIT manufacturing plants (objective 3). The conceptual model proposed as a performance measurement system linked key JIT drivers (X_i) and measurable performance (Y) through a mathematical model and was aimed to assist managers in the systematic identification of the influence of key JIT drivers on organisational competitive priorities using a multidimensional tool such as the extended BSC (Chapter 4).

Phase I finally introduced a novel eight-step implementation procedure to transform the generic conceptual model to a practical performance measurement system in a JIT environment (objective 4) described as follows (details in Chapter 6):

- ***Step 1:*** Identify and narrow down production related problems and causes using *cause and effect analysis* and *relations diagrams*; identify underlying key JIT drivers of those selected causes and KPIs; develop customised performance measurement model
- ***Step 2:*** Design experiments using the *design of experiments (DoE)* technique and develop linear polynomial equations by linking the output (Y) to the key JIT drivers (X_i)
- ***Step 3:*** Conduct experiments on the model using simulation software (e.g. *ProModel simulation and modelling software*) to obtain performance results to test and validate the model
- ***Step 4:*** Analyse simulation experiment results (e.g. using *MINITAB software*) to establish relationships between key JIT drivers and operational performance using *linear mathematical model*
- ***Step 5:*** Appreciate company vision, mission and core competencies; recognise company strategy and CSFs; develop performance hierarchy by linking key JIT drivers and extended BSC
- ***Step 6:*** Design survey instrument and conduct questionnaire survey with top, middle and floor level management
- ***Step 7:*** Conduct *AHP analysis* and identify organisational competitive priorities and the influence of key JIT techniques on extended BSC perspectives and overall performance of the organisation

- ***Step 8:*** Compare simulation experiments and AHP analysis results and present suggestions to optimise both operational and overall performance of the company; re-evaluate key JIT drivers and KPIs periodically

The aforementioned approach has its strengths as well as weaknesses. The strengths of the implementation procedure may be summarised as follows:

- Performance measurement model implementation procedure considers company vision, mission, core competencies and strategies and is integrated with both financial and operational measures
- The key JIT drivers and KPIs are easily recognised using two simple techniques – i.e. 'cause and effect diagrams' and 'relations diagrams' (refer to Section 6.3.1).
- This approach helps to reduce the factors that have great influence on performance into a meaningful and manageable set. The reduction of the number of JIT variables can significantly shorten the DoE, simulation and modelling, and AHP analysis time
- Effects of the key JIT drivers on performance can be built into a simple linear mathematical model. This will help managers to quantify the impact of JIT techniques on operational performance of the production process (refer to Section 6.3.2 and 6.3.4)
- The AHP analysis will help managers to recognise the influence of key JIT techniques on competitive priorities of the organisation based on an extended BSC tool. This will further enable them to identify the impact of those drivers on overall performance of the organisation (refer to Section 6.3.5)
- Both operational and overall performance can be measured and optimised using a simple, easy to understand and clearly defined eight-step approach

The weaknesses of the proposed model implementation procedure are as follows:

- It requires the intuition of researchers/managers to identify production related problems, and key JIT techniques behind those problems and KPIs
- The complexity of the mathematical model increases with the number of key JIT drivers (refer to Eq: 6.12, 6.13, 6.14 and 6.15); fractional factorial design

can be further used where there are more than four key JIT drivers, in order to screen out those with little or no impact on performance

- AHP analysis is subjective and based on individual or group judgements; subjectivity can be reduced by group judgements of experienced, skilled and educated personnel
- The manager's commitment is vital in continuous re-evaluation of PMS in order to accommodate new strategies, core competencies, key JIT drivers and KPIs and to remove existing insignificant drivers identified in continuous improvement exercise

In summary, the eight-step implementation procedure provides a broad performance measurement system to quantify the impact of JIT techniques on operational performance and also to identify the strategic influence of those JIT drivers on the organisation's competitive priorities using the extended BSC tool. Thus, the strengths of the proposed system are greater than weaknesses. The weaknesses highlighted can be minimised or remedied with the aforementioned solutions.

Phase II of the study employed a case study approach to test and validate the conceptual performance measurement model by applying it to an automotive component manufacturing environment, Denso Manufacturing (UK) Ltd. (objective 5). In this phase, data was gathered using documents and archival records, observations and interviews, and analysed using DoE and statistical data analysis techniques. The quantitative data collected from structured interviews were subjected to rigorous AHP analysis. Computer based dynamic simulation tools and consistency calculations were used to validate the findings (Chapter 7).

The study applied the aforementioned procedure to identify key JIT drivers (i.e. line balancing, multifunction employee, setup time elimination plans and quality control activities) and the KPIs (i.e. process and takt times) for DMUK. Experimentation using ProModel software enabled a computer based simulation to determine the impact of selected JIT variables on system performance. Line balancing (multifunction employee) stood out as the most significant parameter with a high impact on process and takt times, while quality control activities had a medium impact. According to the AHP analysis, customer and financial perspectives are

DMUK's competitive priorities, while quality control activities followed by line balancing are the key JIT drivers in overall performance measurement.

By applying the multidimensional and robust performance measurement model developed in this study, DMUK was able to assess the impact of shop floor managers' decisions on the company's competitive priorities and the influence of top management decisions on operational performance. Based on simulation and AHP analyse results, it was suggested that the company should apply optimal line balancing, employ multifunctional associates, build quality into the products and processes rather than routine inspection and also eliminate setup time to optimise the overall performance of DMUK. The proposed performance measurement model was therefore successfully tested and validated by applying it to an automotive component manufacturing environment; hence, the fifth objective of this study was achieved.

Phase III of this study used action research technique to apply the performance model to a non-automotive, small and medium enterprise (Risane Ltd.) in order to test its applicability in a different JIT manufacturing setting (objective 6). The aforementioned systematic procedure was applied to identify key JIT variables (i.e. group technology, setup time elimination plans, and innovation and investment plans) and KPI (i.e. process time) for the mixed model packaging material production process at Risane Ltd. This case study applied simulation and modelling using ProModel software and linear mathematical modelling to identify the impact of key JIT drivers on operational performance. The AHP tool was also used to identify the organisation's competitive priorities (i.e. customer perspective) and assess the impact of key drivers on extended BSC perspectives and overall performance of the company. It was found that the lack of innovation and investment plan practice had very high negative impact on process time. Improper implementation of group technology concepts such as machine integration and cellular manufacturing, and high machine setup times had a negative impact on both operational (although not highly statistically significant) and overall company performance (Chapter 8).

Both simulation and AHP analysis found that operational performance priorities are closely identical to the managers' overall competitive priorities. The robust performance measurement model proposed in this study made it easier for the company to assess and optimise the performance of their manufacturing process by altering values of JIT variables in the mathematical model. Consequently, it was recommended that the company should invest in new in-house printing facilities, integrate the laminator and sheeting machines (providing that the process rate of the new machine would be less than or equal to the process rate of the laminator), improve the new machine's process rate and speed, arrange the machines in a cellular format, reduce the setup time of the laminator and Sammy machine, and reduce the length of the board and suscepters in order to optimise the system performance.

In summary, this study has developed a multidimensional performance measurement model and an eight-step implementation procedure, which is capable of capturing the influence of JIT drivers on performance and hence, optimise the performance of JIT systems. The model has been successfully tested and validated by applying it to automotive and non-automotive component production plants. It can therefore be concluded that performance measurement model and the eight-step procedure is generally applicable to JIT enabled manufacturing environments, with their own JIT drivers and KPIs to optimise system performance. It can be said with confidence that the aim and objectives of this study have been successfully achieved. Contribution to knowledge has been made by developing an innovative, easy to apply, robust methodology to enable industry practitioners optimise their processes and achieve higher productivity.

9.3 CONTRIBUTION TO KNOWLEDGE

In the era of globalisation, it is essential for manufacturing environments to become customer focused, enhance operational performance and profitability as well as promote innovation and growth to remain sustainable. This research in assessing the impact of operational management techniques such as JIT practice on enterprise performance and providing clear understanding of how JIT systems can be optimised, has made the following major contributions to knowledge:

1. An integrated framework of JIT practices and their impact on production performance; an analysis of the current state of JIT implementation in UK manufacturing environments.

2. A critical review of current global financial and multidimensional PMSs in use to understand the usefulness and applicability of multidimensional PMSs leading to an introduction to the restructured extended BSC concept.
3. A robust performance measurement model to capture the influences of key JIT drivers on enterprise performance assessed by multidimensional extended BSC concept. Integrated framework of JIT practices and restructured extended BSC have been configured to develop a JIT performance measurement model. The integrated framework of JIT practices is made up of two components which offer both JIT techniques and BSC to assess KPIs. The resultant performance measurement model will provide feedback to take necessary actions in order to optimise key JIT drivers and performance of extended BSC perspectives.
4. A novel eight step approach to identify key JIT drivers and KPIs, to quantitatively assess impact on operational and organisational performance using tools such as design of experiments, simulation, linear mathematical modelling and analytic hierarchy process analysis.

The overall outcome of this study is a performance measurement model and implementation procedure that guides both industry practitioners and academic researchers on how to assess and optimise performance in a JIT production environment.

9.4 RECOMMENDATIONS FOR PRACTITIONERS

The conceptual model and eight-step implementation procedure presented here is applicable to JIT enabled production environments. It will enable industry practitioners to identify the key drivers of JIT in their particular environment. This will assist them in understanding the effect of the JIT drivers on system performance, thereby providing guidance on performance improvement. The multidimensional performance measurement model developed in this study:

- considers company vision, mission, core competencies and strategies, and integrates with both financial and operational measures

- provides two simple steps to recognise organisational key JIT drivers and KPIs – i.e. cause and effect, and relations diagram analysis
- provides a mechanism where effects of key JIT drivers on performance can be built into a simple mathematical model; this will help managers to quantify the impact of JIT techniques on operational performance of the production process
- helps managers to recognise the influence of key JIT techniques on competitive priorities of the organisation using the analytic hierarchy process tool
- provides a systematic approach to measure and optimise both operational and overall performance using a simple, easy to understand and clearly defined eight-step implementation procedure

The multidimensional performance measurement model will help industry practitioners to generate key JIT drivers and KPIs for successful implementation of the JIT philosophy in production processes.

Having considered the benefits of the proposed performance measurement model, some recommendations can be presented as follows:

- Performance measurement model and implementation procedure, which contains information on the performance measurement of JIT processes, should be in place in JIT enabled manufacturing environments. The model should be reviewed regularly within changes of the organisation's operations management. The manager's commitment is vital in continuous re-evaluation of the performance measurement model in order to accommodate new strategies, core competencies, key JIT drivers and KPIs and to remove existing insignificant JIT techniques identified in continuous improvement exercises
- Performance measurement is a collective effort. It requires the dedication of managers and factory floor workers during brainstorming sessions to identify production related problems, underlying key JIT drivers and KPIs.

- Both top management and line managers should maintain good relationship and communication with each other. The top management should appreciate the constructive ideas and value the work performed by the line managers and the associates. At the same time, the line managers should understand the organisational priorities set by the top management
- Senior management is responsible for introducing the performance measurement model in their operations management strategies and thereby implement it in the day-to-day practices of the manufacturing environment
- It is recommended that fractional factorial design is applied where there are more than four essential JIT drivers, in order to screen out those with little or no impact on performance. It is also recommended that group judgements of experienced, skilled and educated personnel is essential in order to reduce subjectivity of AHP analysis
- Top management should ensure that a dedicated technical resource manager such as performance appraisal manager or coordinator is available to facilitate implementation of performance measurement model. They should also ensure that they have contingency plans in place to deal with resource constraints, e.g. simulation software
- A company-wide performance measurement appraisal process should be carried out in order to compare performance of various processes/assembly lines, which in turn enable the organisation to carry out their work to the highest standards. It will enable the operations managers to assess the existing performance levels and key JIT techniques of various processes and thereby identify where further improvements and changes are needed

9.5 RECOMMENDATIONS FOR FURTHER RESEARCH

The proposed model and research methodology employed in this study could be replicated in other industries such as the construction and service sectors that are trying to achieve benefits from implementation of JIT principles and techniques.

This study used an AHP tool to assess linear hierarchical relationships (e.g. situations where different KPIs are driven by the same JIT techniques). However, when more complex relationships exist within a looser network structure (e.g. circumstances where different KPIs are driven by different JIT techniques), an AHP tool is no longer valid. Then, an analytic network process (ANP) tool can be used to assess the non linear relationships. A further area of research would be to test the performance measurement model with an ANP tool in complex problem analysis and decision making scenarios.

The concept of performance measurement model and implementation procedure proposed in this study can be further used to assess the impact of key drivers on performance of the cutting-edge management principles and practices such as lean manufacturing, supply chain management, concurrent engineering, value chain management and quick response manufacturing.

Finally the model can be integrated with problem analysis, dynamic simulation and multi-criteria decision making software to develop a versatile software package, which becomes self optimising, enabling rapid determination of key control parameters to optimise process performance just in time.

REFERENCES

2GC (2001), *The balanced scorecard vs. the EFQM business excellence model – which is the better strategic management tool?* 2GC Ltd. (CD-ROM). <http://www.2gc.co.uk/pdf/2GC-BSCvBEM.pdf >.

Abdel-Maksoud, A., Dugdale, D. and Luther, R. (2005), Non-financial performance measurement in manufacturing companies. *The British Accounting Review*, **37**, pp. 261 - 297.

Abrahamson, E. (1996), Management fashion. *Academy of Management Review*, **21**(1), pp. 254 - 285.

Abrahamson, E. (1997), Management fashion: Lifecycles, triggers, and collective learning processes. *Academy of Management Proceedings*, pp. 254 – 257.

Adams, R., Bessant, J. and Phelps, R. (2006), Innovation management measurement: A review. *International Journal of Management Reviews*, **8**(1), pp. 21 – 47.

Ahmad, A., Mehra, S. and Pletcher, M. (2004), The perceived impact of JIT implementation on firms' financial/growth performance. *Journal of Manufacturing Technology Management*, **15**(2), pp. 118 - 130.

Ahmad, S., Schroeder, R. G. and Sinha, K. K. (2003), The role of infrastructure practices in the effectiveness of JIT practices: implications for plant competitiveness. *Journal of Engineering and Technology Management*, **20**(3), pp. 161 - 191.

Ahmed, N. U., Montagno, R. V. and Firenze, R. J. (1996), Operations strategy and operational performance: An empirical study. *International Journal of Operations & Production Management*, **16**(5), pp. 41 - 53

Ahmed, N. U., Tunc, E. A. and Montagno, R. V. (1991), A comparative study of US manufacturing firms at various stages of just-in-time implementation. *International Journal of Production Research*, **29**(4), pp. 787 - 802.

Aigbedo, H. and Monden, Y. (1997), A parametric procedure for multi-criteria sequence scheduling for just-in-time mixed model assembly line. *International Journal of Production Research*, **35**(9), pp. 2543 - 2564.

Alles, M., Amershi, A., Datar, S. and Sarkar, R. (2000), Information and incentive effects of inventory in JIT production. *Management Science*, **46**(12), pp.1528-1544.

Amaratunga, D. and Baldry, D. (2002), Moving from performance measurement to performance management. *Facilities*, **20**(5/6), pp. 217 - 223.

Anderson, K. and McAdam, R. (2004), A critique of benchmarking and performance measurement. *Benchmarking: An International Journal*, **11**(5), pp. 465 - 483.

APICS (1992), *APICS Dictionary. in* Cox, J. F., Blackstone, J. H. and Spencer, M. S. Falls Church, VA: American Production and Inventory Control Society, Inc.

Arinze, B., Kim, S. and Banerjee, A. (1995), A multi-criteria model for supporting setup reduction investment decisions. *Production Planning and Control*, **6**(5), pp. 413 - 420.

Azzone, G. and Masella, C. (1991), Design of performance measures for time-based competition. *International Journal of Operations & Production Management*, **11**(3), pp. 77 - 85.

Banks, J. and Gibson, R. R. (1996), Getting started in simulation modelling. *IIE Solutions*, **28**(11), pp. 34 - 39.

Barnes, D. (2001), Research methods for the empirical investigation of the process of formation of operations strategy. *International Journal of Operations & Production Management*, **21**(8), pp. 1076 - 1095.

Bartezzaghi, E. (1999) The evolution of production models: is a new paradigm emerging. *International Journal of Operations & Production Management*, **19**(2), pp. 229 - 250.

Bassioni, H. A., Price, A. D. F. and Hassan, T. M. (2004), Performance measurement in Construction. *Journal of Management in Engineering*, **April**, pp. 42 - 50.

Bates, M., Sturges, J., McGowan, K. and Somerville, J. (1999), *JIT in UK house-building: Feasibility for partial implementation using CAPM.* Singapore.

Billesbach, T., Harrison, A. and Morgan, S. C. (1991), Just-in-time: A United States - United Kingdom comparison. *International Journal of Operations & Production Management*, **11**(10), pp. 44 - 57.

Bititci, U. S., Carrie, A. S. and McDevitt, L. (1997), Integrated performance measurement systems: a development guide. *International Journal of Operations & Production Management*, **17**(5), pp. 522 - 534.

Bititci, U. S., Suwignjo, P. and Carrie, A. S. (2001), Strategy management through quantitative modelling of performance measurement systems. *International Journal of Production Economics*, **69**(1), pp. 15 - 22.

Bocci, F. (2004), Defining performance measurement. *Perspective on Performance*, **3**(1/2).

Bond, T. C. (1999), The role of performance measurement in continuous improvement. *International Journal of Operations & Production Management*, **19**(12), pp. 1318 - 1334.

Bourne, M., Neely, A., Mills, J. and Platts, K. (2003), Implementing performance measurement systems: a literature review. *International Journal of Business Performance Management*, **5**(1), pp. 1 - 24.

Boyd, D. T. (2001), Corporate Adoption of JIT: The Effect of Time and Implementation on Selected Performance Measures. *Southern Business Review*, **26**(2).

Brown, K. L. and Inman, R. A. (1993), Small business and JIT: A managerial overview. *International Journal of Operations & Production Management*, **13**(3), pp. 57 - 66.

Brox, J. A. and Fader, C. (1996), Production elasticity differences between just-in-time and non-just-in-time users in the automotive parts industry. *North American Journal of Economics and Finance*, **7**(1), pp. 77 - 90.

Brox, J. A. and Fader, C. (1997), Assessing the impact of JIT using economic theory. *Journal of Operations Management*, **15**(4), pp. 371 - 388.

Brox, J. A. and Fader, C. (2002), The set of just-in-time management strategies: an assessment of their impact on plant-level productivity and input-factor substitutability using variable cost function estimates. *International Journal of Production Research*, **40**(12), pp. 2705 - 2720.

Bukchin, J. (1998), A comparative study of performance measures for throughput of a mixed model assembly line in a JIT environment. *International Journal of Production Research*, **36**(10), pp. 2669 - 2685.

Callen, J.L., Fader, C. and Krinsky, I. (2000), Just-in-time: A cross-sectional plant analysis. *International Journal of Production Economics*, **63**(3), pp. 277 - 301.

Callen, J. L., Morel, M. and Fader, C. (2001), *The profitability-risk trade-off of just-in-time manufacturing technologies.* (CD-ROM). <http://www.rotman.utoronto.ca/accounting/papers/a2002-04.pdf >.

Chakravorty, S. S. and Atwater, J. B. (1995), Do JIT lines perform better than traditionally balanced lines? *International Journal of Operations & Production Management*, **15**(2), pp. 77 - 88.

Chan, Y. L. and Lynn, B. E. (1991), Performance evaluation and the analytic hierarchy process. *Journal of Management Accounting Research*, **3**, pp. 57 - 87.

Charantimath, P. M. (2006), *Total Quality Management*. Dorling Kindersley (India) Pvt. Ltd. Delhi, India.

Chen, H., Frank, M. and Wu, O. (2005), What actually happened to the inventories of American companies between 1981 and 2000? *Manage. Science*, **51**, pp. 1015 – 1031.

Cheng, E. W. L. and Li, H. (2001), Analytic hierarchy process: An approach to determine measures for business performance. *Measuring Business Excellence*, **5**(3), pp. 30 - 36.

Cheng, T. C. E. (1990), A state-of-the-art review of just-in-time production. *Advanced Manufacturing Engineering*, **2**, pp. 96 - 102.

Chin, K. S., Lam, J., Chan, J. S. F., Poon, K. K. and Yang, J. (2005), A CIMOSA presentation of an integrated product design review framework. *International Journal of Computer Integrated Manufacturing*, **84**(4), pp. 260 - 278.

Christensen, W. J., Germain, R. and Birou, L. (2005), Build-to-order and just-in-time as predictors of applied supply chain knowledge and market performance. *Journal of Operations Management*, **23**, pp. 470 - 481.

Chu, C. H. and Shih, W. I. (1992), Simulation studies in JIT production. *International Journal of Production Research*, **30**(11), pp. 2573 - 2586.

CIMA (1993), *Performance measurement in the manufacturing sector*. Chartered Institute of Management Accountants,. London.

Clinton, B. D. and Hsu, K. C. (1997), JIT and the balanced scorecard: Linking manufacturing control to management control. *Management Accounting*, **79**(3), pp. 18 - 24.

Clinton, B. D., Webber, S. A. and Hassell, J. M. (2002), Implementing the balanced scorecard using the analytic hierarchy process. *Management Accounting Quarterly*, **3**(3), pp. 1 - 11.

Clode, D. M. (1993), A survey of UK manufacturing control over the past ten years. Production and Inventory Management Journal, **34**(2), pp. 53 - 56.

Crawford, K. M., Blackstone, J. H. and Cox, J. F. (1988), A study of JIT implementation and operating problems. *International Journal of Production Research*, **26**(9), pp. 1561 - 1568.

Crawford, K. M. and Cox, J. F. (1991), Addressing manufacturing problem through the implementation of just-in-time. *Production and Inventory Management Journal*, **32**(1), pp. 33 - 36.

Cresswell, J. W. (1998), *Qualitative Inquiry and Research Design: Choosing Among Five Traditions.* Sage Publishers. London, UK.

Cross, K. F. and Lynch, R. L. (1989), The SMART way to define and sustain success. *National Productivity Review*, **8**(1), pp. 23 - 33.

Cua, K. O., McKone, K. E. and Schroeder, R. G. (2001), Relationships between implementation of TQM, JIT, and TPM and manufacturing performance. *Journal of Operations Management*, **19**(6), pp. 675 - 694.

Dabhilkar, M. and Bengtsson, L. (2004), Balanced scorecards for strategic and sustainable continuous improvement capabilities. *Journal of Manufacturing Technology Management*, **15**(4), pp. 350 - 359.

DENSO (2007). < http://www.denso-europe.com/default.aspx >.

Detty, R. B. and Yingling, J. C. (2000), Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study. *International Journal of Production Research*, **38**(2), pp. 429 - 445.

Devaraj, S. and Babu, S. R. (2004), How to measure the relationship between training and job performance. *Communications of the ACM*, **47**(5), pp. 63 - 67.

Dixon, J. R., Nanni, A. J. and Vollman, T. E. (1990), *The new performance challenge: Measuring operations for world class competition*. Dow Jonws-Irwin. Homewood, IL.

DMUK (2006) Denso Manufacturing (UK) Ltd. Notice Board.

Dong, Y., Carter, C. R. and Dresner, M. E. (2001), JIT purchasing and performance: an exploratory analysis of buyer and supplier perspectives. *Journal of Operations Management,* **19**(4), pp. 471 - 483.

Drexl, A. and Kimms, A. (2001), Sequencing JIT mixed-model assembly lines under station-load and part-usage constraints. *Management Science*, **47**(3), pp. 480 - 491.

Easterby-Smith, M., Thorpe, R. and Lowe, A. (2002), *Management Research.* 2nd ed., SAGE Publications. London.

EFQM (2004), EFQM Framework. (CD-ROM). < http://www.efqm.org/ >.

Estrada, F., Villalobos, J. R. and Roderick, L. (1997), Evaluation of just-in-time alternatives in the electric wire-harness industry. *International Journal of Production Research*, **35**(7), pp. 1993 - 2008.

Fallon, D. and Browne, J. (1988), Simulating just-in-time systems. *International Journal of Operations & Production Management*, **8**(6), pp. 30 - 45.

Fawcett, S. E. and Myers, M. B. (2001), Product and employee development in advanced manufacturing: Implementation and impact. *International Journal of Production Research*, **39**(1), pp. 67 - 79.

Fernando, M. M. and Luis, M. A. B. (2002), Modular simulation tool for modelling JIT manufacturing. *International Journal of Production Research*, **40**(7), pp. 1529 - 1547.

Flynn, B. B., Sakakibara, S. and Schroeder, R. G. (1995), Relationship between JIT and TQM: Practices and performance. *Academy of Management Journal*, **38**(5), pp. 1325 - 1360.

Folan, P. and Browne, J. (2005), A review of performance measurement: Towards performance management. *Computers in Industry*, **56**, pp. 663 - 680.

Fox, J. (1997), *Applied regression analysis, linear models and related methods*. Sage Publishers. London.

Fullerton, R. R. (2003), Performance measurement and reward systems in JIT and non-JIT firms. *Journal of Cost management*, **17**(6), pp. 40 - 48.

Fullerton, R. R. and McWatters, C. S. (2001), The production performance benefits from JIT implementation. *Journal of Operations Management*, **19**(1), pp. 81 - 96.

Fullerton, R. R. and McWatters, C. S. (2002), The role of performance measures and incentive systems in relation to the degree of JIT implementation. *Accounting, organisation and Society*, **27**(8), pp. 711 - 735.

Fullerton, R. R., McWatters, C. S. and Fawson, C. (2003), An examination of the relationships between JIT and financial performance. *Journal of Operations Management*, **21**(4), pp. 383 - 404.

Funk, J. L. (1995), Just-in-time manufacturing and logistical complexity: a contingency model. *International Journal of Operations & Production Management*, **15**(5), pp. 60 - 71.

Galbraith, J. R. (1977), *Organisation Design*. Addison-Wesley. Philippines.

Galbraith, L. and Standridge, C. R. (1994), Analysis in manufacturing systems simulation: A case study. *Simulation*, **63**(6), pp. 368 – 375.

Ghalayini, A. M. and Noble, J. S. (1996), The changing basis of performance measurement. *International Journal of Operations & Production Management*, **16**(8), pp. 63 - 80.

Ghalayini, A. M., Noble, J. S. and Crowe, T. J. (1997), An integrated dynamic performance measurement system for improving manufacturing competitiveness. *International Journal of Production Economics*, **48**(3), pp. 207 - 225.

Gill, J. and Johnson, P. (2002), *Research Methods for Managers.* 3rd ed., Sage Publishers. London, UK.

Gravel, M., Price, W. and Gagne, C. (2000), An interactive tool for designing manufacturing cells for an assembly job-shop. *International Journal of Production Research*, **38**(2), pp. 309 - 322.

Gray, G. R. (1993), Quality circles: an update. *SAM Advanced Management Journal*, **58**(2), pp. 41 - 47.

Green, F. B., Amenkhienan, F. and Johnson, G. (1991), Performance measures and JIT. *Management Accounting*, **72**(8), pp. 50 - 53.

Gummesson, E. (2000), *Qualitative Methods in Management Research.* 2nd ed., Sage Publishers. London, UK.

Gunasekaran, A. and Lyu, J. (1997), Implementation of just-in-time in a small company: a case study. *Production Planning and Control*, **8**(4), pp. 406 - 412.

Gupta, S. M. and Al-Turka, Y. A. Y. (1998), The effect of sudden material handling system breakdown on the performance of a JIT system. *International Journal of Production Research*, **36**(7), pp. 1935 - 1960.

Hafeez, K., Zhang, Y. B. and Malak, N. (2002), Determining key capabilities of a firm using analytic hierarchy process. *International Journal of Production Economics*, **76**, pp. 39 - 51.

Halachmi, A. (2002), Performance measurement: A look at some possible dysfunctions. *Work Study*, **51**(5), pp. 230 - 209.

Halachmi, A. (2005), Performance measurement is only one way of managing performance. *International Journal of Productivity and Performance Management*, **54**(7), pp. 502 - 516.

Hall, E. H. (1989), Just-in-time management: A critical assessment. *The Academy of Management Executive*, **3**(4), pp. 315 - 318.

Hall, R. W. (1987), *Attaining manufacturing excellence.* McGraw-Hill Trade. Homewood, Illinois.

Haq, A. N. and Kannan, G. (2006), An integrated approach for selecting a vendor using grey relational analysis. *International Journal of Information Technology and Decision Making*, **5**(2), pp. 277 - 295.

Harker, P. T. and Vargas, L. G. (1987), The theory of ratio scale estimation: Saaty's analytic hierarchy process. *Management Science*, **33**(11), pp. 1389 – 14

Harrell, C., Ghosh, B. K. and Bawden, R. (2003), *Simulation using ProModel.* 2nd ed., McGraw-Hill Higher Education. London, UK.

Harrell, C. R. and Tumay, K. (1992), *ProModel Tutorial*. USA.

Hayes, R. H. (1981), Why Japanese factories work. *Harvard Business Review*, **July - August**, pp. 56 – 66.

Hayes, R. H. and Pisano, G. P. (1994), Beyond world-class: The new manufacturing strategy. *Harvard Business Review*, **72**(1), pp. 77 - 87

Heizer, J. and Render, B. (2004), *Operations Management*. Prentice Hall. Upper Saddle River, NJ

Hendricks, J. A. (1994), Performance measures for a JIT manufacturer : The Role of the IE. *Industrial Engineering*, **26**, pp. 26 - 29.

Hepworth, P. (1998), Weighing it up - a literature review for the balanced scorecard. *Journal of Management Development*, **17**(8), pp. 559 - 563.

Hudson, M., Smart, A. and Bourne, M. (2001), Theory and practice in SME performance measurement system. *International Journal of Operations & Production Management*, **21**(8), pp. 1096 - 1115.

Huson, M. and Nanda, D. (1995), The impact of Just-In-Time manufacturing on firm performance in the US. *Journal of Operations Management*, **12**(3-4), pp. 297 - 310.

Im, J. H. and Lee, S. M. (1989), Implementation of just-in-time systems in US manufacturing firms. *International Journal of Operations & Production Management*, **9**(1), pp. 5 - 14.

Inman, R. A. and Mehra, S. (1993), Financial justification of JIT implementation. *International Journal of Operations & Production Management*, **13**(4), pp. 32 - 39.

Joo, S. H. and Wilhelm, W. E. (1993), A review of quantitative approaches in Just in time manufacturing. *Production Planning and Control*, **4**(3), pp. 207 – 229.

Kagioglou, M., Cooper, R. and Aouad, G. (2001), Performance measurement in construction: a conceptual framework. *Construction Management and Economics*, **19**(1), pp. 85 - 95.

Kanji, G. P. and Sa, P. M. (2001), Kenji's balanced scorecard. *Total Quality Management*, **12**(7 & 8), pp. 898 - 905.

Kaplan, R. S. (1984), The evolution of management accounting. *The Accounting Review*, **59**(3), pp. 390 - 418.

Kaplan, R. S. and Norton, D. P. (1992), The balanced scorecard - Measures that drive performance. *Harvard Business Review*, **70**(1), pp. 71 - 79.

Kaplan, R. S. and Norton, D. P. (1993), Putting the balanced scorecard to work. *Harvard Business Review*, **71**(5), pp. 134 - 142.

Kaplan, R. S. and Norton, D. P. (1996a), Using the balanced scorecard as a strategic management system. *Harvard Business Review*, **74**(1), pp. 75 - 85.

Kaplan, R. S. and Norton, D. P. (1996b), *The balanced scorecard : Translating strategy into action.* Harvard Business School press. Boston, USA.

Kaplan, R. S. and Norton, D. P. (2000), Having a trouble with your strategy? Then map it. *Harvard Business Review*, **Sept - Oct**, pp. 3 - 11.

Kaplan, R. S. and Norton, D. P. (2001), Transforming the balanced scorecard from performance measurement to strategic management: Part II. *Accounting Horizons*, **15**(2), pp. 147 - 160.

Karlsson, C. and Ahlstrom, P. (1996), Assessing changes towards lean production. *International Journal of Operations & Production Management*, **16**(2), pp. 24 - 41.

Katayama, H. and Bennett, D. (1996), Lean production in a changing competitive world: A Japanese perspective. *International Journal of Operations & Production Management*, **16**(2), pp. 8 - 23

Kaynak, H. (2005), Implementing JIT purchasing: Does the level of technical complexity in the production process make a difference? *Journal of Managerial Issues*, **XVII**(1), pp. 76 – 100.

Kazazi, A. and Keller, A. Z. (1994), Benefits derived from JIT by European manufacturing companies. *Industrial Management and Data Systems*, **94**(10), pp. 12 - 14.

Keller, A. Z. and Kazazi, A. (1993), "Just-in-time" manufacturing systems: A literature review. *Industrial Management and Data Systems*, **93**(7), pp. 2-32

Kermode, G. R., Sivaloganathan, S. and Shahin, T. M. (2000), Value Analysis - the Technique: State of the Art and Future Directions. *Engineering Manufacture*, **214**(4), pp. 301 - 312.

Kerssens-van Drongelen, I. C. and Bilderbeek, J. (1999), R & D performance measurement: more than choosing a set of metrics. *R&D Management*, **29**(1), pp. 35 - 46.

Kim, G. C. and Takeda, E. (1996), The JIT philosophy is the culture in Japan. *Production and Inventory Management Journal*, **37**(1), pp. 47 - 51.

Kodali, R. and Routroy, S. (2006), Decision framework for selection of facilities location in competitive supply chain. *Journal of Advanced Manufacturing Systems*, **5**(1), pp. 89 - 110.

Krafcik, J. F. (1988), Triumph of the lean production system. *Sloan Management Review*, **30**(1), pp. 41 – 52.

Kulatunga, U., Amaratunga, D. and Haigh, R. (2007), Performance measurement in the construction research and development. *International Journal of Productivity and Performance Management*, **56**(8), pp. 673 - 688.

Lancaster, G. (2005), *Research methods in management : a concise introduction to research in management and business consultancy.* Oxford. UK.

Laugen, B. T., Acur, N., Boer, H. and Frick, J. (2005), Best manufacturing practices: What do the best-performing companies do? *International Journal of Operations & Production Management*, **25**(2), pp. 131 - 150.

Lee, A. H. I., Chen, W. C. and Chang, C. J. (2008), A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan. *Expert Systems with Applications*, **34**, p. 96–107.

Lessner, J. (1989), Performance measurement in a just-in-time environment: Can traditional performance measurements still be used. *Journal of Cost management for the Manufacturing Industries*, **3**, pp. 22 - 28.

Lohman, C., Fortuin, L. and Wouters, M. (2004), Designing a performance measurement system: A case study. *European Journal of Operational Research*, **156**, pp. 267 - 286.

Longenecker, C. O. and Fink, L. S. (2001), Improving management performance in rapidly changing organisations. *Journal of Management Development*, **20**(1), pp. 7 - 18.

Luu, T. V., Kim, S. Y. and Cao, H. L. (2008), Performance measurement of construction firms in developing countries. *Construction Management and Economics*, **26**(4), pp. 373 - 386.

MacDuffie, J. P. (1995), Human resource bundles and manufacturing performance: Organisational logic and flexible production systems in the world auto industry. *Industrial and Labour Relations Review*, **48**(2), pp. 197 - 221.

Maisel, L. S. (1992), Performance measurement: The balanced scorecard approach. *Journal of Cost management*, **6**(2), pp. 47 - 52.

Manoochehri, G. H. (1988), JIT for small manufacturers. *Journal of Small Business Management*, **26**(4), pp. 22 - 30.

Martin, R. (1997), Do we practise quality principles in the performance measurement of critical success factors? *Total Quality Management*, **8**(6), pp. 428 – 444

Mazany, P. (1995), A case study: Lessons from progressive implementation of just-in-time in a small knitwear manufacturer. *International Journal of Operations & Production Management*, **15**(9), pp. 271 - 288.

McIlhattan, R. D. (1987), How cost management systems can support the JIT philosophy. *Management Accounting*, **69**(3), pp. 20 - 26.

McLachlin, R. (1997), Management initiatives and just-in-time manufacturing. *Journal of Operations Management*, **15**(4), pp. 271 - 292.

Medori, D. and Steeple, D. (2000), A framework for auditing and enhancing performance measurement systems. *International Journal of Operations & Production Management*, **20**(5), pp. 520 - 533.

Mia, L. (2000), Just-in-time manufacturing, management accounting systems and profitability. *Accounting and Business Research*, **30**(2), pp. 137 - 151.

MINITAB (2003), *Meet MINITAB.* Minitab Inc., USA.

Misterek, S. D. A., Dooley, K. J. and Anderson, J. C. (1992), Productivity as a performance measure. *International Journal of Operations & Production Management*, **12**(1), pp. 29 - 45.

Mistry, J. J. (2005), Origins of profitability through JIT processes in the supply chain. *Industrial Management and Data Systems*, **105**(6), pp. 752 - 768.

Monczka, R. and Morgan, J. P. (1996), Supplier integration a new level of supply chain management. *Purchasing*, **120**(1), pp. 110 - 113.

Monden, Y. (1994), *Toyota Production System : An Integrated Approach to Just-in-Time*. 2nd ed., Chapman and Hall. London, UK.

Moullin, M. (2002), *Delivering excellence in health and social care.* Open University Press. Buckingham.

Nakamura, M., Sakakibara, S. and Schroeder, R. G. (1998), Adaptation of just-in-time manufacturing methods at U.S. and Japanese owned plants: Some empirical evidence. *IEEE Transactions on Engineering Management*, **45**(3), pp. 230 - 240.

Nanni, A. J., Dixon, J. R. and Vollman, T. E. (1992), Integrated performance measurement: Management accounting to support the new manufacturing realities. *Journal of Management Accounting Research*, **4**, pp. 1-19.

National Statistics (2006), *Economic trends: Annual supplement.* London: HMSO.

Neely, A. (2005), The evolution of performance measurement research: Developments in the last decade and a research agenda for the next. *International Journal of Operations & Production Management*, **25**(12), pp. 1264 - 1277.

Neely, A., Adams, C. and Crowe, P. (2001), The performance prism in practice. *Journal of Business Performance Management*, **5**(2), pp. 6 - 12.

Neely, A., Gregory, M. and Platts, K. (1995), Performance measurement system design. *International Journal of Operations & Production Management*, **15**(4), pp. 80 - 116.

Norris, D. M. (1992), A study of JIT implementation techniques using the analytic hierarchy process model. *Production and Inventory Management Journal*, **33**(3), pp. 49 - 53.

Oakland, J. S. (2003), *Statistical Process Control.* 5th ed., Butterworth-Heinemann Publishers. Oxford, UK.

Ohno, T. (1982), How the Toyota production system was created. *Japanese Economic Studies*, **10**(4), pp. 83 - 101.

Ohno, T. (1988), *Toyota production system: Beyond large scale production.* Productivity Press. Cambridge, MA.

Oliver, N., Delbridge, R. and Lowe, J. (1996), The European auto components industry: Manufacturing performance and practice. *International Journal of Operations & Production Management*, **16**(11), pp. 85 - 97.

Oliver, N. and Wilkinson, B. (1993), *The Japanization of British industry: New developments in the 1990s*. 2nd ed., Blackwell Publishers. Oxford, UK.

Olsen, E. (2004), *Lean manufacturing management: the relationship between practice and firm level financial performance*. PhD Thesis, Ohio State University (CD-ROM). http://www.cob.calpoly.edu/faculty/CourseMaterials/olsen/Dissertation_EOO_22.pdf .

Oral, E. L., Mistikoglu, G. and Erdis, E. (2003), JIT in developing countries - a case study of the Turkish prefabrication sector. *Building & Environment*, **38**(6), pp. 853 - 860.

Oxford American Dictionary (1980), *Oxford American Dictionary*. *in* Ehrlich, E., Flexner, S. B., Carruth, G. and Hawkins, J. M. USA: Oxford University Press.

Ozbayrak, M., Cagil, G. and Kubat, C. (2004), How successfully does JIT handle machine breakdowns in an automated manufacturing system? *Journal of Manufacturing Technology Management*, **15**(6), pp. 479 - 494.

Pandya, K. V. and Boyd, J. (1995), Appraisal of JIT using financial measures. *International Journal of Operations and Production Management*, **15**(9), pp. 200 - 209.

Pheng, L. S. (1992), The Just-In-Time concept to improving manufacturing productivity: Is it applicable to the construction industry? *Construction Papers*, **Paper No. 08**.

Pheng, L. S. and Chuan, C. J. (2001), Just-In-Time management of precast concrete components. *Journal of Construction Engineering & Management*, **127**(6), pp. 494 - 501.

Pheng, L. S. and Chuan, C. J. (2001), Just-in-Time management in precast concrete construction: a survey of the rediness of main contractors in Singapore. *Integrated Manufacturing Systems*, **12**(6), pp. 416 - 429.

Polat, G. and Arditi, D. (2005), The JIT materials management system in developing countries. *Construction Management and Economics*, **23**, pp.697-712.

Powell, T. C. (1995), Total quality management as competitive advantage: A review and empirical study. *Strategic Management Journal*, **16**(1), pp. 15 - 37

Prasad, B. (1995), JIT quality matrices for strategic planning and implementation. *International Journal of Operations & Production Management*, **15**(9), pp. 116 - 142.

Prasad, B. (1995), A structured methodology to implement judiciously the right JIT tactics. *Production Planning and Control*, **6**(6), pp. 564 - 577.

Procurement Executive Association (1998), *Guide to a balanced scorecard performance measurement methodology.* (CD-ROM).

http://professionals.pr.doe.gov/ma5/MA5Web.nsf/d152596b6fe7366485256a5d005a2259/7363elable5a429a85256ae80042cb6d/$FILE/BalancedScorecardPerfAndMeth.pdf .

Pratt, D. (2005), A comment on the debate between Max Moullin and Fabrizio Bocci. *Perspective on Performance*, 4(2).

Procter, S. J. (1994), Just-in-time manufacturing: Its impact on UK stock ratios. *Logistics Information Management*, **7**(1), pp. 41 - 48.

Production Modelling Limited (2005), *Case Studies - Automotive*. (CD-ROM). <http://www.simulation.co.uk/casestudies_automotive.htm >.

ProModel (2005), *Simulation for the agile enterprise*. (CD-ROM). <http://www.simulation.co.uk/ProModel.pdf >.

Pun, K. F. and White, A. S. (2005), A performance measurement paradigm for integrating strategy formulation: A review of systems and frameworks. *International Journal of Management Reviews*, **7**(1), pp. 49 - 71.

Punniyamoorthy, M. and Murali, R. (2008), Balanced score for the balanced scorecard: a benchmarking tool. *Benchmarking. An International Journal*, **15**(4), pp. 420 - 443.

Rahnejat, H. and Khan, M. K. (1998), Use of analytic hierarchy process approach in classification of push, pull and hybrid push-pull systems for production planning. *International Journal of Operations & Production Management*, **18**(11), pp. 1134 - 1151.

Ramarapu, N. K., Mehra, S. and Frolick, M. N. (1995), A comparative analysis and review of JIT implementation research. *International Journal of Operations & Production Management*, **15**(1), pp. 38 - 49

Rangone, A. (1996), An analytical hierarchy process framework for comparing the overall performance of manufacturing departments. *International Journal of Operations & Production Management*, **16**(8), pp. 104 - 119.

Razmi, J., Rahnejat, H. and Khan, M. K. (1998), Use of analytic hierarchy process approach in classification of push, pull and hybrid push-pull systems for production planning. *International Journal of Operations & Production Management*, **18**(11), pp. 1134 - 1151.

Reid, R. D. and Sanders, N. R. (2005), *Operations management: An integrated approach.* John Wiley & Sons, Inc, USA.

Remenyi, D., Williams, B., Money, A. and Swartz, E. (2000), *Doing Research in Business and Management.* SAGE Publications. London.

Ridgway, V. F. (1956), Dysfunctional consequences of performance measurement. *Administrative Science Quarterly*, **1**(2), pp. 240 - 247.

Robinson, S. (1994), Simulation projects: Building the right conceptual model. *Industrial Engineering*, **26**(9), pp. 34 - 36.

Robson, C. (1993), *Real world research: A resource for social scientists and practitioner researchers*. Blackwell Publishers. Oxford.

Rockart, J. F. (1979), Chief executives define their own data needs. *Harvard Business Review*, **57**(2), pp. 81 - 93.

Roy, R. K. (2001), *Design of experiments using the Taguchi approach.* Wiley Interscience Publication. Canada.

Saaty, T. L. (1980), *The Analytic Hierarchy Process.* McGraw-Hill. New York.

Saaty, T. L. (2001), *The Analytic Network Process*. 2nd ed., Pittsburgh, PA.

Saaty, T. L. (2004), Decision making: The analytic hierarchy and network processes (AHP/ANP). *Journal of Syatems Science and Systems Engineering*, **13**(1), pp. 1 - 34.

Sakakibara, S., Flynn, B. B., Schroeder, R. G. and Morris, W. T. (1997), The impact of just-in-time manufacturing and its infrastructure on manufacturing performance. *Management Science*, **43**(9), pp. 1246 - 1257.

Sandanayake Y.G. and Oduoza C.F. (2005), Development of a Performance Measurement System in JIT Enabled Manufacturing Environments: A Preliminary Study, *The 15th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)*, 18-20th July 2005 at Bilbao, Spain, pp. 778 – 785.

Sandanayake, Y. G. and Oduoza, C. F. (2007), Design of a performance measurement system for just-in-time production: a methodological framework. *International Journal of Manufacturing Technology and Management*, **10**(2/3), pp. 276 - 293.

Sandanayake, Y. G. and Oduoza, C. F. (2008), Performance measurement model for just-in-time manufacturing plant. *The 18th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM).* Skovde, Sweeden, 30th June - 02nd July 2008, pp. 870 – 867.

Sandanayake, Y. G., Oduoza, C. F. and Proverbs, D. G. (2007) Simulation, modelling and analysis of key JIT drivers in an automotive component manufacturing environment. *The 17th International Conference on Flexible Automation and*

Intelligent Manufacturing (FAIM). Philadelphia, USA, 18-20th June 2007, pp. 91 – 98.

Sandanayake, Y. G., Oduoza, C. F. and Proverbs, D. G. (2008), Systematic modelling and simulation approach for JIT performance optimization. *Robotics and Computer Integrated Manufacturing*, 24, pp. 735 – 743.

Sanger, M. (1998), Supporting the balanced scorecard. *Work Study*, **47**(6), pp. 197 - 200.

Sarkar, B. R. and Fitzsimmons, J. A. (1989), The performance of push and pull systems: a simulation and comparative study. *International Journal of Production Research*, **27**(10), pp. 1715 - 1731.

Savsar, M. (1996), Effect of kanban withdrawal policies and other factors on the performance of JIT systems: a simulation study. *International Journal of Production Research*, **34**(10), pp. 2879 - 2899.

Schonberger, R. J. (1982a), *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*. Free Press. New York

Schonberger, R. J. (1982b), The transfer of Japanese manufacturing management approaches to U.S. industry. *Academy of Management Review*, **7**(3), pp. 479 - 487.

Searcy, D. L. (2004), Aligning the balanced scorecard and a firm's strategy using the analytic hierarchy process. *Management Accounting Quarterly*, **5**(4), pp.1-10.

Sedara, D., Gable, G. and Rosemann, M. (2001), *A balanced scorecard approach to enterprise systems performance measurement.* Proceedings of the Twelfth Australasian Conference on Information Systems. ACIS, pp. 573 - 584.

Shah, R. and Ward, P. T. (2003), Lean manufacturing: context, practice bundles and performance. *Journal of Operations Management*, **21**(2), pp. 129 - 149.

Shingo, S. (1985), *A revolution in manufacturing: The SMED system.* Productivity Press. Cambridge, MA.

Singh, R. K., Choudhury, A. K., Tiwari, M. K. and Maull, R. S. (2006), An integrated fuzy-bases decision support system for the selection of lean tools: a case study from the steel industry. *IMechE*, **220**, pp. 1735 - 1749.

Skinner, W. (1974), The focused factory. *Harvard Business Review*, **52**(3), pp. 113 - 121.

Skinner, W. (1986), The productivity paradox. *Harvard Business Review*, **64**(4), pp. 55 - 59.

Sohal, A. S., Keller, A. Z. and Fouad, R. H. (1988), A review of literature relating to JIT. *International Journal of Operations & Production Management*, **9**(3), pp.15 – 25.

Spear, S. and Bowan, H. K. (1999), Decoding the DNA of the Toyota production system. *Harvard Business Review*, **Sept-Oct**, pp. 97 - 106.

Spencer, M. S. and Guide, V. D. (1995), An exploration of the components of JIT: Case study and survey results. *International Journal of Operations & Production Management*, **15**(5), pp. 72 - 83.

Spencer, M. S., Rogers, D. S. and Daugherty, P. J. (1994), JIT systems and external logistics suppliers. *International Journal of Operations and Production Management*, **14**(6), pp. 60 - 74.

Sriparavastu, L. and Gupta, T. (1997), An empirical study of just-in-time and total quality management principles implementation in manufacturing firms in the USA. *International Journal of Operations & Production Management*, **17**(12), pp. 1215 - 1232.

Standard, C. and Davis, D. (2001), *Pull systems: Implementation experience in American manufacturing: JIT manufacturing/lean production*. Orlando, Florida.

Stank, T. P. and Crum, M. R. (1997), Just-In-Time management and transportation service performance in a cross-border setting. *Transportation Journal*, **36**(3), pp. 31 - 42.

Sumanth, D. J. (1984), *Productivity engineering and management.* McGraw-Hill, Inc., USA.

Suwignjo, P., Bititci, U. S. and Carrie, A. S. (2000), Quantitative models for performance measurement system. *International Journal of Production Economics*, **64**(1-3), pp. 231 - 241.

Svensson, G. (2000), JIT - Another re-invension of the wheel. IMRL 2000 - *Third Internaitonal Meeting for Research in Logistics*. Trois Rivieres.

Swamidass, P. M. (2007) The effect of TPS on US manufacturing during 1981 - 1998: Inventory increased or decreased as a function of plant performance. *International Journal of Production Research*, **45**(16), pp. 3763 - 3778.

Swamidass, P. M. and Nair, A. (2004), What top management thinks about benefits of hard and soft manufacturing technologies. *IEEE Transactions on Engineering Management*, **51**, pp. 462 – 471.

Swenson, D. W. and Cassidy, J. (1993), The effect of JIT on management accounting. *Journal of Cost Management for the Manufacturing Industry*, **7**(1), pp. 39 - 47.

The Society of Management Accountants of Canada (1993), *Management accounting guidelines 19: Implementing just-in-time production system.* The Society of Management Accountants of Canada. Ontario, Canada.

Tommelein, I. D. and Weissenberger, M. (1999), *More just-in-time: Location of buffers in structural steel supply and construction process*. University of California, USA.

Toyoda, E. (1987), *Toyota: First Fifty Years in Motion*. Kodansha International. Tokyo

Tsai, C. S. (2002), Evaluation and optimisation of integrated manufacturing system operations using Taguchi's experiment design in computer simulation. *Computers and Industrial Engineering*, **43**(3), pp. 591 - 604.

Tsang, A. H. C. (1999), Measuring maintenance performance: a holistic approach. *International Journal of Operations & Production Management*, **19**(7), pp. 691 - 715.

Unal, R., Stanley, D. O. and Joyner, C. R. (1993), Propulsion system design optimisation using the Taguchi method. *IEEE Transactions on Engineering Management*, **40**(3), pp. 315 - 322.

Upton, D. (1998), Just-in-time and performance measurement systems. *International Journal of Operations and Production Management*, **18**(11), pp. 1101 - 1110.

Voss, C. A. (1984), Japanese manufacturing management practices in the UK. *International Journal of Operations & Production Management*, **4**(2), pp. 31 - 38.

Voss, C. A. (1995), Alternative paradigms for manufacturing strategy. *International Journal of Operations & Production Management*, **15**(4), pp. 5 - 16

Voss, C. A. and Blackmon, K. (1998), Differences in manufacturing strategy decisions between Japanese and Western manufacturing plants: the role of strategic time orientation. *Journal of Operations Management*, **16**(2 - 3), pp. 147 - 158.

Voss, C. A. and Robinson, S. J. (1987), Application of just-in-time manufacturing techniques in the United Kingdom. *International Journal of Operations & Production Management*, **7**(4), pp. 46 - 52.

Vuppalapati, K., Ahire, S. L. and Gupta, T. (1995), JIT and TQM: A case for joint implementation. *International Journal of Operations & Production Management*, **15**(5), pp. 84 - 94.

Wafa, M. and Yasin, M. M. (1998), A conceptual framework for effective implementation of JIT: An empirical investigation. *International Journal of Operations & Production Management*, **18**(11), pp. 1111 - 1124.

Walleigh, R. C. (1986), What's your excuse for not using JIT. *Harvard Business Review*, **64**(2), pp. 38 - 54.

Welgama, P. S. and Mills, R. G. J. (1995), Use of simulation in the design of a JIT system. *International Journal of Operations & Production Management*, **15**(9), pp. 245 - 260.

White, R. E. (1993), An empirical assessment of JIT in U.S. manufacturers. *Production and Inventory Management Journal*, **34**, pp. 38 - 42.

White, R. E., Pearson, J. N. and Wilson, J. R. (1999), JIT manufacturing: A survey of implementations in small and large U.S. manufacturers. *Management Science*, **45**(1), pp. 1 - 15.

White, R. E. and Prybutok, V. (2001), The relationship between JIT practices and type of production system. *Omega: The International Journal of Management Science*, **29**(2), pp. 113 - 124.

White, R. E. and Ruch, W. A. (1990), The composition and scope of JIT. *Operations Management Review*, **7**(3 & 4), pp. 9 - 18.

Williams, K., Haslam, C., Williams, J., Cutler, T., Adcroft, A. and Johal, S. (1992), Against lean production. *Economy and Society*, **21**(3), pp. 321 - 354

Womack, J. P. and Jones, D. T. (1996), *Lean thinking: Banish waste and create wealth in your corporation.* Simon and Schuster. New York.

Womack, J. P., Jones, D. T. and D., R. (1990), *The Machine that Changed the World.* Rawson-MacMillan. New York.

Yasin, M. M., Wafa, M. and Small, M. H. (2004), Benchmarking JIT: An analysis of JIT implementations in the manufacturing service and public sectors. *Benchmarking: An International Journal*, **11**(1), pp. 74 - 92.

Yavuz, H. and Satir, A. (1995), Kanban-based operational planning and control: Simulation modelling. *Production Planning and Control*, **6**(4), pp. 331 - 344.

Yin, R. K. (2003), *Case study research: Design and methods.* Sage Publications. London, UK.

Yurdakul, M. and Ic, Y. T. (2005), Development of a performance measurement model for manufacturing companies using the AHP and TOPSIS approaches. *International Journal of Production Research*, **43**(21), pp. 4609 - 4641.

Zeramdini, W., Aigbedo, H. and Monden, Y. (2000), Bicriteria sequencing for just-in-time mixed model assembly line. *International Journal of Production Research*, **38**(15), pp. 3451 - 3470.

LIST OF APPENDICES

APPENDIX – 1

OPEN-ENDED INTERVIEW INSTRUMENT

Questionnaire for Open-Ended Interviews

Company Name :

Address :

SECTION – I

1. **How many product varieties do you market? (Please state product names and volume)**

   Number of product varieties? ………………………………………………

   Name of main products : …………………………………………………..

   Volume of production : …………………………………………………….

2. **Who are your customers? ……………………………………………….**

   ……………………………………………………………………………..

3. **Number of employees in your plant.**

   Employees in manufacturing operations: ……………………….

   Executive, administration and sales staff: ………………………

4. **Does your company have steady or sporadic demand for your products? ……………………………………………………………**

5. **How many production lines do you have in your plant? ………………**

   ……………………………………………………………………………..

6. **Production process layout of the plant (Please use separate sheet).**

7. **What are the performance / productivity measures you used in your plant? How do you use those measures to interpret performance in your plant?**

   ……………………………………………………………………………..

   ……………………………………………………………………………..

   ……………………………………………………………………………..

   ……………………………………………………………………………..

8. Please indicate to what extent each of the following JIT techniques/practices has been applied in your firm. ***(Please refer table of definitions in page 8 for more details)***

(5) Always used *(4) Usually used* *(3) Reasonably used*
(2) Occasionally used *(1) Never used*

(a)	Various types of communications such as display boards, news letters, meetings, open houses	5	4	3	2	1
(b)	Kanban	5	4	3	2	1
(c)	Quality control activities	5	4	3	2	1
(d)	Quality circles	5	4	3	2	1
(e)	Other control systems such as compensation system, accounting systems, capital appreciation systems, supplier selection procedures, bidding strategies	5	4	3	2	1
(f)	Value added analysis	5	4	3	2	1
(g)	Line balancing	5	4	3	2	1
(h)	Set-up time elimination plans	5	4	3	2	1
(i)	Supplier integration	5	4	3	2	1
(j)	Level schedules	5	4	3	2	1
(k)	Fast inventory transportation systems	5	4	3	2	1
(l)	JIT purchasing	5	4	3	2	1
(m)	Integrated product & process design	5	4	3	2	1
(n)	Total productive and preventive maintenance	5	4	3	2	1
(o)	Work place organisation plans	5	4	3	2	1
(p)	Group technology	5	4	3	2	1
(q)	Focused factory	5	4	3	2	1
(r)	Employee training	5	4	3	2	1
(s)	Multifunctional employee	5	4	3	2	1
(t)	Innovation of new products and processes	5	4	3	2	1

9. Use following *Scale 1* to indicate (By crossing/deleting/highlighting the number) the extent to which, JIT has improved the production and *Scale 2* to indicate importance of those JIT characteristics to your plant.

Scale 1 (of Improvement):

(5) More than 75% *(4) 50% - 74%* *(3) 25% - 49%*
(2) 10% - 24% *(1) 1% - 9%* *(0) No improvement (0%)*

Scale 2 (of Importance):

(3) Extremely Important *(2) Fairly Important* *(1) Not at all Important*

	Characteristics of JIT	***Improvement***							***Importance***		
(a)	Reduce set-up time	5	4	3	2	1	0		3	2	1
(b)	Increase automation	5	4	3	2	1	0		3	2	1
(c)	Improve quality	5	4	3	2	1	0		3	2	1
(d)	Improve productivity	5	4	3	2	1	0		3	2	1
(e)	Improve profitability	5	4	3	2	1	0		3	2	1
(f)	Reduce scrap / waste	5	4	3	2	1	0		3	2	1
(g)	Reduce lead time	5	4	3	2	1	0		3	2	1
(h)	On time delivery	5	4	3	2	1	0		3	2	1
(i)	Improve worker skills flexibility	5	4	3	2	1	0		3	2	1
(j)	Reduce Work-in-Process and finished goods inventory	5	4	3	2	1	0		3	2	1
(k)	Improve production process stability & capability	5	4	3	2	1	0		3	2	1
(l)	Reduce lot size	5	4	3	2	1	0		3	2	1
(m)	Improve customer focus & satisfaction	5	4	3	2	1	0		3	2	1
(n)	Improve supplier relationship	5	4	3	2	1	0		3	2	1
(o)	Reduce unit cost	5	4	3	2	1	0		3	2	1
(p)	Reduce space for storage and production line	5	4	3	2	1	0		3	2	1
(q)	Reduce defect rate, rework and warranty cost	5	4	3	2	1	0		3	2	1
(r)	Reduce equipment down time	5	4	3	2	1	0		3	2	1
(s)	Increase number of new products & processes	5	4	3	2	1	0		3	2	1
(t)	Reduce time for new product /process launch	5	4	3	2	1	0		3	2	1

10. What problems do you encounter in applying JIT techniques in your plant?

(3) Always a barrier (2) Occasionally a barrier (1) Never a barrier

(a)	Workers resistance	3	2	1
(b)	Managers resistance	3	2	1
(c)	Lack of knowledge about JIT principles and techniques	3	2	1
(d)	Lack of support from various departments	3	2	1
(e)	Lack of training and education in the use of JIT techniques	3	2	1
(f)	Lack of advanced machinery	3	2	1
(g)	Lack of funds	3	2	1
(h)	Communication barriers with suppliers	3	2	1
(i)	Material transportation problems	3	2	1
(j)	Influence of trade unions	3	2	1
(k)	Factory floor layout	3	2	1
(l)	Working hours	3	2	1
(m)	Manufacturing process (e.g. Job shop, batch, repetitive, flow process)	3	2	1
(n)	Legislations, regulations and policies	3	2	1
(o)	Other external forces	3	2	1
(p)	Any other (please specify)			

SECTION – II

1. Do you have any customer related problems?

(i) Customer satisfaction retention
(ii) Quality related problems
(iii) Product returns, repairs, defect rates, warranty costs
(iv) On time delivery
(v) Any other …………………………………………

If Yes: Factors affecting to that problem

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

2. Do you have any production process related problems?

(i) High setup time and change over time
(ii) High scrap and waste (waste from overproduction, delays, transportation, unnecessary processing, excess inventory, unnecessary motion and defects)
(iii) Quality related problems (Authority to stop mistakes)
(iv) High lead time
(v) High inventory storage (raw material, WIP and Finished goods)
(vi) Low process stability and capability
(vii) High lot size
(viii) Storage problems
(ix) High equipment downtime
(x) Any other ………………………………………………….

If Yes: Factors affecting to that problem

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

3. Do you have any supplier related problems?

(i) Lack of on time delivery of raw materials
(ii) High cost of raw materials
(iii) Distance from supplier location
(iv) Quality defects of suppliers goods
(v) Lack of supplier relationship
(vi) Any other ………………………………………………….

If Yes: Factors affecting to that problem

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

4. Do you have any employee related problems?

(i) Employee satisfaction
(ii) Lack of training
(iii) Influence of trade unions
(iv) Productivity
(v) Lack of multifunctional knowledge
(vi) High labour idle time
(vii) Any other ………………………………………………….

If Yes: Factors affecting to that problem
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

5. Do you have any environmental related problems?

(i) High scrap and waste (waste from overproduction, delays, transportation, unnecessary processing, excess inventory, unnecessary motion and defects)
(ii) Complaints from social, environmental and statutory bodies
(iii) Any other ………………………………………………….

If Yes: Factors affecting to that problem
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

6. Do you have any innovation related problems?

(i) Lack of innovation
(ii) Time to introduce new product
(iii) Lack of research and development experts
(iv) Lack of finance for R&D
(v) Lack of time for R&D
(vi) Any other ………………………………………………….

If Yes: Factors affecting to that problem
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

7. Do you have any financial related problems?

(i) Low profits
(ii) High unit cost
(iii) High fixed costs (what are fixed costs)
(iv) High variable costs (What are variable costs)
(v) Lack of capital
(vi) Any other ………………………………………………….

If Yes: Factors affecting to that problem
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

Thank you very much for your cooperation.

Yasangika Sandanayake

Table of Definitions

JIT Technique	Definition
Communication methods	Various communication methods such as display boards, newsletters, meetings that are essential to communicate goals, targets and information to employees
Kanban	Pull system for parts-movement that depends on visible records or cards or boxes/containers to take parts from one workstation to another on a production line; it signals a cycle of replenishment for materials
Quality control activities	Techniques such as statistical process control (SPC), fool-proof (pokayoke), automation (jidoka), standardisation, pareto chart, cause and effect diagram, check sheets that can be used to maintain and improve the level of quality and quality control
Quality circles	A small group of employees formed for problem solving
Other control methods	Commonly used other JIT control methods such as compensation systems, individual and department performance evaluation systems, capital appreciation system, make vs. buy decision process and supplier selection procedure
Value added analysis	JIT divides all activities in to two categories as value added and non-value added; waste from over production, delays, transportation, unnecessary processing, excess inventory, unnecessary motion and defects are best-known non-value added activities
Line balancing	Balancing of tasks of an assembly line to work stations to minimise the number of workstations and to minimise the total amount of idle time at all stations
Setup time elimination plans	Plan to reduce or eliminate the time required for a machine or production line to convert from the production of one product to another product
Supplier integration	Find out the best supplier/s and integrate them into the production system with the aim of better quality, lower price and on time delivery to avoid non-value adding activities
Level schedules	Even distribution of material and labour requirements among workstations according to the demand on production
Inventory transportation system	Fast movement of materials to the factory and within the factory floor in response to signals from the pull control system
JIT purchasing	Purchase of materials and components according to the demand from the production process so that they are delivered just as needed for production
Integrated product & process design	Integrate product and process design to production process to avoid quality problems due to poor product and process design and hence to continuous quality improvement
Total productive & preventive maintenance	Continuous effort to maintain and upgrade production plants to avoid breakdowns and to increase flexibility, better quality and continuous flow
Work place organisation plan	Well organised physical layout of the production floor, tools, fixtures and materials according to their ease of use and frequency of use; keep factory floor clean and tidy so that problems are easily visible; eliminate storage facilities
Group technology	Identify similarities of technologies and machines and establish them in the best possible manner on the factory floor, e.g. cell production
Focused factory	Simplify organisation structure, manufacturing system and technologies with limited number of products and minimum complexities
Employee training	Train employees and provide them with new skills to participate in JIT implementation, quality control, pull control system and continuous improvement
Multifunction employee	Employee should be able to move to different plants, work sites or functions according to the demand and type of product in a JIT environment to achieve flexibility
Innovation	Innovation of new products and processes, and investment in the next generation of technologies

APPENDIX – 2

SURVEY INSTRUMENT FOR
DENSO MANUFACTURING (UK) LTD.

15th January 2006

Denso Manufacturing (UK) Ltd.
Queensway Campus
Hortonwood
Telford
TF1 7FS

Dear Sir/Madam

SURVEY INSTRUMENT

I am Mrs. Y. G. Sandanayake, doctoral student in School of Engineering and Built Environment, at the University of Wolverhampton conducting a research under the supervision of Dr. Chike Oduoza and Prof. David Proverbs on developing a performance measurement system for just-in-time (JIT) enabled manufacturing environments. JIT manufacturing is an operational strategy oriented towards planned elimination of all wastes and continuous improvement. The ultimate objective is to supply the right materials at the right time in the right amount at each step in the process to achieve higher productivity, higher quality of processes and products, lower costs and higher profits. This research will develop a performance measurement system to measure performance in JIT enabled manufacturing environments and make appropriate recommendations to industry practitioners.

The purpose of this questionnaire is to recognise the key JIT drivers and key performance indicators and to identify the factors affecting customer satisfaction, financial stability, performance of internal business processes, employee productivity, supplier efficiency, innovation and growth and sustainability. It will further assess the impact of key JIT drivers on aforementioned perspectives.

The company (C/O Phil Tomlinson) has agreed to participate in this case study. It will be appreciated if you would kindly assist me to complete the attached questionnaire. If the space provided is insufficient, or there are other matters on which you wish to comment, please feel free to use supplementary sheets. **Your response to this survey will be held in the strictest confidence**. If you have any questions about this study, or you would like additional information to assist you in reaching a decision about participation, please contact

- Dr. C. F. Oduoza – Director of Studies (C.F.Oduoza@wlv.ac.uk)
- Mr. P. Tomlinson – Senior Training Officer, DMUK (P.Tomlinson@denso-mfg.co.uk)
- Mrs. Y. G. Sandanayake – Researcher (01902323834 or Y.G.Sandanayake@wlv.ac.uk)

Thank you for your time and contribution.

Yours sincerely

Mrs. Y. G. Sandanayake
Doctoral Research Student
RIATec
University of Wolverhampton

QUESTIONNAIRE FOR THE CASE STUDY COMPANY

Company Name : Denso Manufacturing UK Ltd.
Nature of Products : Automotive Components
Address : Denso Manufacturing (UK) Ltd., Queensway Campus, Hortonwood, Telford, TF1 7FS

Please indicate which category in the pair is **more important for measuring overall performance of your company**. If one category is more significant than the other, please indicate the magnitude of its importance over the other category.

The scale for magnitude is as follows

Intensity of Importance	Definition	Description
1	Equal Importance	Two categories are equally important in performance measurement
2	Moderate Importance	One of the categories is slightly more important than the other
3	Strong Importance	One of the categories is strongly more important than the other
4	Very Strong Importance	One of the categories is strongly favoured over the other, and its dominance is demonstrated in practice
5	Extreme Importance	The difference in importance between the two categories is so extreme that the categories are on the verge of not being comparable

Example 1: If customer perspective is judged as strongly more important (3 times more important) than financial perspective in overall performance measurement, please indicate as follows.

COMPARISON PAIR			MORE IMPORTANT A or B		LEVEL OF IMPORTANCE				
A	VS	B							
Customer Perspective	VS	Financial Perspective	[✓ A]	B	1	2	[✓ 3]	4	5

Example 2: If innovation and growth perspective is equally important (level of importance = 1) to the environmental and safety perspective in overall performance measurement, please indicate as follows.

COMPARISON PAIR			MORE IMPORTANT A or B		LEVEL OF IMPORTANCE				
A	VS	B							
Innovation & Growth Perspective	VS	External Environmental Group Perspective	A	B	[✓ 1]	2	3	4	5

PART I – MEASURING OVERALL PERFORMANCE

Please indicate **which category in the pair is more important for measuring overall performance of your Company**. Please indicate the magnitude of importance of each category.

COMPARISON PAIR			MORE IMPORTANT A or B		LEVEL OF IMPORTANCE				
A	**VS**	**B**							
Customer Perspective	VS	Financial Perspective	**A**	**B**	1	2	3	4	5
Customer Perspective	VS	Internal Business Processes Perspective	**A**	**B**	1	2	3	4	5
Customer Perspective	VS	Employee Perspective	**A**	**B**	1	2	3	4	5
Customer Perspective	VS	Supplier Perspective	**A**	**B**	1	2	3	4	5
Customer Perspective	VS	Innovation and Growth Perspective	**A**	**B**	1	2	3	4	5
Customer Perspective	VS	External Environmental Group Perspective	**A**	**B**	1	2	3	4	5
Financial Perspective	VS	Internal Business Processes Perspective	**A**	**B**	1	2	3	4	5
Financial Perspective	VS	Employee Perspective	**A**	**B**	1	2	3	4	5
Financial Perspective	VS	Supplier Perspective	**A**	**B**	1	2	3	4	5
Financial Perspective	VS	Innovation and Growth Perspective	**A**	**B**	1	2	3	4	5
Financial Perspective	VS	External Environmental Group Perspective	**A**	**B**	1	2	3	4	5
Internal Business Processes Perspective	VS	Employee Perspective	**A**	**B**	1	2	3	4	5
Internal Business Processes Perspective	VS	Supplier Perspective	**A**	**B**	1	2	3	4	5
Internal Business Processes Perspective	VS	Innovation and Growth Perspective	**A**	**B**	1	2	3	4	5
Internal Business Processes Perspective	VS	External Environmental Group Perspective	**A**	**B**	1	2	3	4	5
Employee Perspective	VS	Supplier Perspective	**A**	**B**	1	2	3	4	5
Employee Perspective	VS	Innovation and Growth Perspective	**A**	**B**	1	2	3	4	5
Employee Perspective	VS	External Environmental Group Perspective	**A**	**B**	1	2	3	4	5
Supplier Perspective	VS	Innovation and Growth Perspective	**A**	**B**	1	2	3	4	5
Supplier Perspective	VS	External Environmental Group Perspective	**A**	**B**	1	2	3	4	5
Innovation and Growth Perspective	VS	External Environmental Group Perspective	**A**	**B**	1	2	3	4	5

PART II – INFLUENCE OF JIT DRIVERS ON EACH PERSPECTIVE

Customer Perspective

(i) What does your company think about your customers? Did you consider your customer in mission and vision statements?

…………………………………………………………………
…………………………………………………………………
…………………………………………………………………

(ii) What are the key performance indicators you have considered and performance targets you have set in performance measurement of customer perspective?

…………………………………………………………………
…………………………………………………………………
…………………………………………………………………

(iii) What are the factors affecting customer satisfaction?

…………………………………………………………………
…………………………………………………………………
…………………………………………………………………

(iv) Please indicate which JIT driver in the pair is more influential on performance of customer perspective. Please indicate the magnitude of importance of each driver.

COMPARISON PAIR			**MORE IMPORTANT A or B**		**LEVEL OF IMPORTANCE**				
A	**VS**	**B**							
Line balancing	VS	Setup time elimination plans	**A**	**B**	1	2	3	4	5
Line balancing	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Line balancing	VS	Quality control	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Quality control	**A**	**B**	1	2	3	4	5
Multifunction employee	VS	Quality control	**A**	**B**	1	2	3	4	5

(v) Please state the reasons for the selected magnitudes.

…………………………………………………………………
…………………………………………………………………
…………………………………………………………………
…………………………………………………………………
…………………………………………………………………

Financial Perspective

(i) What does your company think about your stake holders? Did you consider your stakeholders in mission and vision statements?

…………………………………………………………………

…………………………………………………………………

…………………………………………………………………

(ii) What are the key performance indicators you have considered and performance targets you have set in performance measurement of financial perspective?

…………………………………………………………………

…………………………………………………………………

…………………………………………………………………

(iii) What are the factors affecting financial prosperity?

…………………………………………………………………

…………………………………………………………………

…………………………………………………………………

…………………………………………………………………

(iv) Please indicate which JIT driver in the pair is more influential on performance of financial perspective. Please indicate the magnitude of importance of each driver.

COMPARISON PAIR			**MORE IMPORTANT A or B**		**LEVEL OF IMPORTANCE**				
A	**VS**	**B**							
Line balancing	VS	Setup time elimination plans	**A**	**B**	1	2	3	4	5
Line balancing	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Line balancing	VS	Quality control	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Quality control	**A**	**B**	1	2	3	4	5
Multifunction employee	VS	Quality control	**A**	**B**	1	2	3	4	5

(v) Please state the reasons for the selected magnitudes.

…………………………………………………………………

…………………………………………………………………

…………………………………………………………………

…………………………………………………………………

…………………………………………………………………

Internal Business Processes Perspective

(i) What does your company think about your internal business processes? Did you consider your internal business processes in mission and vision statements?

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

(ii) What are the key performance indicators you have considered and performance targets you have set in performance measurement of internal business processes?

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

(iii) What are the factors affecting performance of internal business processes?

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

(iv) Please indicate which JIT driver in the pair is more influential on performance of internal business processes perspective. Please indicate the magnitude of importance of each driver.

COMPARISON PAIR			**MORE IMPORTANT A or B**		**LEVEL OF IMPORTANCE**				
A	**VS**	**B**							
Line balancing	VS	Setup time elimination plans	**A**	**B**	1	2	3	4	5
Line balancing	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Line balancing	VS	Quality control	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Quality control	**A**	**B**	1	2	3	4	5
Multifunction employee	VS	Quality control	**A**	**B**	1	2	3	4	5

(v) Please state the reasons for the selected magnitudes.

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

Employee Perspective

(i) What does your company think about your employees? Did you consider your employee in mission and vision statements?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(ii) What are the key performance indicators you have considered and performance targets you have set in performance measurement of employee perspective?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(iii) What are the factors affecting employee performance?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(iv) Please indicate which JIT driver in the pair is more influential on performance of employee perspective. Please indicate the magnitude of importance of each driver.

COMPARISON PAIR			MORE IMPORTANT A or B		LEVEL OF IMPORTANCE				
A	**VS**	**B**							
Line balancing	VS	Setup time elimination plans	**A**	**B**	1	2	3	4	5
Line balancing	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Line balancing	VS	Quality control	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Quality control	**A**	**B**	1	2	3	4	5
Multifunction employee	VS	Quality control	**A**	**B**	1	2	3	4	5

(v) Please state the reasons for the selected magnitudes.

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

Supplier Perspective

(i) What does your company think about your supplier? Did you consider your supplier in mission and vision statements?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(ii) What are the key performance indicators you have considered and performance targets you have set in performance measurement of supplier perspective?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(iii) What are the factors affecting supplier performance?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(iv) Please indicate which JIT driver in the pair is more influential on performance of supplier perspective. Please indicate the magnitude of importance of each driver.

COMPARISON PAIR			**MORE IMPORTANT A or B**		**LEVEL OF IMPORTANCE**				
A	**VS**	**B**							
Line balancing	VS	Setup time elimination plans	**A**	**B**	1	2	3	4	5
Line balancing	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Line balancing	VS	Quality control	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Multifunction employee	**A**	**B**	1	2	3	4	5
Setup time elimination plans	VS	Quality control	**A**	**B**	1	2	3	4	5
Multifunction employee	VS	Quality control	**A**	**B**	1	2	3	4	5

(v) Please state the reasons for the selected magnitudes.

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

Innovation and Growth Perspective

(i) What does your company think about it's innovation and growth? Did you consider innovation and growth in mission and vision statements?

……………………………………………………………………
……………………………………………………………………
……………………………………………………………………

(ii) What are the key performance indicators you have considered and performance targets you have set in performance measurement of innovation and growth?

……………………………………………………………………
……………………………………………………………………
……………………………………………………………………

(iii) What are the factors affecting performance of innovation and growth perspective?

……………………………………………………………………
……………………………………………………………………
……………………………………………………………………
……………………………………………………………………

(iv) Please indicate which JIT driver in the pair is more influential on performance of innovation and growth perspective. Please indicate the magnitude of importance of each driver.

COMPARISON PAIR			**MORE IMPORTANT A or B**	**LEVEL OF IMPORTANCE**
A	**VS**	**B**		
Line balancing	VS	Setup time elimination plans	**A** **B**	1 2 3 4 5
Line balancing	VS	Multifunction employee	**A** **B**	1 2 3 4 5
Line balancing	VS	Quality control	**A** **B**	1 2 3 4 5
Setup time elimination plans	VS	Multifunction employee	**A** **B**	1 2 3 4 5
Setup time elimination plans	VS	Quality control	**A** **B**	1 2 3 4 5
Multifunction employee	VS	Quality control	**A** **B**	1 2 3 4 5

(v) Please state the reasons for the selected magnitudes.

……………………………………………………………………
……………………………………………………………………
……………………………………………………………………
……………………………………………………………………
……………………………………………………………………

External Environmental Groups Perspective

(i) What does your company think about your external environmental groups? Did you consider external environmental groups in mission and vision statements?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(ii) What are the key performance indicators you have considered and performance targets you have set in performance measurement of external environmental groups?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(iii) What are the factors affecting performance of sustainable production?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

(iv) Please indicate which JIT driver in the pair is more influential on performance of external environmental groups perspective. Please indicate the magnitude of importance of each driver.

COMPARISON PAIR			**MORE IMPORTANT A or B**	**LEVEL OF IMPORTANCE**
A	**VS**	**B**		
Line balancing	VS	Setup time elimination plans	**A** **B**	1 2 3 4 5
Line balancing	VS	Multifunction employee	**A** **B**	1 2 3 4 5
Line balancing	VS	Quality control	**A** **B**	1 2 3 4 5
Setup time elimination plans	VS	Multifunction employee	**A** **B**	1 2 3 4 5
Setup time elimination plans	VS	Quality control	**A** **B**	1 2 3 4 5
Multifunction employee	VS	Quality control	**A** **B**	1 2 3 4 5

(v) Please state the reasons for the selected magnitudes.

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

DEFINITIONS

EXTENDED BALANCED SCORECARD

	Perspective	Definition
1	Financial perspective	To succeed financially, how should we appear to our shareholders?
2	Customer perspective	To achieve our mission, how should we appear to our customers?
3	Internal business processes perspective	To satisfy our shareholders and customers, what business processes must we excel at?
4	Innovation and growth perspective	To achieve our vision, how will we sustain our ability to change and improve?
5	Employee perspective	To satisfy our employee and improve their performance, how should we inculcate organisational citizenship?
6	Supplier perspective	To achieve target production, what operating parameters do we want suppliers to adhere to?
7	External environmental groups perspective	To meet with external requirements such as legislations, how will we use our ability and resources to comply?

JIT DRIVERS

	JIT Driver	Definition
1	Line balancing	Balancing of tasks of an assembly line to work stations to minimise the number of workstations and to minimise the total amount of idle time at all stations.
2	Setup time elimination plans	Plan for reduce or eliminate the time required for a machine or production line to convert from the production of one product to another product.
3	Multifunction employee	Employee ability to move into different plants, work sites or functions according to the demand and type of product in JIT environment to achieve flexibility.
4	Quality control (QC)	Use techniques such as statistical process control (SPC), fool-proof (pokayoke), Automation (Jidoka), standardisation, pareto chart, cause and effect diagram, check sheets, quality circles, etc. to maintain and improve the level of quality, quality control and quality management.

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

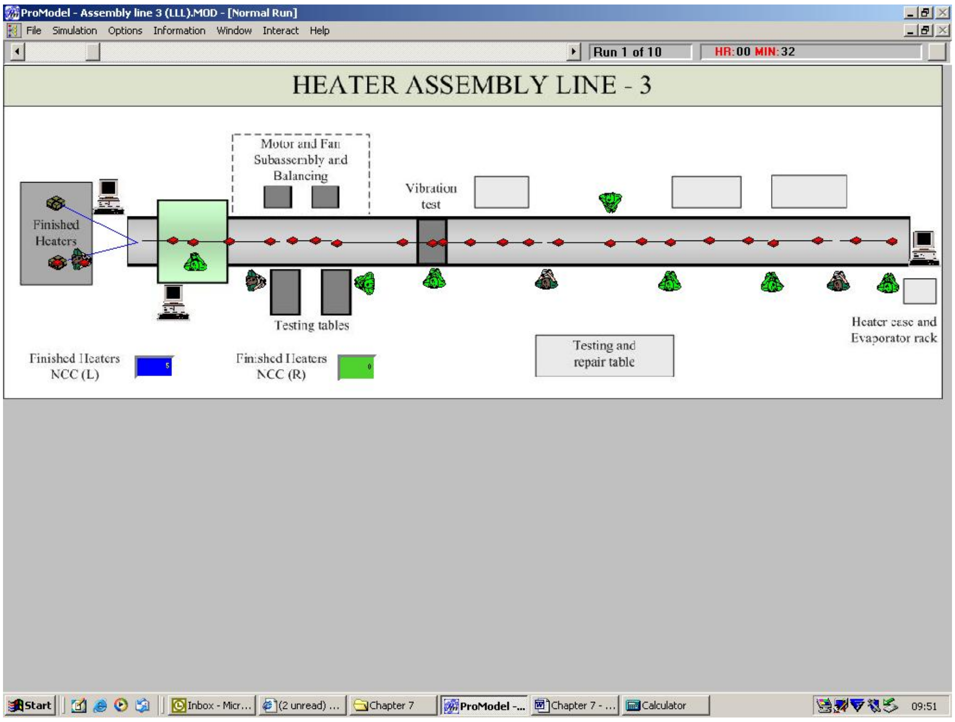
Yasangika Sandanayake

APPENDIX – 3

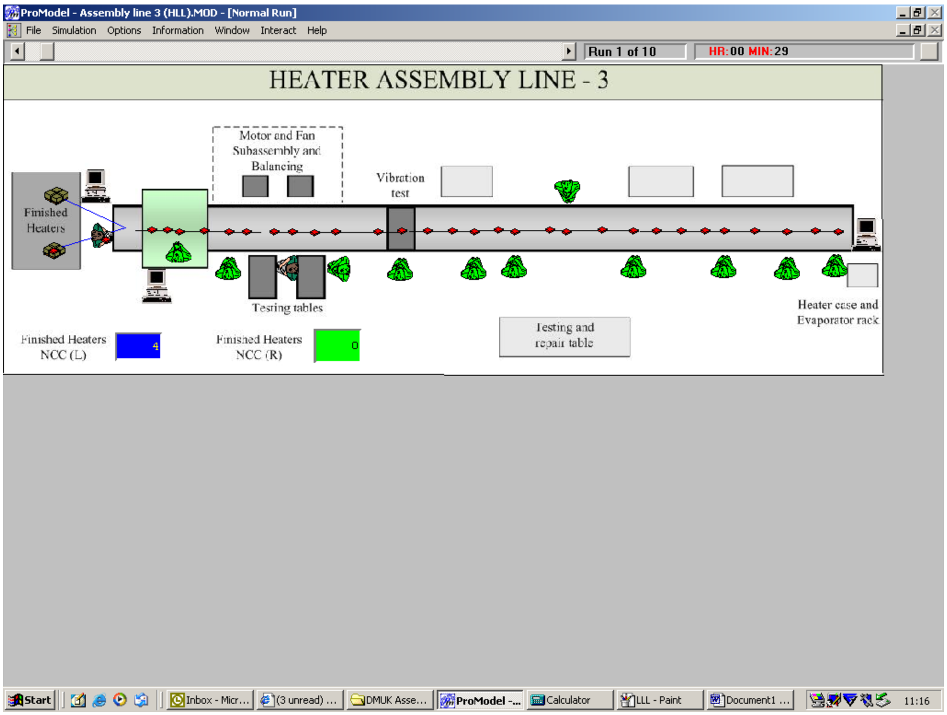
SIMULATION SCREENSHOTS, PROGRAMMING AND RESULTS OF DENSO MANUFACTUTING (UK) LTD. CASE STUDY

SIMULATION EXPERIMENT SCREENSHOTS

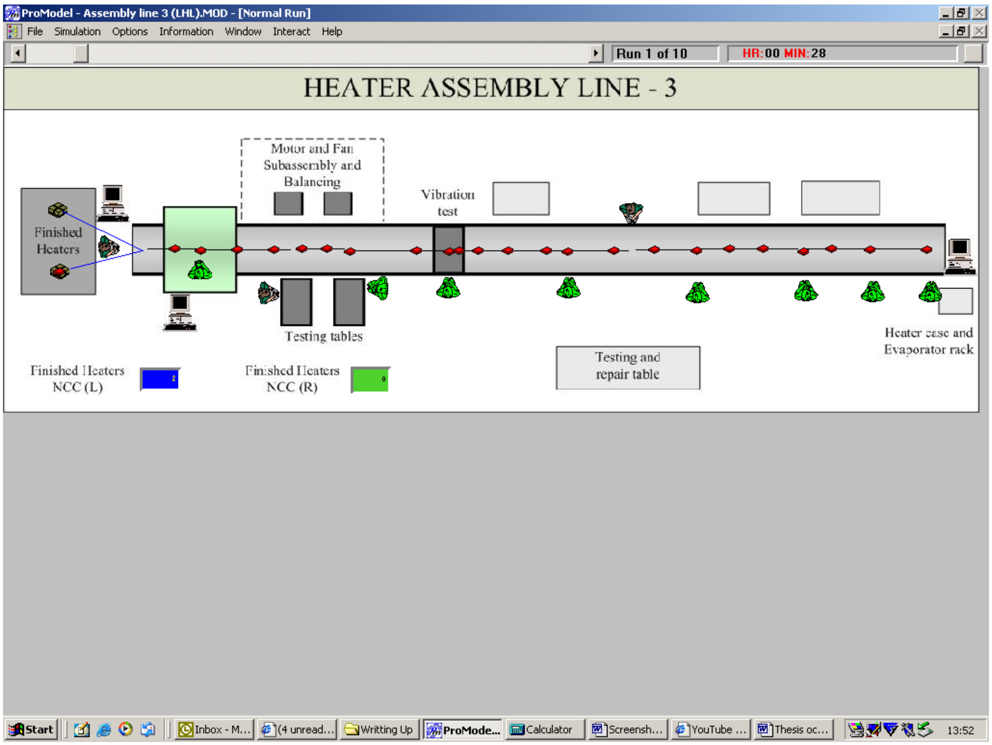
Experiment 1: Line Balancing (Multifunction Employee): 'L', Setup Time: 'L' and Quality Control: 'L'



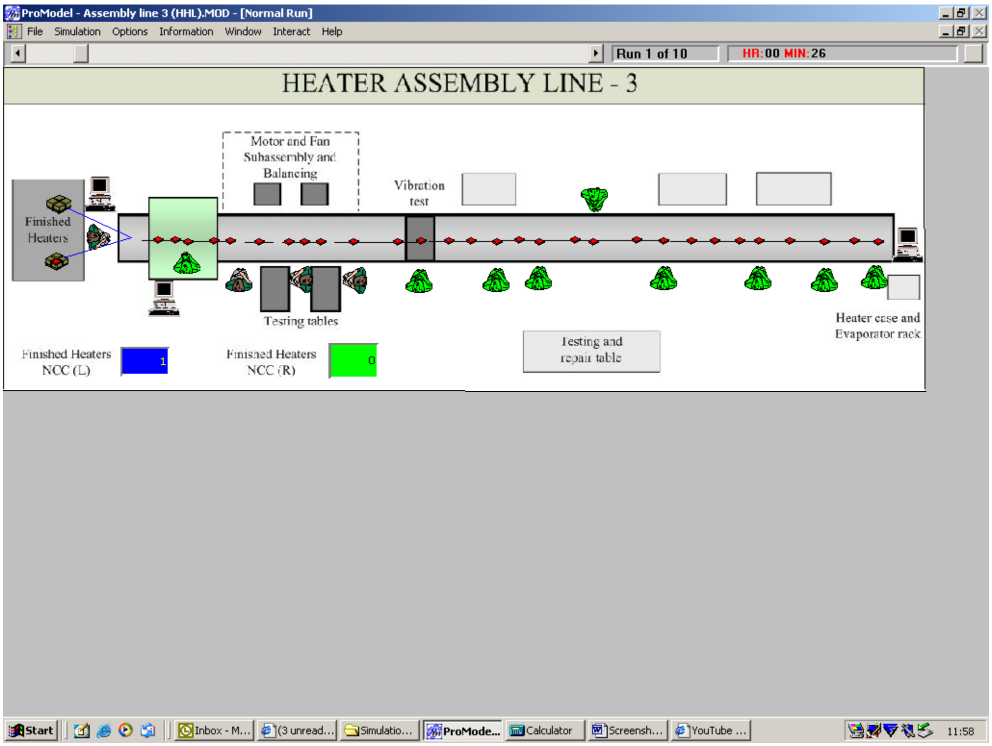
Experiment 2: Line Balancing (Multifunction Employee): 'H', Setup Time: 'L' and Quality Control: 'L'



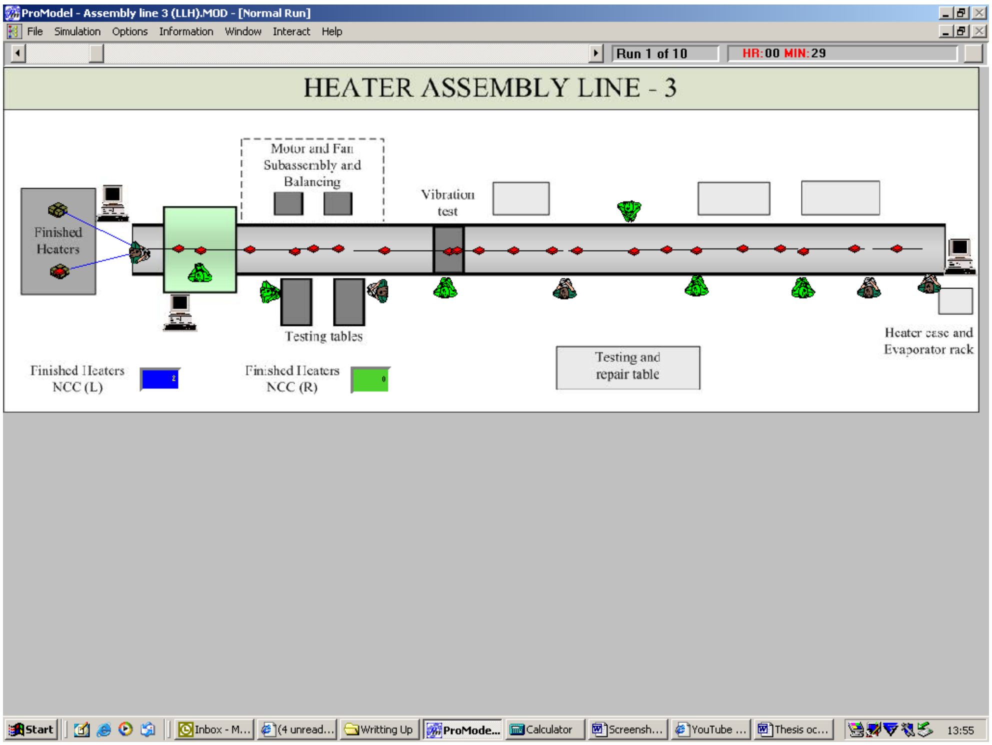
Experiment 3: Line Balancing (Multifunction Employee): ‘L’, Setup Time: ‘H’ and Quality Control: ‘L’



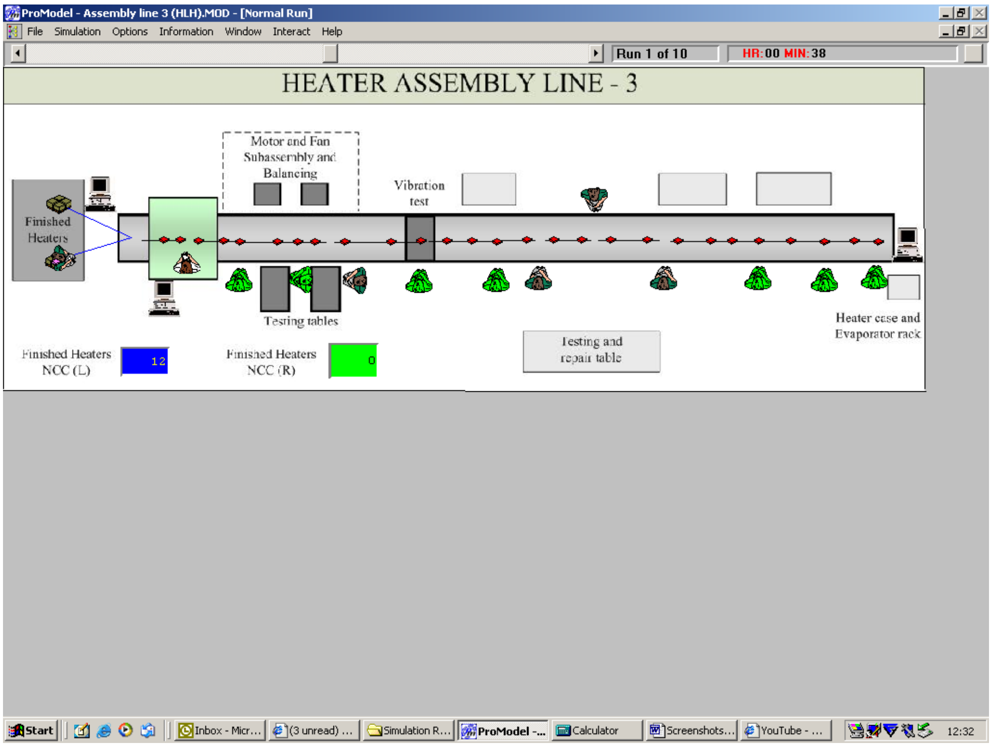
Experiment 4: Line Balancing (Multifunction Employee): ‘H’, Setup Time: ‘H’ and Quality Control: ‘L’



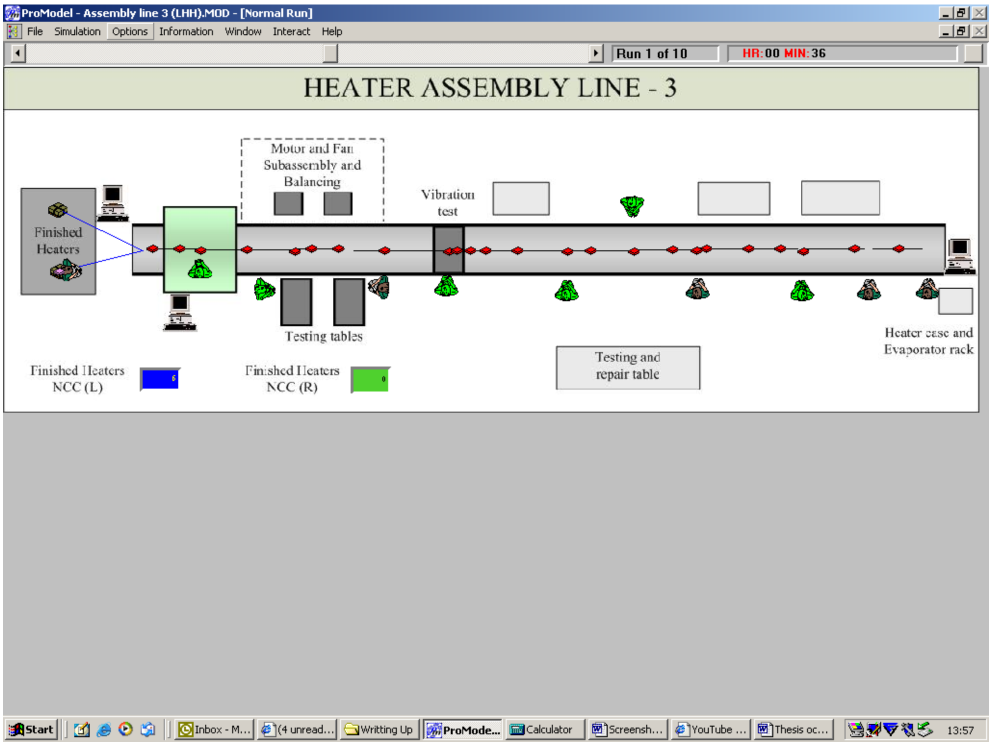
Experiment 5: Line Balancing (Multifunction Employee): 'L', Setup Time: 'L' and Quality Control: 'H'



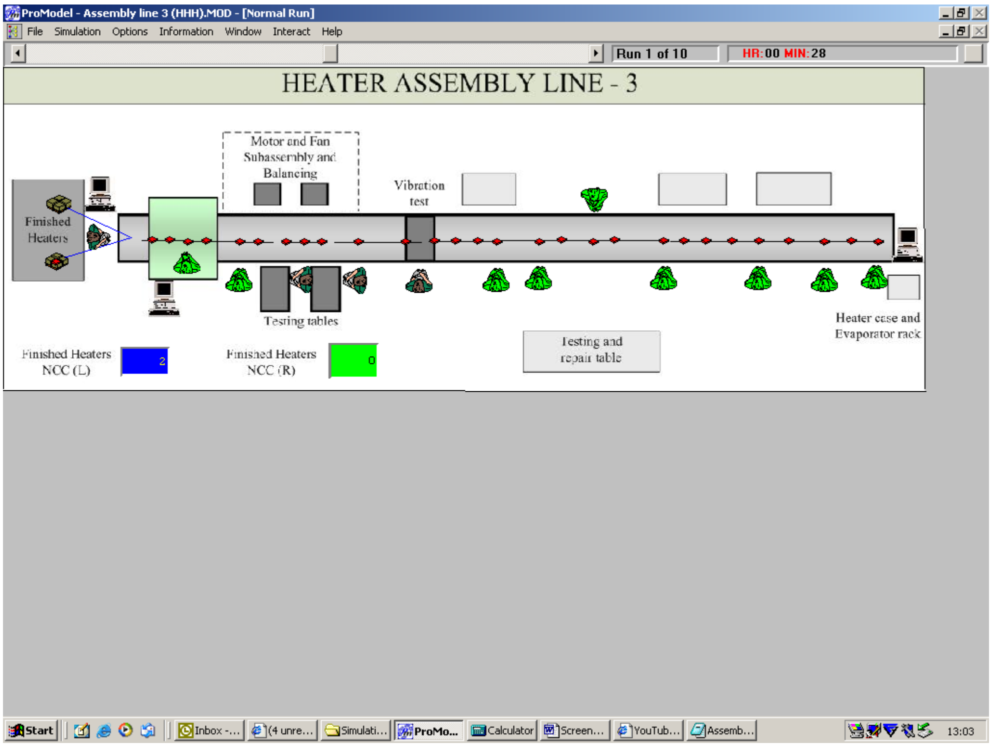
Experiment 6: Line Balancing (Multifunction Employee): 'H', Setup Time: 'L' and Quality Control: 'H'



Experiment 7: Line Balancing (Multifunction Employee): 'L', Setup Time: 'H' and Quality Control: 'H'



Experiment 8: Line Balancing (Multifunction Employee): 'H', Setup Time: 'H' and Quality Control: 'H'



SIMULATION PROGRAMMING

Experiment 1: Line Balancing (Multifunction Employee): ‘L’, Setup Time: ‘L’ and Quality Control: ‘L’

```
********************************************************************************
*                                                                              *
*                         Formatted Listing of Model:                          *
* E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation Programming\Assembly line
3 (LLL).MOD *
*                                                                              *
********************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Meters

********************************************************************************
*                                  Locations                                   *
********************************************************************************

  Name                  Cap      Units Stats       Rules          Cost
  --------------------- -------- ----- ----------- -------------- ------------
  Assembly_station_1    200      1     Time Series Oldest, FIFO,
  Assembly_station_2    1        1     Time Series Oldest, FIFO,
  Assembly_station_3    1        1     Time Series Oldest, FIFO,
  Assembly_station_4    1        1     Time Series Oldest, FIFO,
  Assembly_station_5    1        1     Time Series Oldest, FIFO,
  Assembly_station_6    1        1     Time Series Oldest, FIFO,
  Assembly_station_7    1        1     Time Series Oldest, FIFO,
  Assembly_station_8    1        1     Time Series Oldest, FIFO,
  Assembly_station_9    1        1     Time Series Oldest, FIFO,
  Assembly_station_10   1        1     Time Series Oldest, FIFO,
  Assembly_station_11   1        1     Time Series Oldest, FIFO,
  Conveyor_1_2          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_2_3          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_3_4          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_4_5          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_5_6          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_6_7          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_7_8          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_8_9          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_9_10         INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_10_11        INFINITE 1     Time Series Oldest, FIFO,
  Finished_heater_box_L 6        1     Time Series Oldest, FIFO,
  Finished_heater_box_R 6        1     Time Series Oldest, FIFO,

********************************************************************************
*                                   Entities                                   *
********************************************************************************

  Name                    Speed (mpm)  Stats       Cost
  ----------------------- ------------ ----------- ------------
  NCC_L                   0            Time Series
  Finished_heater_boxes_L 0            Time Series
  NCC_R                   0            Time Series
  Finished_heater_boxes_R 0            Time Series

********************************************************************************
*                                Path Networks                                 *
********************************************************************************

  Name     Type        T/S              From     To       BI   Dist/Time  Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------- ------------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0        1
                                        N1       N3       Bi   2.0        1

********************************************************************************
*                                  Interfaces                                  *
********************************************************************************

  Net        Node       Location
  ---------- ---------- --------------------
  Net1       N1         Assembly_station_11
             N2         Finished_heater_box_L
             N3         Finished_heater_box_R

********************************************************************************
*                                  Resources                                   *
********************************************************************************

                              Res        Ent
  Name         Units Stats    Search     Search Path       Motion        Cost
  ------------ ----- -------- ---------- ------ ---------- ------------- -----------
  Associate_1  1     By Unit  Least Used Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_2  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_3  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm
  Associate_4  1     By Unit  None       Oldest           Empty: 50 mpm
                                                          Full: 50 mpm

  Associate_5  1     By Unit  None       Oldest           Empty: 50 mpm
                                                          Full: 50 mpm

  Associate_6  1     By Unit  None       Oldest           Empty: 50 mpm
                                                          Full: 50 mpm

  Associate_7  1     By Unit  None       Oldest           Empty: 50 mpm
                                                          Full: 50 mpm

  Associate_8  1     By Unit  None       Oldest           Empty: 50 mpm
                                                          Full: 50 mpm

  Associate_9  1     By Unit  None       Oldest           Empty: 50 mpm
                                                          Full: 50 mpm

  QA_Associate 1     By Unit  None       Oldest           Empty: 50 mpm
                                                          Full: 50 mpm

  Associate_10 1     By Unit  Closest    Oldest Net1      Empty: 50 mpm
                                                Home: N1  Full: 50 mpm
                                                (Return)


********************************************************************************
*                                  Processing                                  *
********************************************************************************

                                                         Process
Routing

 Entity                  Location              Operation            Blk  Output
Destination           Rule     Move Logic
 ----------------------- -------------------- ------------------   ---- ---------------------- ----
----------------- -------  ------------
 NCC_L                   Assembly_station_1    USE Associate_1 FOR N(9.28, 1.1) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_1_2


                                                                    1    NCC_L
Conveyor_1_2          SEND 1
 NCC_L                   Conveyor_1_2          SEND 1 NCC_L TO Assembly_station_2
                                                                    1    NCC_L
Assembly_station_2    SEND 1
 NCC_L                   Assembly_station_2    USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_L TO Conveyor_2_3
                                                                    1    NCC_L
Conveyor_2_3          SEND 1
 NCC_L                   Conveyor_2_3          SEND 1 NCC_L TO Assembly_station_3
                                                                    1    NCC_L
Assembly_station_3    SEND 1
 NCC_L                   Assembly_station_3    USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               USE Associate_3 FOR N(10.8, 0.162) Sec
                                               SEND 1 NCC_L TO Conveyor_3_4
                                                                    1    NCC_L
Conveyor_3_4          SEND 1
 NCC_L                   Conveyor_3_4          SEND 1 NCC_L TO Assembly_station_4
                                                                    1    NCC_L
Assembly_station_4    SEND 1
 NCC_L                   Assembly_station_4    USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               USE Associate_4 FOR N(9.84, 0.855) Sec
                                               SEND 1 NCC_L TO Conveyor_4_5
                                                                    1    NCC_L
Conveyor_4_5          SEND 1
 NCC_L                   Conveyor_4_5          SEND 1 NCC_L TO Assembly_station_5
                                                                    1    NCC_L
Assembly_station_5    SEND 1
 NCC_L                   Assembly_station_5    USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               USE Associate_5 FOR N(13.4, 0.306) Sec
                                               SEND 1 NCC_L TO Conveyor_5_6
                                                                    1    NCC_L
Conveyor_5_6          SEND 1
 NCC_L                   Conveyor_5_6          SEND 1 NCC_L TO Assembly_station_6
                                                                    1    NCC_L
Assembly_station_6    SEND 1
 NCC_L                   Assembly_station_6    USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               USE Associate_6 FOR N(12.8, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_6_7
                                                                    1    NCC_L
Conveyor_6_7          SEND 1
 NCC_L                   Conveyor_6_7          SEND 1 NCC_L TO Assembly_station_7
                                                                    1    NCC_L
Assembly_station_7    SEND 1
 NCC_L                   Assembly_station_7    USE Associate_7 FOR N(18.4, 0.907) Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               USE Associate_7 FOR N(17.9, 0.831) Sec
                                               SEND 1 NCC_L TO Conveyor_7_8
                                                                    1    NCC_L
Conveyor_7_8          SEND 1
 NCC_L                   Conveyor_7_8          SEND 1 NCC_L TO Assembly_station_8
                                                                    1    NCC_L
Assembly_station_8    SEND 1
 NCC_L                   Assembly_station_8    USE Associate_8 FOR N(15.5, 1.72) Sec
```

```
                                               USE Associate_8 FOR N(5.6, 0.39) Sec
                                               USE Associate_8 FOR N(10.2, 1.16) Sec
                                               USE Associate_8 FOR N(9.72, 0.154) Sec
                                               SEND 1 NCC_L TO Conveyor_8_9
                                                                    1    NCC_L
Conveyor_8_9          SEND 1
 NCC_L                   Conveyor_8_9          SEND 1 NCC_L TO Assembly_station_9
                                                                    1    NCC_L
Assembly_station_9    SEND 1
 NCC_L                   Assembly_station_9    USE Associate_9 FOR N(10.3, 1.41) Sec
                                               USE Associate_9 FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_L TO Conveyor_9_10
                                                                    1    NCC_L
Conveyor_9_10         SEND 1
 NCC_L                   Conveyor_9_10         SEND 1 NCC_L TO Assembly_station_10
                                                                    1    NCC_L
Assembly_station_10   SEND 1
 NCC_L                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_L TO Conveyor_10_11
                                                                    1    NCC_L
Conveyor_10_11        SEND 1
 NCC_L                   Conveyor_10_11        SEND 1 NCC_L TO Assembly_station_11
                                                                    1    NCC_L
Assembly_station_11   SEND 1
 NCC_L                   Assembly_station_11   SEND 1 NCC_L TO Finished_heater_box_L
                                               INC Finished_Heaters_L

                                                                    1    NCC_L
Finished_heater_box_L FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_L                   Finished_heater_box_L ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_L

 Finished_heater_boxes_L Finished_heater_box_L USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_L Finished_heater_box_L                      1    Finished_heater_boxes_L EXIT
FIRST 1
 NCC_R                   Assembly_station_1    USE Associate_1 FOR N(9.28, 1.1) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_1_2
                                                                    1    NCC_R
Conveyor_1_2          SEND 1
 NCC_R                   Conveyor_1_2          SEND 1 NCC_R TO Assembly_station_2
                                                                    1    NCC_R
Assembly_station_2    SEND 1
 NCC_R                   Assembly_station_2    USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_R TO Conveyor_2_3
                                                                    1    NCC_R
Conveyor_2_3          SEND 1
 NCC_R                   Conveyor_2_3          SEND 1 NCC_R TO Assembly_station_3
                                                                    1    NCC_R
Assembly_station_3    SEND 1
 NCC_R                   Assembly_station_3    USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               USE Associate_3 FOR N(10.8, 0.162) Sec
                                               SEND 1 NCC_R TO Conveyor_3_4
                                                                    1    NCC_R
Conveyor_3_4          SEND 1
 NCC_R                   Conveyor_3_4          SEND 1 NCC_R TO Assembly_station_4
                                                                    1    NCC_R
Assembly_station_4    SEND 1
 NCC_R                   Assembly_station_4    USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               USE Associate_4 FOR N(9.84, 0.855) Sec
                                               SEND 1 NCC_R TO Conveyor_4_5
                                                                    1    NCC_R
Conveyor_4_5          SEND 1
 NCC_R                   Conveyor_4_5          SEND 1 NCC_R TO Assembly_station_5
                                                                    1    NCC_R
Assembly_station_5    SEND 1
 NCC_R                   Assembly_station_5    USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               USE Associate_5 FOR N(13.4, 0.306) Sec
                                               SEND 1 NCC_R TO Conveyor_5_6
                                                                    1    NCC_R
Conveyor_5_6          SEND 1
 NCC_R                   Conveyor_5_6          SEND 1 NCC_R TO Assembly_station_6
                                                                    1    NCC_R
Assembly_station_6    SEND 1
 NCC_R                   Assembly_station_6    USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               USE Associate_6 FOR N(12.8, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_6_7
                                                                    1    NCC_R
Conveyor_6_7          SEND 1
 NCC_R                   Conveyor_6_7          SEND 1 NCC_R TO Assembly_station_7
                                                                    1    NCC_R
Assembly_station_7    SEND 1
 NCC_R                   Assembly_station_7    USE Associate_7 FOR N(18.4, 0.907) Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               USE Associate_7 FOR N(17.9, 0.831) Sec
                                               SEND 1 NCC_R TO Conveyor_7_8
                                                                    1    NCC_R
Conveyor_7_8          SEND 1
 NCC_R                   Conveyor_7_8          SEND 1 NCC_R TO Assembly_station_8
                                                                    1    NCC_R
Assembly_station_8    SEND 1
```

```
 NCC_R                   Assembly_station_8    USE Associate_8 FOR N(15.5, 1.72) Sec
                                               USE Associate_8 FOR N(5.6, 0.39) Sec
                                               USE Associate_8 FOR N(10.2, 1.16) Sec
                                               USE Associate_8 FOR N(9.72, 0.154) Sec
                                               SEND 1 NCC_R TO Conveyor_8_9
                                                                    1    NCC_R
Conveyor_8_9          SEND 1
 NCC_R                   Conveyor_8_9          SEND 1 NCC_R TO Assembly_station_9
                                                                    1    NCC_R
Assembly_station_9    SEND 1
 NCC_R                   Assembly_station_9    USE Associate_9 FOR N(10.3, 1.41) Sec
                                               USE Associate_9 FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_R TO Conveyor_9_10
                                                                    1    NCC_R
Conveyor_9_10         SEND 1
 NCC_R                   Conveyor_9_10         SEND 1 NCC_R TO Assembly_station_10
                                                                    1    NCC_R
Assembly_station_10   SEND 1
 NCC_R                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_R TO Conveyor_10_11
                                                                    1    NCC_R
Conveyor_10_11        SEND 1
 NCC_R                   Conveyor_10_11        SEND 1 NCC_R TO Assembly_station_11
                                                                    1    NCC_R
Assembly_station_11   SEND 1
 NCC_R                   Assembly_station_11   SEND 1 NCC_R TO Finished_heater_box_R
                                               INC Finished_Heaters_R
                                                                    1    NCC_R
Finished_heater_box_R FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_R                   Finished_heater_box_R ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_R

 Finished_heater_boxes_R Finished_heater_box_R USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_R Finished_heater_box_R                     1    Finished_heater_boxes_R EXIT
FIRST 1

********************************************************************************
*                                   Arrivals                                   *
********************************************************************************

  Entity   Location           Qty each   First Time Occurrences Frequency  Logic
  -------- ------------------ ---------- ---------- ----------- ---------- ------------
  NCC_L    Assembly_station_1 1                     200         1.16
  NCC_R    Assembly_station_1 1                     100         1.16


********************************************************************************
*                              Variables (global)                              *
********************************************************************************

  ID                 Type         Initial value Stats
  ------------------ ------------ ------------- -----------
  Finished_Heaters_L Integer      0             Time Series
  Finished_Heaters_R Integer      0             Time Series
```

Experiment 2: Line Balancing (Multifunction Employee): ‘H’, Setup Time: ‘L’ and Quality Control: ‘L’

```
********************************************************************************
*                                                                              *
*                         Formatted Listing of Model:                          *
* E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation Programming\Assembly line
3 (HLL).MOD *
*                                                                              *
********************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Meters


********************************************************************************
*                                  Locations                                   *
********************************************************************************

  Name                  Cap      Units Stats       Rules          Cost
  --------------------- -------- ----- ----------- -------------- ------------
  Assembly_station_1    200      1     Time Series Oldest, FIFO,
  Assembly_station_2    1        1     Time Series Oldest, FIFO,
  Assembly_station_3    1        1     Time Series Oldest, FIFO,
  Assembly_station_4    1        1     Time Series Oldest, FIFO,
  Assembly_station_5    1        1     Time Series Oldest, FIFO,
  Assembly_station_6    1        1     Time Series Oldest, FIFO,
  Assembly_station_A    1        1     Time Series Oldest, FIFO,
  Assembly_station_7    1        1     Time Series Oldest, FIFO,
  Assembly_station_8    1        1     Time Series Oldest, FIFO,
  Assembly_station_9    1        1     Time Series Oldest, FIFO,
  Assembly_station_B    1        1     Time Series Oldest, FIFO,
  Assembly_station_10   1        1     Time Series Oldest, FIFO,
  Assembly_station_11   1        1     Time Series Oldest, FIFO,
  Conveyor_1_2          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_2_3          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_3_4          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_4_5          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_5_6          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_6_A          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_A_7          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_7_8          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_8_9          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_9_B          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_B_10         INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_10_11        INFINITE 1     Time Series Oldest, FIFO,
  Finished_heater_box_L 6        1     Time Series Oldest, FIFO,
  Finished_heater_box_R 6        1     Time Series Oldest, FIFO,


********************************************************************************
*                                   Entities                                   *
********************************************************************************

  Name                    Speed (mpm)  Stats       Cost
  ----------------------- ------------ ----------- ------------
  NCC_L                   0            Time Series
  Finished_heater_boxes_L 0            Time Series
  NCC_R                   0            Time Series
  Finished_heater_boxes_R 0            Time Series


********************************************************************************
*                                Path Networks                                 *
********************************************************************************

  Name     Type        T/S              From     To       BI   Dist/Time  Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------- ------------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0        1
                                        N1       N3       Bi   2.0        1


********************************************************************************
*                                  Interfaces                                  *
********************************************************************************

  Net        Node       Location
  ---------- ---------- ---------------------
  Net1       N1         Assembly_station_11
             N2         Finished_heater_box_L
             N3         Finished_heater_box_R


********************************************************************************
*                                  Resources                                   *
********************************************************************************

                              Res        Ent
  Name         Units Stats    Search     Search Path       Motion        Cost
  ------------ ----- -------- ---------- ------ ---------- ------------- ------------
  Associate_1  1     By Unit  Least Used Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_2  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_3  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_4  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_5  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_6  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_A  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_7  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_8  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_9  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_B  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  QA_Associate 1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_10 1     By Unit  Closest    Oldest Net1       Empty: 50 mpm
                                                Home: N1   Full: 50 mpm
                                                (Return)


********************************************************************************
*                                  Processing                                  *
********************************************************************************

                                                         Process
Routing

 Entity                  Location              Operation            Blk  Output
Destination           Rule     Move Logic
 ---------------------- -------------------- ------------------   ---- ---------------------- ----
---------------- ------- ------------
 NCC_L                   Assembly_station_1    USE Associate_1 FOR N(9.28, 1.11) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_1_2
                                                                    1    NCC_L
Conveyor_1_2          SEND 1
 NCC_L                   Conveyor_1_2          SEND 1 NCC_L TO Assembly_station_2
                                                                    1    NCC_L
Assembly_station_2    SEND 1
 NCC_L                   Assembly_station_2    USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_L TO Conveyor_2_3
                                                                    1    NCC_L
Conveyor_2_3          SEND 1
 NCC_L                   Conveyor_2_3          SEND 1 NCC_L TO Assembly_station_3
                                                                    1    NCC_L
Assembly_station_3    SEND 1
 NCC_L                   Assembly_station_3    USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               SEND 1 NCC_L TO Conveyor_3_4
                                                                    1    NCC_L
Conveyor_3_4          SEND 1
 NCC_L                   Conveyor_3_4          SEND 1 NCC_L TO Assembly_station_4
                                                                    1    NCC_L
Assembly_station_4    SEND 1
 NCC_L                   Assembly_station_4    USE Associate_4 FOR N(10.8, 0.162) Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               SEND 1 NCC_L TO Conveyor_4_5
                                                                    1    NCC_L
Conveyor_4_5          SEND 1
 NCC_L                   Conveyor_4_5          SEND 1 NCC_L TO Assembly_station_5
                                                                    1    NCC_L
Assembly_station_5    SEND 1
 NCC_L                   Assembly_station_5    USE Associate_5 FOR N(9.84, 0.855) Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               SEND 1 NCC_L TO Conveyor_5_6
                                                                    1    NCC_L
Conveyor_5_6          SEND 1
 NCC_L                   Conveyor_5_6          SEND 1 NCC_L TO Assembly_station_6
                                                                    1    NCC_L
Assembly_station_6    SEND 1
 NCC_L                   Assembly_station_6    USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.4, 0.306) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               SEND 1 NCC_L TO Conveyor_6_A
                                                                    1    NCC_L
Conveyor_6_A          SEND 1
 NCC_L                   Conveyor_6_A          SEND 1 NCC_L TO Assembly_station_A
                                                                    1    NCC_L
Assembly_station_A    SEND 1
 NCC_L                   Assembly_station_A    USE Associate_A FOR N(12.8, 1.29) Sec
                                               USE Associate_A FOR N(18.4, 0.907) Sec
                                               SEND 1 NCC_L TO Conveyor_A_7
                                                                    1    NCC_L
Conveyor_A_7          SEND 1
 NCC_L                   Conveyor_A_7          SEND 1 NCC_L TO Assembly_station_7
                                                                    1    NCC_L
Assembly_station_7    SEND 1
 NCC_L                   Assembly_station_7    USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               SEND 1 NCC_L TO Conveyor_7_8
                                                                    1    NCC_L
Conveyor_7_8          SEND 1
 NCC_L                   Conveyor_7_8          SEND 1 NCC_L TO Assembly_station_8
                                                                    1    NCC_L
Assembly_station_8    SEND 1
 NCC_L                   Assembly_station_8    USE Associate_8 FOR N(17.9, 0.831) Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               SEND 1 NCC_L TO Conveyor_8_9
                                                                    1    NCC_L
Conveyor_8_9          SEND 1
 NCC_L                   Conveyor_8_9          SEND 1 NCC_L TO Assembly_station_9
                                                                    1    NCC_L
Assembly_station_9    SEND 1
 NCC_L                   Assembly_station_9    USE Associate_9 FOR N(5.6, 0.39) Sec
                                               USE Associate_9 FOR N(10.2, 1.16) Sec
                                               USE Associate_9 FOR N(9.72, 0.154) Sec
                                               USE Associate_9 FOR N(10.3, 1.41) Sec
                                               SEND 1 NCC_L TO Conveyor_9_B
                                                                    1    NCC_L
Conveyor_9_B          SEND 1
 NCC_L                   Conveyor_9_B          SEND 1 NCC_L TO Assembly_station_B
                                                                    1    NCC_L
Assembly_station_B    SEND 1
 NCC_L                   Assembly_station_B    USE Associate_B FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_L TO Conveyor_B_10
                                                                    1    NCC_L
Conveyor_B_10         SEND 1
 NCC_L                   Conveyor_B_10         SEND 1 NCC_L TO Assembly_station_10
                                                                    1    NCC_L
Assembly_station_10   SEND 1
 NCC_L                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_L TO Conveyor_10_11
                                                                    1    NCC_L
Conveyor_10_11        SEND 1
 NCC_L                   Conveyor_10_11        SEND 1 NCC_L TO Assembly_station_11
                                                                    1    NCC_L
Assembly_station_11   SEND 1
 NCC_L                   Assembly_station_11   SEND 1 NCC_L TO Finished_heater_box_L
                                               INC Finished_Heaters_L
                                                                    1    NCC_L
Finished_heater_box_L FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_L                   Finished_heater_box_L ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_L
 Finished_heater_boxes_L Finished_heater_box_L USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_L Finished_heater_box_L                      1    Finished_heater_boxes_L EXIT
FIRST 1
 NCC_R                   Assembly_station_1    USE Associate_1 FOR N(9.28, 1.11) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_1_2
                                                                    1    NCC_R
Conveyor_1_2          SEND 1
 NCC_R                   Conveyor_1_2          SEND 1 NCC_R TO Assembly_station_2
                                                                    1    NCC_R
Assembly_station_2    SEND 1
 NCC_R                   Assembly_station_2    USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_R TO Conveyor_2_3
                                                                    1    NCC_R
Conveyor_2_3          SEND 1
 NCC_R                   Conveyor_2_3          SEND 1 NCC_R TO Assembly_station_3
                                                                    1    NCC_R
Assembly_station_3    SEND 1
 NCC_R                   Assembly_station_3    USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               SEND 1 NCC_R TO Conveyor_3_4
                                                                    1    NCC_R
Conveyor_3_4          SEND 1
 NCC_R                   Conveyor_3_4          SEND 1 NCC_R TO Assembly_station_4
                                                                    1    NCC_R
Assembly_station_4    SEND 1
 NCC_R                   Assembly_station_4    USE Associate_4 FOR N(10.8, 0.162) Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               SEND 1 NCC_R TO Conveyor_4_5
                                                                    1    NCC_R
Conveyor_4_5          SEND 1
 NCC_R                   Conveyor_4_5          SEND 1 NCC_R TO Assembly_station_5
                                                                    1    NCC_R
Assembly_station_5    SEND 1
 NCC_R                   Assembly_station_5    USE Associate_5 FOR N(9.84, 0.855) Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               SEND 1 NCC_R TO Conveyor_5_6
                                                                    1    NCC_R
Conveyor_5_6          SEND 1
 NCC_R                   Conveyor_5_6          SEND 1 NCC_R TO Assembly_station_6
                                                                    1    NCC_R
Assembly_station_6    SEND 1
 NCC_R                   Assembly_station_6    USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.4, 0.306) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               SEND 1 NCC_R TO Conveyor_6_A
                                                                    1    NCC_R
Conveyor_6_A          SEND 1
 NCC_R                   Conveyor_6_A          SEND 1 NCC_R TO Assembly_station_A
                                                                    1    NCC_R
Assembly_station_A    SEND 1
 NCC_R                   Assembly_station_A    USE Associate_A FOR N(12.8, 1.29) Sec
                                               USE Associate_A FOR N(18.4, 0.907) Sec
                                               SEND 1 NCC_R TO Conveyor_A_7
                                                                    1    NCC_R
Conveyor_A_7          SEND 1
 NCC_R                   Conveyor_A_7          SEND 1 NCC_R TO Assembly_station_7
                                                                    1    NCC_R
Assembly_station_7    SEND 1
 NCC_R                   Assembly_station_7    USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               SEND 1 NCC_R TO Conveyor_7_8
                                                                    1    NCC_R
Conveyor_7_8          SEND 1
 NCC_R                   Conveyor_7_8          SEND 1 NCC_R TO Assembly_station_8
                                                                    1    NCC_R
Assembly_station_8    SEND 1
 NCC_R                   Assembly_station_8    USE Associate_8 FOR N(17.9, 0.831) Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               SEND 1 NCC_R TO Conveyor_8_9
                                                                    1    NCC_R
Conveyor_8_9          SEND 1
 NCC_R                   Conveyor_8_9          SEND 1 NCC_R TO Assembly_station_9
                                                                    1    NCC_R
Assembly_station_9    SEND 1
 NCC_R                   Assembly_station_9    USE Associate_9 FOR N(5.6, 0.39) Sec
                                               USE Associate_9 FOR N(10.2, 1.16) Sec
                                               USE Associate_9 FOR N(9.72, 0.154) Sec
                                               USE Associate_9 FOR N(10.3, 1.41) Sec
                                               SEND 1 NCC_R TO Conveyor_9_B
                                                                    1    NCC_R
Conveyor_9_B          SEND 1
 NCC_R                   Conveyor_9_B          SEND 1 NCC_R TO Assembly_station_B
                                                                    1    NCC_R
Assembly_station_B    SEND 1
 NCC_R                   Assembly_station_B    USE Associate_B FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_R TO Conveyor_B_10
                                                                    1    NCC_R
Conveyor_B_10         SEND 1
 NCC_R                   Conveyor_B_10         SEND 1 NCC_R TO Assembly_station_10
                                                                    1    NCC_R
Assembly_station_10   SEND 1
 NCC_R                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_R TO Conveyor_10_11
```

```
                                                                    1    NCC_R
Conveyor_10_11        SEND 1
 NCC_R                   Conveyor_10_11       SEND 1 NCC_R TO Assembly_station_11
                                                                    1    NCC_R
Assembly_station_11   SEND 1
 NCC_R                   Assembly_station_11   SEND 1 NCC_R TO Finished_heater_box_R
                                               INC Finished_Heaters_R
                                                                    1    NCC_R
Finished_heater_box_R FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE
 NCC_R                   Finished_heater_box_R ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_R
 Finished_heater_boxes_R Finished_heater_box_R USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10
 Finished_heater_boxes_R Finished_heater_box_R                      1    Finished_heater_boxes_R EXIT
FIRST 1

********************************************************************************
*                                    Arrivals                                  *
********************************************************************************

  Entity   Location           Qty each   First Time Occurrences Frequency  Logic
  -------- ------------------ ---------- ---------- ----------- ---------- ------------
  NCC_L    Assembly_station_1 1                     200         0.88
  NCC_R    Assembly_station_1 1                     100         0.88

********************************************************************************
*                               Variables (global)                             *
********************************************************************************

  ID                 Type         Initial value Stats
  ------------------ ------------ ------------- -----------
  Finished_Heaters_L Integer      0             Time Series
  Finished_Heaters_R Integer      0             Time Series
```

Experiment 3: Line Balancing (Multifunction Employee): ‘L’, Setup Time: ‘H’ and Quality Control: ‘L’

```
********************************************************************************
*                                                                              *
*                          Formatted Listing of Model:                         *
* E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation Programming\Assembly line
3 (LHL).MOD *
*                                                                              *
********************************************************************************

  Time Units:                      Minutes
  Distance Units:                  Meters

********************************************************************************
*                                   Locations                                  *
*******************************************************************************

  Name                  Cap      Units Stats       Rules          Cost
  --------------------- -------- ----- ----------- -------------- ------------
  Assembly_station_1    200      1     Time Series Oldest, FIFO,
  Assembly_station_2    1        1     Time Series Oldest, FIFO,
  Assembly_station_3    1        1     Time Series Oldest, FIFO,
  Assembly_station_4    1        1     Time Series Oldest, FIFO,
  Assembly_station_5    1        1     Time Series Oldest, FIFO,
  Assembly_station_6    1        1     Time Series Oldest, FIFO,
  Assembly_station_7    1        1     Time Series Oldest, FIFO,
  Assembly_station_8    1        1     Time Series Oldest, FIFO,
  Assembly_station_9    1        1     Time Series Oldest, FIFO,
  Assembly_station_10   1        1     Time Series Oldest, FIFO,
  Assembly_station_11   1        1     Time Series Oldest, FIFO,
  Conveyor_1_2          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_2_3          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_3_4          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_4_5          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_5_6          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_6_7          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_7_8          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_8_9          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_9_10         INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_10_11        INFINITE 1     Time Series Oldest, FIFO,
  Finished_heater_box_L 6        1     Time Series Oldest, FIFO,
  Finished_heater_box_R 6        1     Time Series Oldest, FIFO,

********************************************************************************
*                                    Entities                                  *
******************************************************************************

  Name                    Speed (mpm)  Stats       Cost
  ----------------------- ------------ ----------- ------------
  NCC_L                   0            Time Series
  Finished_heater_boxes_L 0            Time Series
  NCC_R                   0            Time Series
  Finished_heater_boxes_R 0            Time Series

********************************************************************************
*                                 Path Networks                                *
********************************************************************************

  Name     Type        T/S              From     To       BI   Dist/Time  Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------- ------------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0        1
                                        N1       N3       Bi   2.0        1
```

```
********************************************************************************
*                                  Interfaces                                  *
********************************************************************************
  Net        Node       Location
  ---------- ---------- ---------------------
  Net1       N1         Assembly_station_11
             N2         Finished_heater_box_L
             N3         Finished_heater_box_R


********************************************************************************
*                                  Resources                                   *
********************************************************************************
                              Res        Ent
  Name         Units Stats    Search     Search Path       Motion        Cost
  ------------ ----- -------- ---------- ------ ---------- ------------- ------------
  Associate_1  1     By Unit  Least Used Oldest            Empty: 50 mpm
                                                           Full: 50 mpm
                                                (Return)

  Associate_2  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_3  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_4  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_5  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_6  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_7  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_8  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_9  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  QA_Associate 1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_10 1     By Unit  Closest    Oldest Net1       Empty: 50 mpm
                                                Home: N1   Full: 50 mpm
                                                (Return)

********************************************************************************
*                                  Processing                                  *
********************************************************************************
                                                         Process
Routing

 Entity                   Location              Operation             Blk  Output
Destination           Rule     Move Logic
 ---------------------- -------------------- ------------------   ---- ---------------------- ----
----------------- -------  ------------
 NCC_L                    Assembly_station_1    USE Associate_1 FOR N(9.28, 1.1) Sec
                                                USE Associate_1 FOR N(7.8, 0.98) Sec
                                                USE Associate_1 FOR N(19.5, 0.902) Sec
                                                USE Associate_1 FOR N(7.99, 1.29) Sec
                                                SEND 1 NCC_L TO Conveyor_1_2


                                                                    1    NCC_L
Conveyor_1_2          SEND 1
 NCC_L                    Conveyor_1_2          SEND 1 NCC_L TO Assembly_station_2
                                                                    1    NCC_L
Assembly_station_2    SEND 1
 NCC_L                    Assembly_station_2    USE Associate_2 FOR N(21.7, 1.97) Sec
                                                USE Associate_2 FOR N(22.9, 2.74) Sec
                                                SEND 1 NCC_L TO Conveyor_2_3
                                                                    1    NCC_L
Conveyor_2_3          SEND 1
 NCC_L                    Conveyor_2_3          SEND 1 NCC_L TO Assembly_station_3
                                                                    1    NCC_L
Assembly_station_3    SEND 1
 NCC_L                    Assembly_station_3    USE Associate_3 FOR N(21.8, 0.821) Sec
                                                USE Associate_3 FOR N(22.1, 0.84) Sec
                                                USE Associate_3 FOR N(10.8, 0.162) Sec
                                                SEND 1 NCC_L TO Conveyor_3_4
                                                                    1    NCC_L
Conveyor_3_4          SEND 1
 NCC_L                    Conveyor_3_4          SEND 1 NCC_L TO Assembly_station_4
                                                                    1    NCC_L
Assembly_station_4    SEND 1
 NCC_L                    Assembly_station_4    USE Associate_4 FOR N(5.44, 0.385) Sec
                                                USE Associate_4 FOR N(11.8, 0.428) Sec
                                                USE Associate_4 FOR N(16.4, 0.265) Sec
                                                USE Associate_4 FOR N(9.84, 0.855) Sec
                                                SEND 1 NCC_L TO Conveyor_4_5
                                                                    1    NCC_L
Conveyor_4_5          SEND 1
 NCC_L                    Conveyor_4_5          SEND 1 NCC_L TO Assembly_station_5
                                                                    1    NCC_L
Assembly_station_5    SEND 1
 NCC_L                    Assembly_station_5    USE Associate_5 FOR N(3.38, 0.492) Sec
                                                USE Associate_5 FOR N(14.2, 0.196) Sec
                                                USE Associate_5 FOR N(11.5, 0.652) Sec
                                                USE Associate_5 FOR N(4.04, 0.612) Sec
                                                USE Associate_5 FOR N(13.4, 0.306) Sec
```

```
                                               SEND 1 NCC_L TO Conveyor_5_6
                                                                    1    NCC_L
Conveyor_5_6          SEND 1
 NCC_L                   Conveyor_5_6          SEND 1 NCC_L TO Assembly_station_6
                                                                    1    NCC_L
Assembly_station_6    SEND 1
 NCC_L                   Assembly_station_6    USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               USE Associate_6 FOR N(12.8, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_6_7
                                                                    1    NCC_L
Conveyor_6_7          SEND 1
 NCC_L                   Conveyor_6_7          SEND 1 NCC_L TO Assembly_station_7
                                                                    1    NCC_L
Assembly_station_7    SEND 1
 NCC_L                   Assembly_station_7    USE Associate_7 FOR N(18.4, 0.907) Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               USE Associate_7 FOR N(17.9, 0.831) Sec
                                               SEND 1 NCC_L TO Conveyor_7_8
                                                                    1    NCC_L
Conveyor_7_8          SEND 1
 NCC_L                   Conveyor_7_8          SEND 1 NCC_L TO Assembly_station_8
                                                                    1    NCC_L
Assembly_station_8    SEND 1
 NCC_L                   Assembly_station_8    USE Associate_8 FOR N(15.5, 1.72) Sec
                                               USE Associate_8 FOR N(5.6, 0.39) Sec
                                               USE Associate_8 FOR N(10.2, 1.16) Sec
                                               USE Associate_8 FOR N(9.72, 0.154) Sec
                                               SEND 1 NCC_L TO Conveyor_8_9
                                                                    1    NCC_L
Conveyor_8_9          SEND 1
 NCC_L                   Conveyor_8_9          SEND 1 NCC_L TO Assembly_station_9
                                                                    1    NCC_L
Assembly_station_9    SEND 1
 NCC_L                   Assembly_station_9    USE Associate_9 FOR N(10.3, 1.41) Sec
                                               USE Associate_9 FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_L TO Conveyor_9_10
                                                                    1    NCC_L
Conveyor_9_10         SEND 1
 NCC_L                   Conveyor_9_10         SEND 1 NCC_L TO Assembly_station_10
                                                                    1    NCC_L
Assembly_station_10   SEND 1
 NCC_L                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_L TO Conveyor_10_11
                                                                    1    NCC_L
Conveyor_10_11        SEND 1
 NCC_L                   Conveyor_10_11        SEND 1 NCC_L TO Assembly_station_11
                                                                    1    NCC_L
Assembly_station_11   SEND 1
 NCC_L                   Assembly_station_11   SEND 1 NCC_L TO Finished_heater_box_L
                                               INC Finished_Heaters_L

                                                                    1    NCC_L
Finished_heater_box_L FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_L                   Finished_heater_box_L ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_L

 Finished_heater_boxes_L Finished_heater_box_L USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_L Finished_heater_box_L                      1    Finished_heater_boxes_L EXIT
FIRST 1
 NCC_R                   Assembly_station_1    USE Associate_1 FOR N(9.28, 1.1) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_1_2
                                                                    1    NCC_R
Conveyor_1_2          SEND 1
 NCC_R                   Conveyor_1_2          SEND 1 NCC_R TO Assembly_station_2
                                                                    1    NCC_R
Assembly_station_2    SEND 1
 NCC_R                   Assembly_station_2    USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_R TO Conveyor_2_3
                                                                    1    NCC_R
Conveyor_2_3          SEND 1
 NCC_R                   Conveyor_2_3          SEND 1 NCC_R TO Assembly_station_3
                                                                    1    NCC_R
Assembly_station_3    SEND 1
 NCC_R                   Assembly_station_3    USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               USE Associate_3 FOR N(10.8, 0.162) Sec
                                               SEND 1 NCC_R TO Conveyor_3_4
                                                                    1    NCC_R
Conveyor_3_4          SEND 1
 NCC_R                   Conveyor_3_4          SEND 1 NCC_R TO Assembly_station_4
                                                                    1    NCC_R
Assembly_station_4    SEND 1
 NCC_R                   Assembly_station_4    USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               USE Associate_4 FOR N(9.84, 0.855) Sec
                                               SEND 1 NCC_R TO Conveyor_4_5
                                                                    1    NCC_R
Conveyor_4_5          SEND 1
 NCC_R                   Conveyor_4_5          SEND 1 NCC_R TO Assembly_station_5
                                                                    1    NCC_R
Assembly_station_5    SEND 1
 NCC_R                   Assembly_station_5    USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               USE Associate_5 FOR N(13.4, 0.306) Sec
                                               SEND 1 NCC_R TO Conveyor_5_6
                                                                    1    NCC_R
Conveyor_5_6          SEND 1
 NCC_R                   Conveyor_5_6          SEND 1 NCC_R TO Assembly_station_6
                                                                    1    NCC_R
Assembly_station_6    SEND 1
 NCC_R                   Assembly_station_6    USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               USE Associate_6 FOR N(12.8, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_6_7
                                                                    1    NCC_R
Conveyor_6_7          SEND 1
 NCC_R                   Conveyor_6_7          SEND 1 NCC_R TO Assembly_station_7
                                                                    1    NCC_R
Assembly_station_7    SEND 1
 NCC_R                   Assembly_station_7    USE Associate_7 FOR N(18.4, 0.907) Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               USE Associate_7 FOR N(17.9, 0.831) Sec
                                               SEND 1 NCC_R TO Conveyor_7_8
                                                                    1    NCC_R
Conveyor_7_8          SEND 1
 NCC_R                   Conveyor_7_8          SEND 1 NCC_R TO Assembly_station_8
                                                                    1    NCC_R
Assembly_station_8    SEND 1
 NCC_R                   Assembly_station_8    USE Associate_8 FOR N(15.5, 1.72) Sec
                                               USE Associate_8 FOR N(5.6, 0.39) Sec
                                               USE Associate_8 FOR N(10.2, 1.16) Sec
                                               USE Associate_8 FOR N(9.72, 0.154) Sec
                                               SEND 1 NCC_R TO Conveyor_8_9
                                                                    1    NCC_R
Conveyor_8_9          SEND 1
 NCC_R                   Conveyor_8_9          SEND 1 NCC_R TO Assembly_station_9
                                                                    1    NCC_R
Assembly_station_9    SEND 1
 NCC_R                   Assembly_station_9    USE Associate_9 FOR N(10.3, 1.41) Sec
                                               USE Associate_9 FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_R TO Conveyor_9_10
                                                                    1    NCC_R
Conveyor_9_10         SEND 1
 NCC_R                   Conveyor_9_10         SEND 1 NCC_R TO Assembly_station_10
                                                                    1    NCC_R
Assembly_station_10   SEND 1
 NCC_R                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_R TO Conveyor_10_11
                                                                    1    NCC_R
Conveyor_10_11        SEND 1
 NCC_R                   Conveyor_10_11        SEND 1 NCC_R TO Assembly_station_11
                                                                    1    NCC_R
Assembly_station_11   SEND 1
 NCC_R                   Assembly_station_11   SEND 1 NCC_R TO Finished_heater_box_R
                                               INC Finished_Heaters_R
                                                                    1    NCC_R
Finished_heater_box_R FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_R                   Finished_heater_box_R ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_R

 Finished_heater_boxes_R Finished_heater_box_R USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_R Finished_heater_box_R                      1    Finished_heater_boxes_R EXIT
FIRST 1

********************************************************************************
*                                   Arrivals                                   *
********************************************************************************

  Entity   Location           Qty each   First Time Occurrences Frequency  Logic
  -------- ------------------ ---------- ---------- ----------- ---------- ------------
  NCC_L    Assembly_station_1 1                     200         1.13
  NCC_R    Assembly_station_1 1                     100         1.13

********************************************************************************
*                              Variables (global)                              *
********************************************************************************

  ID                 Type         Initial value Stats
  ------------------ ------------ ------------- -----------
  Finished_Heaters_L Integer      0             Time Series
  Finished_Heaters_R Integer      0             Time Series
```

Experiment 4: Line Balancing (Multifunction Employee): ‘H’, Setup Time: ‘H’ and Quality Control: ‘L’

```
********************************************************************************
*                                                                              *
*                         Formatted Listing of Model:                          *
* E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation Programming\Assembly line
3 (HHL).MOD *
*                                                                              *
********************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Meters


********************************************************************************
```

```
*                                  Locations                                   *
********************************************************************************

  Name                  Cap      Units Stats       Rules          Cost
  --------------------- -------- ----- ----------- -------------- ------------
  Assembly_station_1    200      1     Time Series Oldest, FIFO,
  Assembly_station_2    1        1     Time Series Oldest, FIFO,
  Assembly_station_3    1        1     Time Series Oldest, FIFO,
  Assembly_station_4    1        1     Time Series Oldest, FIFO,
  Assembly_station_5    1        1     Time Series Oldest, FIFO,
  Assembly_station_6    1        1     Time Series Oldest, FIFO,
  Assembly_station_A    1        1     Time Series Oldest, FIFO,
  Assembly_station_7    1        1     Time Series Oldest, FIFO,
  Assembly_station_8    1        1     Time Series Oldest, FIFO,
  Assembly_station_9    1        1     Time Series Oldest, FIFO,
  Assembly_station_B    1        1     Time Series Oldest, FIFO,
  Assembly_station_10   1        1     Time Series Oldest, FIFO,
  Assembly_station_11   1        1     Time Series Oldest, FIFO,
  Conveyor_1_2          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_2_3          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_3_4          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_4_5          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_5_6          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_6_A          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_A_7          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_7_8          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_8_9          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_9_B          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_B_10         INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_10_11        INFINITE 1     Time Series Oldest, FIFO,
  Finished_heater_box_L 6        1     Time Series Oldest, FIFO,
  Finished_heater_box_R 6        1     Time Series Oldest, FIFO,


********************************************************************************
*                                   Entities                                   *
********************************************************************************

  Name                    Speed (mpm)  Stats       Cost
  ----------------------- ------------ ----------- ------------
  NCC_L                   0            Time Series
  Finished_heater_boxes_L 0            Time Series
  NCC_R                   0            Time Series
  Finished_heater_boxes_R 0            Time Series


********************************************************************************
*                                Path Networks                                 *
********************************************************************************

  Name     Type        T/S              From     To       BI   Dist/Time  Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------- ------------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0        1
                                        N1       N3       Bi   2.0        1


********************************************************************************
*                                  Interfaces                                  *
********************************************************************************

  Net        Node       Location
  ---------- ---------- ---------------------
  Net1       N1         Assembly_station_11
             N2         Finished_heater_box_L
             N3         Finished_heater_box_R


********************************************************************************
*                                  Resources                                   *
********************************************************************************

                              Res        Ent
  Name         Units Stats    Search     Search Path       Motion        Cost
  ------------ ----- -------- ---------- ------ ---------- ------------- ------------
  Associate_1  1     By Unit  Least Used Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_2  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_3  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_4  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_5  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_6  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_A  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_7  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_8  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_9  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_B  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm
  QA_Associate 1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_10 1     By Unit  Closest    Oldest Net1      Empty: 50 mpm
                                                Home: N1   Full: 50 mpm
                                                (Return)

********************************************************************************
*                                  Processing                                  *
********************************************************************************

                                                         Process
Routing

 Entity                  Location              Operation            Blk  Output
Destination           Rule     Move Logic
 ----------------------- --------------------- ------------------   ---- ---------------------- ----
----------------- -------  ------------
 NCC_L                   Assembly_station_1    USE Associate_1 FOR N(9.28, 1.11) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_1_2
                                                                    1    NCC_L
Conveyor_1_2          SEND 1
 NCC_L                   Conveyor_1_2          SEND 1 NCC_L TO Assembly_station_2
                                                                    1    NCC_L
Assembly_station_2    SEND 1
 NCC_L                   Assembly_station_2    USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_L TO Conveyor_2_3
                                                                    1    NCC_L
Conveyor_2_3          SEND 1
 NCC_L                   Conveyor_2_3          SEND 1 NCC_L TO Assembly_station_3
                                                                    1    NCC_L
Assembly_station_3    SEND 1
 NCC_L                   Assembly_station_3    USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               SEND 1 NCC_L TO Conveyor_3_4
                                                                    1    NCC_L
Conveyor_3_4          SEND 1
 NCC_L                   Conveyor_3_4          SEND 1 NCC_L TO Assembly_station_4
                                                                    1    NCC_L
Assembly_station_4    SEND 1
 NCC_L                   Assembly_station_4    USE Associate_4 FOR N(10.8, 0.162) Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               SEND 1 NCC_L TO Conveyor_4_5
                                                                    1    NCC_L
Conveyor_4_5          SEND 1
 NCC_L                   Conveyor_4_5          SEND 1 NCC_L TO Assembly_station_5
                                                                    1    NCC_L
Assembly_station_5    SEND 1
 NCC_L                   Assembly_station_5    USE Associate_5 FOR N(9.84, 0.855) Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               SEND 1 NCC_L TO Conveyor_5_6
                                                                    1    NCC_L
Conveyor_5_6          SEND 1
 NCC_L                   Conveyor_5_6          SEND 1 NCC_L TO Assembly_station_6
                                                                    1    NCC_L
Assembly_station_6    SEND 1
 NCC_L                   Assembly_station_6    USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.4, 0.306) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               SEND 1 NCC_L TO Conveyor_6_A
                                                                    1    NCC_L
Conveyor_6_A          SEND 1
 NCC_L                   Conveyor_6_A          SEND 1 NCC_L TO Assembly_station_A
                                                                    1    NCC_L
Assembly_station_A    SEND 1
 NCC_L                   Assembly_station_A    USE Associate_A FOR N(12.8, 1.29) Sec
                                               USE Associate_A FOR N(18.4, 0.907) Sec
                                               SEND 1 NCC_L TO Conveyor_A_7
                                                                    1    NCC_L
Conveyor_A_7          SEND 1
 NCC_L                   Conveyor_A_7          SEND 1 NCC_L TO Assembly_station_7
                                                                    1    NCC_L
Assembly_station_7    SEND 1
 NCC_L                   Assembly_station_7    USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               SEND 1 NCC_L TO Conveyor_7_8
                                                                    1    NCC_L
Conveyor_7_8          SEND 1
 NCC_L                   Conveyor_7_8          SEND 1 NCC_L TO Assembly_station_8
                                                                    1    NCC_L
Assembly_station_8    SEND 1
 NCC_L                   Assembly_station_8    USE Associate_8 FOR N(17.9, 0.831) Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               SEND 1 NCC_L TO Conveyor_8_9
                                                                    1    NCC_L
Conveyor_8_9          SEND 1
 NCC_L                   Conveyor_8_9          SEND 1 NCC_L TO Assembly_station_9
                                                                    1    NCC_L
Assembly_station_9    SEND 1
 NCC_L                   Assembly_station_9    USE Associate_9 FOR N(5.6, 0.39) Sec
                                               USE Associate_9 FOR N(10.2, 1.16) Sec
                                               USE Associate_9 FOR N(9.72, 0.154) Sec
                                               USE Associate_9 FOR N(10.3, 1.41) Sec
                                               SEND 1 NCC_L TO Conveyor_9_B
                                                                    1    NCC_L
Conveyor_9_B          SEND 1
 NCC_L                   Conveyor_9_B          SEND 1 NCC_L TO Assembly_station_B
```

```
                                                                    1    NCC_L
Assembly_station_B    SEND 1
 NCC_L                   Assembly_station_B    USE Associate_B FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_L TO Conveyor_B_10
                                                                    1    NCC_L
Conveyor_B_10         SEND 1
 NCC_L                   Conveyor_B_10         SEND 1 NCC_L TO Assembly_station_10
                                                                    1    NCC_L
Assembly_station_10   SEND 1
 NCC_L                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_L TO Conveyor_10_11
                                                                    1    NCC_L
Conveyor_10_11        SEND 1
 NCC_L                   Conveyor_10_11        SEND 1 NCC_L TO Assembly_station_11
                                                                    1    NCC_L
Assembly_station_11   SEND 1
 NCC_L                   Assembly_station_11   SEND 1 NCC_L TO Finished_heater_box_L
                                               INC Finished_Heaters_L
                                                                    1    NCC_L
Finished_heater_box_L FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_L                   Finished_heater_box_L ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_L

 Finished_heater_boxes_L Finished_heater_box_L USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_L Finished_heater_box_L                      1    Finished_heater_boxes_L EXIT
FIRST 1
 NCC_R                   Assembly_station_1    USE Associate_1 FOR N(9.28, 1.11) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_1_2
                                                                    1    NCC_R
Conveyor_1_2          SEND 1
 NCC_R                   Conveyor_1_2          SEND 1 NCC_R TO Assembly_station_2
                                                                    1    NCC_R
Assembly_station_2    SEND 1
 NCC_R                   Assembly_station_2    USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_R TO Conveyor_2_3
                                                                    1    NCC_R
Conveyor_2_3          SEND 1
 NCC_R                   Conveyor_2_3          SEND 1 NCC_R TO Assembly_station_3
                                                                    1    NCC_R
Assembly_station_3    SEND 1
 NCC_R                   Assembly_station_3    USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               SEND 1 NCC_R TO Conveyor_3_4
                                                                    1    NCC_R
Conveyor_3_4          SEND 1
 NCC_R                   Conveyor_3_4          SEND 1 NCC_R TO Assembly_station_4
                                                                    1    NCC_R
Assembly_station_4    SEND 1
 NCC_R                   Assembly_station_4    USE Associate_4 FOR N(10.8, 0.162) Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               SEND 1 NCC_R TO Conveyor_4_5
                                                                    1    NCC_R
Conveyor_4_5          SEND 1
 NCC_R                   Conveyor_4_5          SEND 1 NCC_R TO Assembly_station_5
                                                                    1    NCC_R
Assembly_station_5    SEND 1
 NCC_R                   Assembly_station_5    USE Associate_5 FOR N(9.84, 0.855) Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               SEND 1 NCC_R TO Conveyor_5_6
                                                                    1    NCC_R
Conveyor_5_6          SEND 1
 NCC_R                   Conveyor_5_6          SEND 1 NCC_R TO Assembly_station_6
                                                                    1    NCC_R
Assembly_station_6    SEND 1
 NCC_R                   Assembly_station_6    USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.4, 0.306) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               SEND 1 NCC_R TO Conveyor_6_A
                                                                    1    NCC_R
Conveyor_6_A          SEND 1
 NCC_R                   Conveyor_6_A          SEND 1 NCC_R TO Assembly_station_A
                                                                    1    NCC_R
Assembly_station_A    SEND 1
 NCC_R                   Assembly_station_A    USE Associate_A FOR N(12.8, 1.29) Sec
                                               USE Associate_A FOR N(18.4, 0.907) Sec
                                               SEND 1 NCC_R TO Conveyor_A_7
                                                                    1    NCC_R
Conveyor_A_7          SEND 1
 NCC_R                   Conveyor_A_7          SEND 1 NCC_R TO Assembly_station_7
                                                                    1    NCC_R
Assembly_station_7    SEND 1
 NCC_R                   Assembly_station_7    USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               SEND 1 NCC_R TO Conveyor_7_8
                                                                    1    NCC_R
Conveyor_7_8          SEND 1
 NCC_R                   Conveyor_7_8          SEND 1 NCC_R TO Assembly_station_8
                                                                    1    NCC_R
Assembly_station_8    SEND 1
 NCC_R                   Assembly_station_8    USE Associate_8 FOR N(17.9, 0.831) Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               SEND 1 NCC_R TO Conveyor_8_9
```

```
                                                                    1    NCC_R
Conveyor_8_9          SEND 1
 NCC_R                   Conveyor_8_9         SEND 1 NCC_R TO Assembly_station_9
                                                                    1    NCC_R
Assembly_station_9    SEND 1
 NCC_R                   Assembly_station_9   USE Associate_9 FOR N(5.6, 0.39) Sec
                                              USE Associate_9 FOR N(10.2, 1.16) Sec
                                              USE Associate_9 FOR N(9.72, 0.154) Sec
                                              USE Associate_9 FOR N(10.3, 1.41) Sec
                                              SEND 1 NCC_R TO Conveyor_9_B
                                                                    1    NCC_R
Conveyor_9_B          SEND 1
 NCC_R                   Conveyor_9_B         SEND 1 NCC_R TO Assembly_station_B
                                                                    1    NCC_R
Assembly_station_B    SEND 1
 NCC_R                   Assembly_station_B   USE Associate_B FOR N(46.6, 1.07) Sec
                                              SEND 1 NCC_R TO Conveyor_B_10
                                                                    1    NCC_R
Conveyor_B_10         SEND 1
 NCC_R                   Conveyor_B_10        SEND 1 NCC_R TO Assembly_station_10
                                                                    1    NCC_R
Assembly_station_10   SEND 1
 NCC_R                   Assembly_station_10  USE QA_Associate FOR N(48.9, 3.97) Sec
                                              SEND 1 NCC_R TO Conveyor_10_11
                                                                    1    NCC_R
Conveyor_10_11        SEND 1
 NCC_R                   Conveyor_10_11       SEND 1 NCC_R TO Assembly_station_11
                                                                    1    NCC_R
Assembly_station_11   SEND 1
 NCC_R                   Assembly_station_11  SEND 1 NCC_R TO Finished_heater_box_R
                                              INC Finished_Heaters_R
                                                                    1    NCC_R
Finished_heater_box_R FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE
 NCC_R                   Finished_heater_box_R ACCUM 6
                                              GROUP 6 AS Finished_heater_boxes_R
 Finished_heater_boxes_R Finished_heater_box_R USE Associate_10 FOR N(63.3, 3.46) Sec
                                              USE Associate_10 FOR N(15.6, 3.34) Sec
                                              USE Associate_10 FOR N(30.2, 5.36) Sec
                                              FREE Associate_10
 Finished_heater_boxes_R Finished_heater_box_R                      1    Finished_heater_boxes_R EXIT
FIRST 1


********************************************************************************
*                                  Arrivals                                    *
********************************************************************************

  Entity   Location           Qty each   First Time Occurrences Frequency  Logic
  -------- ------------------ ---------- ---------- ----------- ---------- ------------
  NCC_L    Assembly_station_1 1                     200         0.88
  NCC_R    Assembly_station_1 1                     100         0.88


********************************************************************************
*                              Variables (global)                              *
********************************************************************************

  ID                 Type         Initial value Stats
  ------------------ ------------ ------------- -----------
  Finished_Heaters_L Integer      0             Time Series
  Finished_Heaters_R Integer      0             Time Series
```

Experiment 5: Line Balancing (Multifunction Employee): 'L', Setup Time: 'L' and Quality Control: 'H'

```
********************************************************************************
*                                                                              *
*                          Formatted Listing of Model:                         *
* E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation Programming\Assembly line
3 (LLH).MOD *
*                                                                              *
********************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Meters


********************************************************************************
*                                  Locations                                   *
********************************************************************************

  Name                  Cap      Units Stats       Rules          Cost
  --------------------- -------- ----- ----------- -------------- ------------
  Assembly_station_1    200      1     Time Series Oldest, FIFO,
  Assembly_station_2    1        1     Time Series Oldest, FIFO,
  Assembly_station_3    1        1     Time Series Oldest, FIFO,
  Assembly_station_4    1        1     Time Series Oldest, FIFO,
  Assembly_station_5    1        1     Time Series Oldest, FIFO,
  Assembly_station_6    1        1     Time Series Oldest, FIFO,
  Assembly_station_7    1        1     Time Series Oldest, FIFO,
  Assembly_station_8    1        1     Time Series Oldest, FIFO,
  Assembly_station_9    1        1     Time Series Oldest, FIFO,
  Assembly_station_10   1        1     Time Series Oldest, FIFO,
  Assembly_station_11   1        1     Time Series Oldest, FIFO,
  Conveyor_1_2          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_2_3          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_3_4          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_4_5          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_5_6          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_6_7          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_7_8          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_8_9          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_9_10         INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_10_11        INFINITE 1     Time Series Oldest, FIFO,
  Finished_heater_box_L 6        1     Time Series Oldest, FIFO,
  Finished_heater_box_R 6        1     Time Series Oldest, FIFO,


********************************************************************************
*                                   Entities                                   *
********************************************************************************

  Name                    Speed (mpm)  Stats       Cost
  ----------------------- ------------ ----------- ------------
  NCC_L                   0            Time Series
  Finished_heater_boxes_L 0            Time Series
  NCC_R                   0            Time Series
  Finished_heater_boxes_R 0            Time Series


********************************************************************************
*                                Path Networks                                 *
********************************************************************************

  Name     Type        T/S              From     To       BI   Dist/Time  Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------- ------------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0        1
                                        N1       N3       Bi   2.0        1


********************************************************************************
*                                  Interfaces                                  *
********************************************************************************

  Net        Node       Location
  ---------- ---------- ---------------------
  Net1       N1         Assembly_station_11
             N2         Finished_heater_box_L
             N3         Finished_heater_box_R


********************************************************************************
*                                  Resources                                   *
********************************************************************************

                              Res        Ent
  Name         Units Stats    Search     Search Path       Motion        Cost
  ------------ ----- -------- ---------- ------ ---------- ------------- ------------
  Associate_1  1     By Unit  Least Used Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_2  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_3  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_4  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_5  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_6  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_7  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_8  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_9  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  QA_Associate 1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_10 1     By Unit  Closest    Oldest Net1       Empty: 50 mpm
                                                Home: N1   Full: 50 mpm
                                                (Return)


********************************************************************************
*                                  Processing                                  *
********************************************************************************

                                                         Process
Routing

 Entity                  Location              Operation            Blk  Output
Destination           Rule     Move Logic
 ----------------------- --------------------- ------------------   ---- ----------------------- ----
----------------- -------  ------------
 NCC_L                   Assembly_station_1    USE Associate_1 FOR 5 Sec
                                               USE Associate_1 FOR N(9.28, 1.1) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_1_2


                                                                    1    NCC_L
Conveyor_1_2          SEND 1
 NCC_L                   Conveyor_1_2          SEND 1 NCC_L TO Assembly_station_2
```

```
                                                                    1    NCC_L
Assembly_station_2    SEND 1
 NCC_L                   Assembly_station_2    USE Associate_2 FOR 5 Sec
                                               USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_L TO Conveyor_2_3
                                                                    1    NCC_L
Conveyor_2_3          SEND 1
 NCC_L                   Conveyor_2_3          SEND 1 NCC_L TO Assembly_station_3
                                                                    1    NCC_L
Assembly_station_3    SEND 1
 NCC_L                   Assembly_station_3    USE Associate_3 FOR 5 Sec
                                               USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               USE Associate_3 FOR N(10.8, 0.162) Sec
                                               SEND 1 NCC_L TO Conveyor_3_4
                                                                    1    NCC_L
Conveyor_3_4          SEND 1
 NCC_L                   Conveyor_3_4          SEND 1 NCC_L TO Assembly_station_4
                                                                    1    NCC_L
Assembly_station_4    SEND 1
 NCC_L                   Assembly_station_4    USE Associate_4 FOR 5 Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               USE Associate_4 FOR N(9.84, 0.855) Sec
                                               SEND 1 NCC_L TO Conveyor_4_5
                                                                    1    NCC_L
Conveyor_4_5          SEND 1
 NCC_L                   Conveyor_4_5          SEND 1 NCC_L TO Assembly_station_5
                                                                    1    NCC_L
Assembly_station_5    SEND 1
 NCC_L                   Assembly_station_5    USE Associate_5 FOR 5 Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               USE Associate_5 FOR N(13.4, 0.306) Sec
                                               SEND 1 NCC_L TO Conveyor_5_6
                                                                    1    NCC_L
Conveyor_5_6          SEND 1
 NCC_L                   Conveyor_5_6          SEND 1 NCC_L TO Assembly_station_6
                                                                    1    NCC_L
Assembly_station_6    SEND 1
 NCC_L                   Assembly_station_6    USE Associate_6 FOR 5 Sec
                                               USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               USE Associate_6 FOR N(12.8, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_6_7
                                                                    1    NCC_L
Conveyor_6_7          SEND 1
 NCC_L                   Conveyor_6_7          SEND 1 NCC_L TO Assembly_station_7
                                                                    1    NCC_L
Assembly_station_7    SEND 1
 NCC_L                   Assembly_station_7    USE Associate_7 FOR 5 Sec
                                               USE Associate_7 FOR N(18.4, 0.907) Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               USE Associate_7 FOR N(17.9, 0.831) Sec
                                               SEND 1 NCC_L TO Conveyor_7_8
                                                                    1    NCC_L
Conveyor_7_8          SEND 1
 NCC_L                   Conveyor_7_8          SEND 1 NCC_L TO Assembly_station_8
                                                                    1    NCC_L
Assembly_station_8    SEND 1
 NCC_L                   Assembly_station_8    USE Associate_8 FOR 5 Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               USE Associate_8 FOR N(5.6, 0.39) Sec
                                               USE Associate_8 FOR N(10.2, 1.16) Sec
                                               USE Associate_8 FOR N(9.72, 0.154) Sec
                                               SEND 1 NCC_L TO Conveyor_8_9
                                                                    1    NCC_L
Conveyor_8_9          SEND 1
 NCC_L                   Conveyor_8_9          SEND 1 NCC_L TO Assembly_station_9
                                                                    1    NCC_L
Assembly_station_9    SEND 1
 NCC_L                   Assembly_station_9    USE Associate_9 FOR N(10.3, 1.41) Sec
                                               USE Associate_9 FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_L TO Conveyor_9_10
                                                                    1    NCC_L
Conveyor_9_10         SEND 1
 NCC_L                   Conveyor_9_10         SEND 1 NCC_L TO Assembly_station_10
                                                                    1    NCC_L
Assembly_station_10   SEND 1
 NCC_L                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_L TO Conveyor_10_11
                                                                    1    NCC_L
Conveyor_10_11        SEND 1
 NCC_L                   Conveyor_10_11        SEND 1 NCC_L TO Assembly_station_11
                                                                    1    NCC_L
Assembly_station_11   SEND 1
 NCC_L                   Assembly_station_11   SEND 1 NCC_L TO Finished_heater_box_L
                                               INC Finished_Heaters_L

                                                                    1    NCC_L
Finished_heater_box_L FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_L                   Finished_heater_box_L ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_L

 Finished_heater_boxes_L Finished_heater_box_L USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_L Finished_heater_box_L                      1    Finished_heater_boxes_L EXIT
FIRST 1
```

```
 NCC_R                   Assembly_station_1    USE Associate_1 FOR 5 Sec
                                               USE Associate_1 FOR N(9.28, 1.1) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_1_2
                                                                    1    NCC_R
Conveyor_1_2          SEND 1
 NCC_R                   Conveyor_1_2          SEND 1 NCC_R TO Assembly_station_2
                                                                    1    NCC_R
Assembly_station_2    SEND 1
 NCC_R                   Assembly_station_2    USE Associate_2 FOR 5 Sec
                                               USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_R TO Conveyor_2_3
                                                                    1    NCC_R
Conveyor_2_3          SEND 1
 NCC_R                   Conveyor_2_3          SEND 1 NCC_R TO Assembly_station_3
                                                                    1    NCC_R
Assembly_station_3    SEND 1
 NCC_R                   Assembly_station_3    USE Associate_3 FOR 5 Sec
                                               USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               USE Associate_3 FOR N(10.8, 0.162) Sec
                                               SEND 1 NCC_R TO Conveyor_3_4
                                                                    1    NCC_R
Conveyor_3_4          SEND 1
 NCC_R                   Conveyor_3_4          SEND 1 NCC_R TO Assembly_station_4
                                                                    1    NCC_R
Assembly_station_4    SEND 1
 NCC_R                   Assembly_station_4    USE Associate_4 FOR 5 Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               USE Associate_4 FOR N(9.84, 0.855) Sec
                                               SEND 1 NCC_R TO Conveyor_4_5
                                                                    1    NCC_R
Conveyor_4_5          SEND 1
 NCC_R                   Conveyor_4_5          SEND 1 NCC_R TO Assembly_station_5
                                                                    1    NCC_R
Assembly_station_5    SEND 1
 NCC_R                   Assembly_station_5    USE Associate_5 FOR 5 Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               USE Associate_5 FOR N(13.4, 0.306) Sec
                                               SEND 1 NCC_R TO Conveyor_5_6
                                                                    1    NCC_R
Conveyor_5_6          SEND 1
 NCC_R                   Conveyor_5_6          SEND 1 NCC_R TO Assembly_station_6
                                                                    1    NCC_R
Assembly_station_6    SEND 1
 NCC_R                   Assembly_station_6    USE Associate_6 FOR 5 Sec
                                               USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               USE Associate_6 FOR N(12.8, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_6_7
                                                                    1    NCC_R
Conveyor_6_7          SEND 1
 NCC_R                   Conveyor_6_7          SEND 1 NCC_R TO Assembly_station_7
                                                                    1    NCC_R
Assembly_station_7    SEND 1
 NCC_R                   Assembly_station_7    USE Associate_7 FOR 5 Sec
                                               USE Associate_7 FOR N(18.4, 0.907) Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               USE Associate_7 FOR N(17.9, 0.831) Sec
                                               SEND 1 NCC_R TO Conveyor_7_8
                                                                    1    NCC_R
Conveyor_7_8          SEND 1
 NCC_R                   Conveyor_7_8          SEND 1 NCC_R TO Assembly_station_8
                                                                    1    NCC_R
Assembly_station_8    SEND 1
 NCC_R                   Assembly_station_8    USE Associate_8 FOR 5 Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               USE Associate_8 FOR N(5.6, 0.39) Sec
                                               USE Associate_8 FOR N(10.2, 1.16) Sec
                                               USE Associate_8 FOR N(9.72, 0.154) Sec
                                               SEND 1 NCC_R TO Conveyor_8_9
                                                                    1    NCC_R
Conveyor_8_9          SEND 1
 NCC_R                   Conveyor_8_9          SEND 1 NCC_R TO Assembly_station_9
                                                                    1    NCC_R
Assembly_station_9    SEND 1
 NCC_R                   Assembly_station_9    USE Associate_9 FOR N(10.3, 1.41) Sec
                                               USE Associate_9 FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_R TO Conveyor_9_10
                                                                    1    NCC_R
Conveyor_9_10         SEND 1
 NCC_R                   Conveyor_9_10         SEND 1 NCC_R TO Assembly_station_10
                                                                    1    NCC_R
Assembly_station_10   SEND 1
 NCC_R                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_R TO Conveyor_10_11
                                                                    1    NCC_R
Conveyor_10_11        SEND 1
 NCC_R                   Conveyor_10_11        SEND 1 NCC_R TO Assembly_station_11
                                                                    1    NCC_R
Assembly_station_11   SEND 1
 NCC_R                   Assembly_station_11   SEND 1 NCC_R TO Finished_heater_box_R
                                               INC Finished_Heaters_R
                                                                    1    NCC_R
Finished_heater_box_R FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_R                   Finished_heater_box_R ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_R
 Finished_heater_boxes_R Finished_heater_box_R USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_R Finished_heater_box_R                      1    Finished_heater_boxes_R EXIT
FIRST 1

********************************************************************************
*                                   Arrivals                                   *
********************************************************************************

  Entity   Location           Qty each   First Time Occurrences Frequency  Logic
  -------- ------------------ ---------- ---------- ----------- ---------- ------------
  NCC_L    Assembly_station_1 1                     200         1.24
  NCC_R    Assembly_station_1 1                     100         1.24


********************************************************************************
*                              Variables (global)                              *
********************************************************************************

  ID                 Type         Initial value Stats
  ------------------ ------------ ------------- -----------
  Finished_Heaters_L Integer      0             Time Series
  Finished_Heaters_R Integer      0             Time Series
```

Experiment 6: Line Balancing (Multifunction Employee): 'H', Setup Time: 'L' and Quality Control: 'H'

```
********************************************************************************
*                                                                              *
*                          Formatted Listing of Model:                         *
* E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation Programming\Assembly line
3 (HLH).MOD *
*                                                                              *
********************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Meters


********************************************************************************
*                                  Locations                                   *
********************************************************************************

  Name                  Cap      Units Stats       Rules          Cost
  --------------------- -------- ----- ----------- -------------- ------------
  Assembly_station_1    200      1     Time Series Oldest, FIFO,
  Assembly_station_2    1        1     Time Series Oldest, FIFO,
  Assembly_station_3    1        1     Time Series Oldest, FIFO,
  Assembly_station_4    1        1     Time Series Oldest, FIFO,
  Assembly_station_5    1        1     Time Series Oldest, FIFO,
  Assembly_station_6    1        1     Time Series Oldest, FIFO,
  Assembly_station_A    1        1     Time Series Oldest, FIFO,
  Assembly_station_7    1        1     Time Series Oldest, FIFO,
  Assembly_station_8    1        1     Time Series Oldest, FIFO,
  Assembly_station_9    1        1     Time Series Oldest, FIFO,
  Assembly_station_B    1        1     Time Series Oldest, FIFO,
  Assembly_station_10   1        1     Time Series Oldest, FIFO,
  Assembly_station_11   1        1     Time Series Oldest, FIFO,
  Conveyor_1_2          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_2_3          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_3_4          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_4_5          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_5_6          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_6_A          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_A_7          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_7_8          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_8_9          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_9_B          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_B_10         INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_10_11        INFINITE 1     Time Series Oldest, FIFO,
  Finished_heater_box_L 6        1     Time Series Oldest, FIFO,
  Finished_heater_box_R 6        1     Time Series Oldest, FIFO,


********************************************************************************
*                                   Entities                                   *
********************************************************************************

  Name                    Speed (mpm)  Stats       Cost
  ----------------------- ------------ ----------- ------------
  NCC_L                   0            Time Series
  Finished_heater_boxes_L 0            Time Series
  NCC_R                   0            Time Series
  Finished_heater_boxes_R 0            Time Series


********************************************************************************
*                                Path Networks                                 *
********************************************************************************
```

```
  Name     Type        T/S              From     To       BI   Dist/Time  Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------- ------------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0        1
                                        N1       N3       Bi   2.0        1


********************************************************************************
*                                  Interfaces                                  *
********************************************************************************

  Net        Node       Location
  ---------- ---------- ---------------------
  Net1       N1         Assembly_station_11
             N2         Finished_heater_box_L
             N3         Finished_heater_box_R


********************************************************************************
*                                  Resources                                   *
********************************************************************************

                              Res        Ent
  Name         Units Stats    Search     Search Path       Motion        Cost
  ------------ ----- -------- ---------- ------ ---------- ------------- ------------
  Associate_1  1     By Unit  Least Used Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_2  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_3  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_4  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_5  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_6  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_A  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_7  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_8  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_9  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_B  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  QA_Associate 1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_10 1     By Unit  Closest    Oldest Net1       Empty: 50 mpm
                                                Home: N1   Full: 50 mpm
                                                (Return)


********************************************************************************
*                                  Processing                                  *
********************************************************************************

                                                         Process
Routing

 Entity                  Location              Operation            Blk  Output
Destination           Rule     Move Logic
 ----------------------- --------------------- ------------------   ---- ---------------------- ----
----------------- -------  ------------
 NCC_L                   Assembly_station_1    USE Associate_1 FOR 5 Sec
                                               USE Associate_1 FOR N(9.28, 1.11) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_1_2
                                                                    1    NCC_L
Conveyor_1_2          SEND 1
 NCC_L                   Conveyor_1_2          SEND 1 NCC_L TO Assembly_station_2
                                                                    1    NCC_L
Assembly_station_2    SEND 1
 NCC_L                   Assembly_station_2    USE Associate_2 FOR 5 Sec
                                               USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_L TO Conveyor_2_3
                                                                    1    NCC_L
Conveyor_2_3          SEND 1
 NCC_L                   Conveyor_2_3          SEND 1 NCC_L TO Assembly_station_3
                                                                    1    NCC_L
Assembly_station_3    SEND 1
 NCC_L                   Assembly_station_3    USE Associate_3 FOR 5 Sec
                                               USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               SEND 1 NCC_L TO Conveyor_3_4
                                                                    1    NCC_L
Conveyor_3_4          SEND 1
 NCC_L                   Conveyor_3_4          SEND 1 NCC_L TO Assembly_station_4
                                                                    1    NCC_L
Assembly_station_4    SEND 1
 NCC_L                   Assembly_station_4    USE Associate_4 FOR 5 Sec
                                               USE Associate_4 FOR N(10.8, 0.162) Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               SEND 1 NCC_L TO Conveyor_4_5
                                                                    1    NCC_L
Conveyor_4_5          SEND 1
 NCC_L                   Conveyor_4_5          SEND 1 NCC_L TO Assembly_station_5
                                                                    1    NCC_L
Assembly_station_5    SEND 1
 NCC_L                   Assembly_station_5    USE Associate_5 FOR 5 Sec
                                               USE Associate_5 FOR N(9.84, 0.855) Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               SEND 1 NCC_L TO Conveyor_5_6
                                                                    1    NCC_L
Conveyor_5_6          SEND 1
 NCC_L                   Conveyor_5_6          SEND 1 NCC_L TO Assembly_station_6
                                                                    1    NCC_L
Assembly_station_6    SEND 1
 NCC_L                   Assembly_station_6    USE Associate_6 FOR 5 Sec
                                               USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.4, 0.306) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               SEND 1 NCC_L TO Conveyor_6_A
                                                                    1    NCC_L
Conveyor_6_A          SEND 1
 NCC_L                   Conveyor_6_A          SEND 1 NCC_L TO Assembly_station_A
                                                                    1    NCC_L
Assembly_station_A    SEND 1
 NCC_L                   Assembly_station_A    USE Associate_A FOR 5 Sec
                                               USE Associate_A FOR N(12.8, 1.29) Sec
                                               USE Associate_A FOR N(18.4, 0.907) Sec
                                               SEND 1 NCC_L TO Conveyor_A_7
                                                                    1    NCC_L
Conveyor_A_7          SEND 1
 NCC_L                   Conveyor_A_7          SEND 1 NCC_L TO Assembly_station_7
                                                                    1    NCC_L
Assembly_station_7    SEND 1
 NCC_L                   Assembly_station_7    USE Associate_7 FOR 5 Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               SEND 1 NCC_L TO Conveyor_7_8
                                                                    1    NCC_L
Conveyor_7_8          SEND 1
 NCC_L                   Conveyor_7_8          SEND 1 NCC_L TO Assembly_station_8
                                                                    1    NCC_L
Assembly_station_8    SEND 1
 NCC_L                   Assembly_station_8    USE Associate_8 FOR N(17.9, 0.831) Sec
                                               USE Associate_8 FOR 5 Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               SEND 1 NCC_L TO Conveyor_8_9
                                                                    1    NCC_L
Conveyor_8_9          SEND 1
 NCC_L                   Conveyor_8_9          SEND 1 NCC_L TO Assembly_station_9
                                                                    1    NCC_L
Assembly_station_9    SEND 1
 NCC_L                   Assembly_station_9    USE Associate_9 FOR 5 Sec
                                               USE Associate_9 FOR N(5.6, 0.39) Sec
                                               USE Associate_9 FOR N(10.2, 1.16) Sec
                                               USE Associate_9 FOR N(9.72, 0.154) Sec
                                               USE Associate_9 FOR N(10.3, 1.41) Sec
                                               SEND 1 NCC_L TO Conveyor_9_B
                                                                    1    NCC_L
Conveyor_9_B          SEND 1
 NCC_L                   Conveyor_9_B          SEND 1 NCC_L TO Assembly_station_B
                                                                    1    NCC_L
Assembly_station_B    SEND 1
 NCC_L                   Assembly_station_B    USE Associate_B FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_L TO Conveyor_B_10
                                                                    1    NCC_L
Conveyor_B_10         SEND 1
 NCC_L                   Conveyor_B_10         SEND 1 NCC_L TO Assembly_station_10
                                                                    1    NCC_L
Assembly_station_10   SEND 1
 NCC_L                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_L TO Conveyor_10_11
                                                                    1    NCC_L
Conveyor_10_11        SEND 1
 NCC_L                   Conveyor_10_11        SEND 1 NCC_L TO Assembly_station_11
                                                                    1    NCC_L
Assembly_station_11   SEND 1
 NCC_L                   Assembly_station_11   SEND 1 NCC_L TO Finished_heater_box_L
                                               INC Finished_Heaters_L
                                                                    1    NCC_L
Finished_heater_box_L FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_L                   Finished_heater_box_L ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_L

 Finished_heater_boxes_L Finished_heater_box_L USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_L Finished_heater_box_L                      1    Finished_heater_boxes_L EXIT
FIRST 1
 NCC_R                   Assembly_station_1    USE Associate_1 FOR 5 Sec
                                               USE Associate_1 FOR N(9.28, 1.11) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_1_2
                                                                    1    NCC_R
Conveyor_1_2          SEND 1
 NCC_R                   Conveyor_1_2          SEND 1 NCC_R TO Assembly_station_2
```

```
                                                                    1    NCC_R
Assembly_station_2    SEND 1
 NCC_R                   Assembly_station_2    USE Associate_2 FOR 5 Sec
                                               USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_R TO Conveyor_2_3
                                                                    1    NCC_R
Conveyor_2_3          SEND 1
 NCC_R                   Conveyor_2_3          SEND 1 NCC_R TO Assembly_station_3
                                                                    1    NCC_R
Assembly_station_3    SEND 1
 NCC_R                   Assembly_station_3    USE Associate_3 FOR 5 Sec
                                               USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               SEND 1 NCC_R TO Conveyor_3_4
                                                                    1    NCC_R
Conveyor_3_4          SEND 1
 NCC_R                   Conveyor_3_4          SEND 1 NCC_R TO Assembly_station_4
                                                                    1    NCC_R
Assembly_station_4    SEND 1
 NCC_R                   Assembly_station_4    USE Associate_4 FOR 5 Sec
                                               USE Associate_4 FOR N(10.8, 0.162) Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               SEND 1 NCC_R TO Conveyor_4_5
                                                                    1    NCC_R
Conveyor_4_5          SEND 1
 NCC_R                   Conveyor_4_5          SEND 1 NCC_R TO Assembly_station_5
                                                                    1    NCC_R
Assembly_station_5    SEND 1
 NCC_R                   Assembly_station_5    USE Associate_5 FOR 5 Sec
                                               USE Associate_5 FOR N(9.84, 0.855) Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               SEND 1 NCC_R TO Conveyor_5_6
                                                                    1    NCC_R
Conveyor_5_6          SEND 1
 NCC_R                   Conveyor_5_6          SEND 1 NCC_R TO Assembly_station_6
                                                                    1    NCC_R
Assembly_station_6    SEND 1
 NCC_R                   Assembly_station_6    USE Associate_6 FOR 5 Sec
                                               USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.4, 0.306) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               SEND 1 NCC_R TO Conveyor_6_A
                                                                    1    NCC_R
Conveyor_6_A          SEND 1
 NCC_R                   Conveyor_6_A          SEND 1 NCC_R TO Assembly_station_A
                                                                    1    NCC_R
Assembly_station_A    SEND 1
 NCC_R                   Assembly_station_A    USE Associate_A FOR 5 Sec
                                               USE Associate_A FOR N(12.8, 1.29) Sec
                                               USE Associate_A FOR N(18.4, 0.907) Sec
                                               SEND 1 NCC_R TO Conveyor_A_7
                                                                    1    NCC_R
Conveyor_A_7          SEND 1
 NCC_R                   Conveyor_A_7          SEND 1 NCC_R TO Assembly_station_7
                                                                    1    NCC_R
Assembly_station_7    SEND 1
 NCC_R                   Assembly_station_7    USE Associate_7 FOR 5 Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               SEND 1 NCC_R TO Conveyor_7_8
                                                                    1    NCC_R
Conveyor_7_8          SEND 1
 NCC_R                   Conveyor_7_8          SEND 1 NCC_R TO Assembly_station_8
                                                                    1    NCC_R
Assembly_station_8    SEND 1
 NCC_R                   Assembly_station_8    USE Associate_8 FOR N(17.9, 0.831) Sec
                                               USE Associate_8 FOR 5 Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               SEND 1 NCC_R TO Conveyor_8_9
                                                                    1    NCC_R
Conveyor_8_9          SEND 1
 NCC_R                   Conveyor_8_9          SEND 1 NCC_R TO Assembly_station_9
                                                                    1    NCC_R
Assembly_station_9    SEND 1
 NCC_R                   Assembly_station_9    USE Associate_9 FOR 5 Sec
                                               USE Associate_9 FOR N(5.6, 0.39) Sec
                                               USE Associate_9 FOR N(10.2, 1.16) Sec
                                               USE Associate_9 FOR N(9.72, 0.154) Sec
                                               USE Associate_9 FOR N(10.3, 1.41) Sec
                                               SEND 1 NCC_R TO Conveyor_9_B
                                                                    1    NCC_R
Conveyor_9_B          SEND 1
 NCC_R                   Conveyor_9_B          SEND 1 NCC_R TO Assembly_station_B
                                                                    1    NCC_R
Assembly_station_B    SEND 1
 NCC_R                   Assembly_station_B    USE Associate_B FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_R TO Conveyor_B_10
                                                                    1    NCC_R
Conveyor_B_10         SEND 1
 NCC_R                   Conveyor_B_10         SEND 1 NCC_R TO Assembly_station_10
                                                                    1    NCC_R
Assembly_station_10   SEND 1
 NCC_R                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_R TO Conveyor_10_11
                                                                    1    NCC_R
Conveyor_10_11        SEND 1
 NCC_R                   Conveyor_10_11        SEND 1 NCC_R TO Assembly_station_11
                                                                    1    NCC_R
Assembly_station_11   SEND 1
 NCC_R                   Assembly_station_11   SEND 1 NCC_R TO Finished_heater_box_R
                                               INC Finished_Heaters_R
```

```
                                                                    1    NCC_R
Finished_heater_box_R FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE
 NCC_R                  Finished_heater_box_R ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_R
 Finished_heater_boxes_R Finished_heater_box_R USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10
 Finished_heater_boxes_R Finished_heater_box_R                      1    Finished_heater_boxes_R EXIT
FIRST 1

********************************************************************************
*                                    Arrivals                                  *
********************************************************************************

  Entity   Location           Qty each   First Time Occurrences Frequency  Logic
  -------- ------------------ ---------- ---------- ----------- ---------- ------------
  NCC_L    Assembly_station_1 1                     200         0.98
  NCC_R    Assembly_station_1 1                     100         0.98


********************************************************************************
*                               Variables (global)                             *
********************************************************************************

  ID                 Type         Initial value Stats
  ------------------ ------------ ------------- -----------
  Finished_Heaters_L Integer      0             Time Series
  Finished_Heaters_R Integer      0             Time Series
```

Experiment 7: Line Balancing (Multifunction Employee): ‘L’, Setup Time: ‘H’ and Quality Control: ‘H’

```
********************************************************************************
*                                                                              *
*                          Formatted Listing of Model:                         *
* E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation Programming\Assembly line
3 (LHH).MOD *
*                                                                              *
********************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Meters


********************************************************************************
*                                   Locations                                  *
********************************************************************************

  Name                  Cap      Units Stats       Rules          Cost
  --------------------- -------- ----- ----------- -------------- ------------
  Assembly_station_1    200      1     Time Series Oldest, FIFO,
  Assembly_station_2    1        1     Time Series Oldest, FIFO,
  Assembly_station_3    1        1     Time Series Oldest, FIFO,
  Assembly_station_4    1        1     Time Series Oldest, FIFO,
  Assembly_station_5    1        1     Time Series Oldest, FIFO,
  Assembly_station_6    1        1     Time Series Oldest, FIFO,
  Assembly_station_7    1        1     Time Series Oldest, FIFO,
  Assembly_station_8    1        1     Time Series Oldest, FIFO,
  Assembly_station_9    1        1     Time Series Oldest, FIFO,
  Assembly_station_10   1        1     Time Series Oldest, FIFO,
  Assembly_station_11   1        1     Time Series Oldest, FIFO,
  Conveyor_1_2          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_2_3          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_3_4          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_4_5          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_5_6          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_6_7          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_7_8          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_8_9          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_9_10         INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_10_11        INFINITE 1     Time Series Oldest, FIFO,
  Finished_heater_box_L 6        1     Time Series Oldest, FIFO,
  Finished_heater_box_R 6        1     Time Series Oldest, FIFO,


********************************************************************************
*                                    Entities                                  *
********************************************************************************

  Name                    Speed (mpm)  Stats       Cost
  ----------------------- ------------ ----------- ------------
  NCC_L                   0            Time Series
  Finished_heater_boxes_L 0            Time Series
  NCC_R                   0            Time Series
  Finished_heater_boxes_R 0            Time Series


********************************************************************************
*                                 Path Networks                                *
********************************************************************************

  Name     Type        T/S              From     To       BI   Dist/Time  Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------- ------------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0        1
                                        N1       N3       Bi   2.0        1
```

```
********************************************************************************
*                                  Interfaces                                  *
********************************************************************************

  Net        Node       Location
  ---------- ---------- ---------------------
  Net1       N1         Assembly_station_11
             N2         Finished_heater_box_L
             N3         Finished_heater_box_R

********************************************************************************
*                                  Resources                                   *
********************************************************************************

                              Res        Ent
  Name         Units Stats    Search     Search Path       Motion        Cost
  ------------ ----- -------- ---------- ------ ---------- ------------- ------------
  Associate_1  1     By Unit  Least Used Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_2  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_3  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_4  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_5  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_6  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_7  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_8  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_9  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  QA_Associate 1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_10 1     By Unit  Closest    Oldest Net1       Empty: 50 mpm
                                                Home: N1   Full: 50 mpm
                                                (Return)

********************************************************************************
*                                  Processing                                  *
********************************************************************************

                                                         Process
Routing

 Entity                  Location              Operation            Blk  Output
Destination           Rule     Move Logic
 ----------------------- -------------------- ------------------   ---- ---------------------- ----
----------------- -------  -----------
 NCC_L                   Assembly_station_1    USE Associate_1 FOR 5 Sec
                                               USE Associate_1 FOR N(9.28, 1.1) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_1_2


                                                                    1    NCC_L
Conveyor_1_2          SEND 1
 NCC_L                   Conveyor_1_2          SEND 1 NCC_L TO Assembly_station_2
                                                                    1    NCC_L
Assembly_station_2    SEND 1
 NCC_L                   Assembly_station_2    USE Associate_2 FOR 5 Sec
                                               USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_L TO Conveyor_2_3
                                                                    1    NCC_L
Conveyor_2_3          SEND 1
 NCC_L                   Conveyor_2_3          SEND 1 NCC_L TO Assembly_station_3
                                                                    1    NCC_L
Assembly_station_3    SEND 1
 NCC_L                   Assembly_station_3    USE Associate_3 FOR 5 Sec
                                               USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               USE Associate_3 FOR N(10.8, 0.162) Sec
                                               SEND 1 NCC_L TO Conveyor_3_4
                                                                    1    NCC_L
Conveyor_3_4          SEND 1
 NCC_L                   Conveyor_3_4          SEND 1 NCC_L TO Assembly_station_4
                                                                    1    NCC_L
Assembly_station_4    SEND 1
 NCC_L                   Assembly_station_4    USE Associate_4 FOR 5 Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               USE Associate_4 FOR N(9.84, 0.855) Sec
                                               SEND 1 NCC_L TO Conveyor_4_5
                                                                    1    NCC_L
Conveyor_4_5          SEND 1
 NCC_L                   Conveyor_4_5          SEND 1 NCC_L TO Assembly_station_5
                                                                    1    NCC_L
Assembly_station_5    SEND 1
```

```
 NCC_L                   Assembly_station_5    USE Associate_5 FOR 5 Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               USE Associate_5 FOR N(13.4, 0.306) Sec
                                               SEND 1 NCC_L TO Conveyor_5_6
                                                                    1    NCC_L
Conveyor_5_6          SEND 1
 NCC_L                   Conveyor_5_6          SEND 1 NCC_L TO Assembly_station_6
                                                                    1    NCC_L
Assembly_station_6    SEND 1
 NCC_L                   Assembly_station_6    USE Associate_6 FOR 5 Sec
                                               USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               USE Associate_6 FOR N(12.8, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_6_7
                                                                    1    NCC_L
Conveyor_6_7          SEND 1
 NCC_L                   Conveyor_6_7          SEND 1 NCC_L TO Assembly_station_7
                                                                    1    NCC_L
Assembly_station_7    SEND 1
 NCC_L                   Assembly_station_7    USE Associate_7 FOR 5 Sec
                                               USE Associate_7 FOR N(18.4, 0.907) Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               USE Associate_7 FOR N(17.9, 0.831) Sec
                                               SEND 1 NCC_L TO Conveyor_7_8
                                                                    1    NCC_L
Conveyor_7_8          SEND 1
 NCC_L                   Conveyor_7_8          SEND 1 NCC_L TO Assembly_station_8
                                                                    1    NCC_L
Assembly_station_8    SEND 1
 NCC_L                   Assembly_station_8    USE Associate_8 FOR 5 Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               USE Associate_8 FOR N(5.6, 0.39) Sec
                                               USE Associate_8 FOR N(10.2, 1.16) Sec
                                               USE Associate_8 FOR N(9.72, 0.154) Sec
                                               SEND 1 NCC_L TO Conveyor_8_9
                                                                    1    NCC_L
Conveyor_8_9          SEND 1
 NCC_L                   Conveyor_8_9          SEND 1 NCC_L TO Assembly_station_9
                                                                    1    NCC_L
Assembly_station_9    SEND 1
 NCC_L                   Assembly_station_9    USE Associate_9 FOR N(10.3, 1.41) Sec
                                               USE Associate_9 FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_L TO Conveyor_9_10
                                                                    1    NCC_L
Conveyor_9_10         SEND 1
 NCC_L                   Conveyor_9_10         SEND 1 NCC_L TO Assembly_station_10
                                                                    1    NCC_L
Assembly_station_10   SEND 1
 NCC_L                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_L TO Conveyor_10_11
                                                                    1    NCC_L
Conveyor_10_11        SEND 1
 NCC_L                   Conveyor_10_11        SEND 1 NCC_L TO Assembly_station_11
                                                                    1    NCC_L
Assembly_station_11   SEND 1
 NCC_L                   Assembly_station_11   SEND 1 NCC_L TO Finished_heater_box_L
                                               INC Finished_Heaters_L

                                                                    1    NCC_L
Finished_heater_box_L FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_L                   Finished_heater_box_L ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_L

 Finished_heater_boxes_L Finished_heater_box_L USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_L Finished_heater_box_L                      1    Finished_heater_boxes_L EXIT
FIRST 1
 NCC_R                   Assembly_station_1    USE Associate_1 FOR 5 Sec
                                               USE Associate_1 FOR N(9.28, 1.1) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_1_2
                                                                    1    NCC_R
Conveyor_1_2          SEND 1
 NCC_R                   Conveyor_1_2          SEND 1 NCC_R TO Assembly_station_2
                                                                    1    NCC_R
Assembly_station_2    SEND 1
 NCC_R                   Assembly_station_2    USE Associate_2 FOR 5 Sec
                                               USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_R TO Conveyor_2_3
                                                                    1    NCC_R
Conveyor_2_3          SEND 1
 NCC_R                   Conveyor_2_3          SEND 1 NCC_R TO Assembly_station_3
                                                                    1    NCC_R
Assembly_station_3    SEND 1
 NCC_R                   Assembly_station_3    USE Associate_3 FOR 5 Sec
                                               USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               USE Associate_3 FOR N(10.8, 0.162) Sec
                                               SEND 1 NCC_R TO Conveyor_3_4
                                                                    1    NCC_R
Conveyor_3_4          SEND 1
 NCC_R                   Conveyor_3_4          SEND 1 NCC_R TO Assembly_station_4
                                                                    1    NCC_R
Assembly_station_4    SEND 1
 NCC_R                   Assembly_station_4    USE Associate_4 FOR 5 Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               USE Associate_4 FOR N(9.84, 0.855) Sec
                                               SEND 1 NCC_R TO Conveyor_4_5
                                                                    1    NCC_R
Conveyor_4_5          SEND 1
 NCC_R                   Conveyor_4_5          SEND 1 NCC_R TO Assembly_station_5
                                                                    1    NCC_R
Assembly_station_5    SEND 1
 NCC_R                   Assembly_station_5    USE Associate_5 FOR 5 Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               USE Associate_5 FOR N(13.4, 0.306) Sec
                                               SEND 1 NCC_R TO Conveyor_5_6
                                                                    1    NCC_R
Conveyor_5_6          SEND 1
 NCC_R                   Conveyor_5_6          SEND 1 NCC_R TO Assembly_station_6
                                                                    1    NCC_R
Assembly_station_6    SEND 1
 NCC_R                   Assembly_station_6    USE Associate_6 FOR 5 Sec
                                               USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               USE Associate_6 FOR N(12.8, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_6_7
                                                                    1    NCC_R
Conveyor_6_7          SEND 1
 NCC_R                   Conveyor_6_7          SEND 1 NCC_R TO Assembly_station_7
                                                                    1    NCC_R
Assembly_station_7    SEND 1
 NCC_R                   Assembly_station_7    USE Associate_7 FOR 5 Sec
                                               USE Associate_7 FOR N(18.4, 0.907) Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               USE Associate_7 FOR N(17.9, 0.831) Sec
                                               SEND 1 NCC_R TO Conveyor_7_8
                                                                    1    NCC_R
Conveyor_7_8          SEND 1
 NCC_R                   Conveyor_7_8          SEND 1 NCC_R TO Assembly_station_8
                                                                    1    NCC_R
Assembly_station_8    SEND 1
 NCC_R                   Assembly_station_8    USE Associate_8 FOR 5 Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               USE Associate_8 FOR N(5.6, 0.39) Sec
                                               USE Associate_8 FOR N(10.2, 1.16) Sec
                                               USE Associate_8 FOR N(9.72, 0.154) Sec
                                               SEND 1 NCC_R TO Conveyor_8_9
                                                                    1    NCC_R
Conveyor_8_9          SEND 1
 NCC_R                   Conveyor_8_9          SEND 1 NCC_R TO Assembly_station_9
                                                                    1    NCC_R
Assembly_station_9    SEND 1
 NCC_R                   Assembly_station_9    USE Associate_9 FOR N(10.3, 1.41) Sec
                                               USE Associate_9 FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_R TO Conveyor_9_10
                                                                    1    NCC_R
Conveyor_9_10         SEND 1
 NCC_R                   Conveyor_9_10         SEND 1 NCC_R TO Assembly_station_10
                                                                    1    NCC_R
Assembly_station_10   SEND 1
 NCC_R                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_R TO Conveyor_10_11
                                                                    1    NCC_R
Conveyor_10_11        SEND 1
 NCC_R                   Conveyor_10_11        SEND 1 NCC_R TO Assembly_station_11
                                                                    1    NCC_R
Assembly_station_11   SEND 1
 NCC_R                   Assembly_station_11   SEND 1 NCC_R TO Finished_heater_box_R
                                               INC Finished_Heaters_R
                                                                    1    NCC_R
Finished_heater_box_R FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_R                   Finished_heater_box_R ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_R

 Finished_heater_boxes_R Finished_heater_box_R USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_R Finished_heater_box_R                      1    Finished_heater_boxes_R EXIT
FIRST 1


********************************************************************************
*                                   Arrivals                                   *
********************************************************************************

  Entity   Location           Qty each   First Time Occurrences Frequency  Logic
  -------- ------------------ ---------- ---------- ----------- ---------- ------------
  NCC_L    Assembly_station_1 1                     200         1.21
  NCC_R    Assembly_station_1 1                     100         1.21


********************************************************************************
*                              Variables (global)                              *
********************************************************************************

  ID                 Type         Initial value Stats
  ------------------ ------------ ------------- -----------
  Finished_Heaters_L Integer      0             Time Series
  Finished_Heaters_R Integer      0             Time Series
```

Experiment 8: Line Balancing (Multifunction Employee): ‘H’, Setup Time: ‘H’ and Quality Control: ‘H’

```
********************************************************************************
*                                                                              *
*                          Formatted Listing of Model:                         *
* E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation Programming\Assembly line
3 (HHH).MOD *
*                                                                              *
********************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Meters


********************************************************************************
*                                  Locations                                   *
********************************************************************************

  Name                  Cap      Units Stats       Rules          Cost
  --------------------- -------- ----- ----------- -------------- ------------
  Assembly_station_1    200      1     Time Series Oldest, FIFO,
  Assembly_station_2    1        1     Time Series Oldest, FIFO,
  Assembly_station_3    1        1     Time Series Oldest, FIFO,
  Assembly_station_4    1        1     Time Series Oldest, FIFO,
  Assembly_station_5    1        1     Time Series Oldest, FIFO,
  Assembly_station_6    1        1     Time Series Oldest, FIFO,
  Assembly_station_A    1        1     Time Series Oldest, FIFO,
  Assembly_station_7    1        1     Time Series Oldest, FIFO,
  Assembly_station_8    1        1     Time Series Oldest, FIFO,
  Assembly_station_9    1        1     Time Series Oldest, FIFO,
  Assembly_station_B    1        1     Time Series Oldest, FIFO,
  Assembly_station_10   1        1     Time Series Oldest, FIFO,
  Assembly_station_11   1        1     Time Series Oldest, FIFO,
  Conveyor_1_2          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_2_3          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_3_4          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_4_5          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_5_6          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_6_A          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_A_7          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_7_8          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_8_9          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_9_B          INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_B_10         INFINITE 1     Time Series Oldest, FIFO,
  Conveyor_10_11        INFINITE 1     Time Series Oldest, FIFO,
  Finished_heater_box_L 6        1     Time Series Oldest, FIFO,
  Finished_heater_box_R 6        1     Time Series Oldest, FIFO,


********************************************************************************
*                                   Entities                                   *
********************************************************************************

  Name                    Speed (mpm)  Stats       Cost
  ----------------------- ------------ ----------- ------------
  NCC_L                   0            Time Series
  Finished_heater_boxes_L 0            Time Series
  NCC_R                   0            Time Series
  Finished_heater_boxes_R 0            Time Series


********************************************************************************
*                                Path Networks                                 *
********************************************************************************

  Name     Type        T/S              From     To       BI   Dist/Time  Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------- ------------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0        1
                                        N1       N3       Bi   2.0        1


********************************************************************************
*                                  Interfaces                                  *
********************************************************************************

  Net        Node       Location
  ---------- ---------- --------------------
  Net1       N1         Assembly_station_11
             N2         Finished_heater_box_L
             N3         Finished_heater_box_R


********************************************************************************
*                                  Resources                                   *
********************************************************************************

                              Res        Ent
  Name         Units Stats    Search     Search Path       Motion        Cost
  ------------ ----- -------- ---------- ------ ---------- ------------- ------------
  Associate_1  1     By Unit  Least Used Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_2  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_3  1     By Unit  None       Oldest            Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_4  1     By Unit  None       Oldest            Empty: 50 mpm
```

```
                                                           Full: 50 mpm

  Associate_5  1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_6  1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_A  1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_7  1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_8  1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_9  1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_B  1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  QA_Associate 1     By Unit  None       Oldest           Empty: 50 mpm
                                                           Full: 50 mpm

  Associate_10 1     By Unit  Closest    Oldest Net1      Empty: 50 mpm
                                                Home: N1   Full: 50 mpm
                                                (Return)


********************************************************************************
*                                  Processing                                  *
********************************************************************************

                                                         Process
Routing

 Entity                  Location              Operation            Blk  Output
Destination           Rule     Move Logic
 ---------------------- --------------------- ------------------   ---- ---------------------- ----
----------------- -------  ------------
 NCC_L                   Assembly_station_1    USE Associate_1 FOR 5 Sec
                                               USE Associate_1 FOR N(9.28, 1.11) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_L TO Conveyor_1_2
                                                                    1    NCC_L
Conveyor_1_2          SEND 1
 NCC_L                   Conveyor_1_2          SEND 1 NCC_L TO Assembly_station_2
                                                                    1    NCC_L
Assembly_station_2    SEND 1
 NCC_L                   Assembly_station_2    USE Associate_2 FOR 5 Sec
                                               USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_L TO Conveyor_2_3
                                                                    1    NCC_L
Conveyor_2_3          SEND 1
 NCC_L                   Conveyor_2_3          SEND 1 NCC_L TO Assembly_station_3
                                                                    1    NCC_L
Assembly_station_3    SEND 1
 NCC_L                   Assembly_station_3    USE Associate_3 FOR 5 Sec
                                               USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               SEND 1 NCC_L TO Conveyor_3_4
                                                                    1    NCC_L
Conveyor_3_4          SEND 1
 NCC_L                   Conveyor_3_4          SEND 1 NCC_L TO Assembly_station_4
                                                                    1    NCC_L
Assembly_station_4    SEND 1
 NCC_L                   Assembly_station_4    USE Associate_4 FOR 5 Sec
                                               USE Associate_4 FOR N(10.8, 0.162) Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               SEND 1 NCC_L TO Conveyor_4_5
                                                                    1    NCC_L
Conveyor_4_5          SEND 1
 NCC_L                   Conveyor_4_5          SEND 1 NCC_L TO Assembly_station_5
                                                                    1    NCC_L
Assembly_station_5    SEND 1
 NCC_L                   Assembly_station_5    USE Associate_5 FOR 5 Sec
                                               USE Associate_5 FOR N(9.84, 0.855) Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               SEND 1 NCC_L TO Conveyor_5_6
                                                                    1    NCC_L
Conveyor_5_6          SEND 1
 NCC_L                   Conveyor_5_6          SEND 1 NCC_L TO Assembly_station_6
                                                                    1    NCC_L
Assembly_station_6    SEND 1
 NCC_L                   Assembly_station_6    USE Associate_6 FOR 5 Sec
                                               USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.4, 0.306) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               SEND 1 NCC_L TO Conveyor_6_A
                                                                    1    NCC_L
Conveyor_6_A          SEND 1
 NCC_L                   Conveyor_6_A          SEND 1 NCC_L TO Assembly_station_A
                                                                    1    NCC_L
Assembly_station_A    SEND 1
 NCC_L                   Assembly_station_A    USE Associate_A FOR 5 Sec
                                               USE Associate_A FOR N(12.8, 1.29) Sec
                                               USE Associate_A FOR N(18.4, 0.907) Sec
                                               SEND 1 NCC_L TO Conveyor_A_7
                                                                    1    NCC_L
Conveyor_A_7          SEND 1
 NCC_L                   Conveyor_A_7          SEND 1 NCC_L TO Assembly_station_7
                                                                    1    NCC_L
Assembly_station_7    SEND 1
 NCC_L                   Assembly_station_7    USE Associate_7 FOR 5 Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               SEND 1 NCC_L TO Conveyor_7_8
                                                                    1    NCC_L
Conveyor_7_8          SEND 1
 NCC_L                   Conveyor_7_8          SEND 1 NCC_L TO Assembly_station_8
                                                                    1    NCC_L
Assembly_station_8    SEND 1
 NCC_L                   Assembly_station_8    USE Associate_8 FOR N(17.9, 0.831) Sec
                                               USE Associate_8 FOR 5 Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               SEND 1 NCC_L TO Conveyor_8_9
                                                                    1    NCC_L
Conveyor_8_9          SEND 1
 NCC_L                   Conveyor_8_9          SEND 1 NCC_L TO Assembly_station_9
                                                                    1    NCC_L
Assembly_station_9    SEND 1
 NCC_L                   Assembly_station_9    USE Associate_9 FOR 5 Sec
                                               USE Associate_9 FOR N(5.6, 0.39) Sec
                                               USE Associate_9 FOR N(10.2, 1.16) Sec
                                               USE Associate_9 FOR N(9.72, 0.154) Sec
                                               USE Associate_9 FOR N(10.3, 1.41) Sec
                                               SEND 1 NCC_L TO Conveyor_9_B
                                                                    1    NCC_L
Conveyor_9_B          SEND 1
 NCC_L                   Conveyor_9_B          SEND 1 NCC_L TO Assembly_station_B
                                                                    1    NCC_L
Assembly_station_B    SEND 1
 NCC_L                   Assembly_station_B    USE Associate_B FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_L TO Conveyor_B_10
                                                                    1    NCC_L
Conveyor_B_10         SEND 1
 NCC_L                   Conveyor_B_10         SEND 1 NCC_L TO Assembly_station_10
                                                                    1    NCC_L
Assembly_station_10   SEND 1
 NCC_L                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_L TO Conveyor_10_11
                                                                    1    NCC_L
Conveyor_10_11        SEND 1
 NCC_L                   Conveyor_10_11        SEND 1 NCC_L TO Assembly_station_11
                                                                    1    NCC_L
Assembly_station_11   SEND 1
 NCC_L                   Assembly_station_11   SEND 1 NCC_L TO Finished_heater_box_L
                                               INC Finished_Heaters_L
                                                                    1    NCC_L
Finished_heater_box_L FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE

 NCC_L                   Finished_heater_box_L ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_L

 Finished_heater_boxes_L Finished_heater_box_L USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10

 Finished_heater_boxes_L Finished_heater_box_L                      1    Finished_heater_boxes_L EXIT
FIRST 1
 NCC_R                   Assembly_station_1    USE Associate_1 FOR 5 Sec
                                               USE Associate_1 FOR N(9.28, 1.11) Sec
                                               USE Associate_1 FOR N(7.8, 0.98) Sec
                                               USE Associate_1 FOR N(19.5, 0.902) Sec
                                               USE Associate_1 FOR N(7.99, 1.29) Sec
                                               SEND 1 NCC_R TO Conveyor_1_2
                                                                    1    NCC_R
Conveyor_1_2          SEND 1
 NCC_R                   Conveyor_1_2          SEND 1 NCC_R TO Assembly_station_2
                                                                    1    NCC_R
Assembly_station_2    SEND 1
 NCC_R                   Assembly_station_2    USE Associate_2 FOR 5 Sec
                                               USE Associate_2 FOR N(21.7, 1.97) Sec
                                               USE Associate_2 FOR N(22.9, 2.74) Sec
                                               SEND 1 NCC_R TO Conveyor_2_3
                                                                    1    NCC_R
Conveyor_2_3          SEND 1
 NCC_R                   Conveyor_2_3          SEND 1 NCC_R TO Assembly_station_3
                                                                    1    NCC_R
Assembly_station_3    SEND 1
 NCC_R                   Assembly_station_3    USE Associate_3 FOR 5 Sec
                                               USE Associate_3 FOR N(21.8, 0.821) Sec
                                               USE Associate_3 FOR N(22.1, 0.84) Sec
                                               SEND 1 NCC_R TO Conveyor_3_4
                                                                    1    NCC_R
Conveyor_3_4          SEND 1
 NCC_R                   Conveyor_3_4          SEND 1 NCC_R TO Assembly_station_4
                                                                    1    NCC_R
Assembly_station_4    SEND 1
 NCC_R                   Assembly_station_4    USE Associate_4 FOR 5 Sec
                                               USE Associate_4 FOR N(10.8, 0.162) Sec
                                               USE Associate_4 FOR N(5.44, 0.385) Sec
                                               USE Associate_4 FOR N(11.8, 0.428) Sec
                                               USE Associate_4 FOR N(16.4, 0.265) Sec
                                               SEND 1 NCC_R TO Conveyor_4_5
                                                                    1    NCC_R
Conveyor_4_5          SEND 1
 NCC_R                   Conveyor_4_5          SEND 1 NCC_R TO Assembly_station_5
                                                                    1    NCC_R
Assembly_station_5    SEND 1
 NCC_R                   Assembly_station_5    USE Associate_5 FOR 5 Sec
                                               USE Associate_5 FOR N(9.84, 0.855) Sec
                                               USE Associate_5 FOR N(3.38, 0.492) Sec
                                               USE Associate_5 FOR N(14.2, 0.196) Sec
                                               USE Associate_5 FOR N(11.5, 0.652) Sec
                                               USE Associate_5 FOR N(4.04, 0.612) Sec
                                               SEND 1 NCC_R TO Conveyor_5_6
                                                                    1    NCC_R
Conveyor_5_6          SEND 1
 NCC_R                   Conveyor_5_6          SEND 1 NCC_R TO Assembly_station_6
                                                                    1    NCC_R
Assembly_station_6    SEND 1
 NCC_R                   Assembly_station_6    USE Associate_6 FOR 5 Sec
                                               USE Associate_6 FOR N(17.8, 0.412) Sec
                                               USE Associate_6 FOR N(13.4, 0.306) Sec
                                               USE Associate_6 FOR N(13.3, 0.543) Sec
                                               SEND 1 NCC_R TO Conveyor_6_A
                                                                    1    NCC_R
Conveyor_6_A          SEND 1
 NCC_R                   Conveyor_6_A          SEND 1 NCC_R TO Assembly_station_A
                                                                    1    NCC_R
Assembly_station_A    SEND 1
 NCC_R                   Assembly_station_A    USE Associate_A FOR 5 Sec
                                               USE Associate_A FOR N(12.8, 1.29) Sec
                                               USE Associate_A FOR N(18.4, 0.907) Sec
                                               SEND 1 NCC_R TO Conveyor_A_7
                                                                    1    NCC_R
Conveyor_A_7          SEND 1
 NCC_R                   Conveyor_A_7          SEND 1 NCC_R TO Assembly_station_7
                                                                    1    NCC_R
Assembly_station_7    SEND 1
 NCC_R                   Assembly_station_7    USE Associate_7 FOR 5 Sec
                                               USE Associate_7 FOR N(12.5, 0.834) Sec
                                               USE Associate_7 FOR N(25.3, 0.439) Sec
                                               SEND 1 NCC_R TO Conveyor_7_8
                                                                    1    NCC_R
Conveyor_7_8          SEND 1
 NCC_R                   Conveyor_7_8          SEND 1 NCC_R TO Assembly_station_8
                                                                    1    NCC_R
Assembly_station_8    SEND 1
 NCC_R                   Assembly_station_8    USE Associate_8 FOR N(17.9, 0.831) Sec
                                               USE Associate_8 FOR 5 Sec
                                               USE Associate_8 FOR N(15.5, 1.72) Sec
                                               SEND 1 NCC_R TO Conveyor_8_9
                                                                    1    NCC_R
Conveyor_8_9          SEND 1
 NCC_R                   Conveyor_8_9          SEND 1 NCC_R TO Assembly_station_9
                                                                    1    NCC_R
Assembly_station_9    SEND 1
 NCC_R                   Assembly_station_9    USE Associate_9 FOR 5 Sec
                                               USE Associate_9 FOR N(5.6, 0.39) Sec
                                               USE Associate_9 FOR N(10.2, 1.16) Sec
                                               USE Associate_9 FOR N(9.72, 0.154) Sec
                                               USE Associate_9 FOR N(10.3, 1.41) Sec
                                               SEND 1 NCC_R TO Conveyor_9_B
                                                                    1    NCC_R
Conveyor_9_B          SEND 1
 NCC_R                   Conveyor_9_B          SEND 1 NCC_R TO Assembly_station_B
                                                                    1    NCC_R
Assembly_station_B    SEND 1
 NCC_R                   Assembly_station_B    USE Associate_B FOR N(46.6, 1.07) Sec
                                               SEND 1 NCC_R TO Conveyor_B_10
                                                                    1    NCC_R
Conveyor_B_10         SEND 1
 NCC_R                   Conveyor_B_10         SEND 1 NCC_R TO Assembly_station_10
                                                                    1    NCC_R
Assembly_station_10   SEND 1
 NCC_R                   Assembly_station_10   USE QA_Associate FOR N(48.9, 3.97) Sec
                                               SEND 1 NCC_R TO Conveyor_10_11
                                                                    1    NCC_R
Conveyor_10_11        SEND 1
 NCC_R                   Conveyor_10_11        SEND 1 NCC_R TO Assembly_station_11
                                                                    1    NCC_R
Assembly_station_11   SEND 1
 NCC_R                   Assembly_station_11   SEND 1 NCC_R TO Finished_heater_box_R
                                               INC Finished_Heaters_R
                                                                    1    NCC_R
Finished_heater_box_R FIRST 1  MOVE WITH Associate_10 FOR N(12.9, 2.12) Sec THEN FREE
 NCC_R                   Finished_heater_box_R ACCUM 6
                                               GROUP 6 AS Finished_heater_boxes_R
 Finished_heater_boxes_R Finished_heater_box_R USE Associate_10 FOR N(63.3, 3.46) Sec
                                               USE Associate_10 FOR N(15.6, 3.34) Sec
                                               USE Associate_10 FOR N(30.2, 5.36) Sec
                                               FREE Associate_10
 Finished_heater_boxes_R Finished_heater_box_R                      1    Finished_heater_boxes_R EXIT
FIRST 1


********************************************************************************
*                                   Arrivals                                   *
********************************************************************************

  Entity   Location           Qty each   First Time Occurrences Frequency  Logic
  -------- ------------------ ---------- ---------- ----------- ---------- ------------
  NCC_L    Assembly_station_1 1                     200         0.96
  NCC_R    Assembly_station_1 1                     100         0.96


********************************************************************************
*                              Variables (global)                              *
********************************************************************************

  ID                 Type         Initial value Stats
  ------------------ ------------ ------------- -----------
  Finished_Heaters_L Integer      0             Time Series
  Finished_Heaters_R Integer      0             Time Series
```

SIMULATION EXPERIMENT RESULTS

Experiment 1 - Results: Line Balancing (Multifunction Employee): 'L', Setup Time: 'L' and Quality Control: 'L'

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation
Programming\Assembly line 3 (LLL).MOD
Date: Sep/25/2007   Time: 10:39:25 AM
--------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 6.606083333 hr Elapsed: 6.606083333 hr)
Simulation Time : 6.617516667 hr (Std. Dev. 0.00
--------------------------------------------------------------------------------


LOCATIONS

                                         Average
Location            Scheduled            Total   Minutes   Average  Maximum  Current
Name                    Hours  Capacity  Entries Per Entry Contents Contents Contents % Util
-------------------- --------- -------- ------- --------- -------- -------- -------- ------
Assembly station 1       6.60     200     300     0.74     0.56       1       0   0.28  (Rep 1)
Assembly station 1       6.62     200     300     0.74     0.55       1       0   0.28  (Rep 2)
Assembly station 1       6.61     200     300     0.74     0.56       1       0   0.28  (Rep 3)
Assembly station 1       6.61     200     300     0.74     0.56       1       0   0.28  (Rep 4)
Assembly station 1       6.63     200     300     0.74     0.56       1       0   0.28  (Rep 5)
Assembly station 1       6.61     200     300     0.74     0.56       1       0   0.28  (Rep 6)
Assembly station 1       6.61     200     300     0.74     0.56       1       0   0.28  (Rep 7)
Assembly station 1       6.61     200     300     0.74     0.56       1       0   0.28  (Rep 8)
Assembly station 1       6.62     200     300     0.74     0.56       1       0   0.28  (Rep 9)
Assembly station 1       6.60     200     300     0.74     0.56       1       0   0.28  (Rep 10)
Assembly station 1       6.61     200     300     0.74     0.56       1       0   0.28  (Average)
Assembly station 1       0.00       0       0     0.00     0.00       0       0   0.00  (Std. Dev.)
Assembly station 1       6.60     200     300     0.74     0.55       1       0   0.28  (Min)
Assembly station 1       6.63     200     300     0.74     0.56       1       0   0.28  (Max)

Assembly station 2       6.60       1     300     0.74     0.56       1       0  56.32  (Rep 1)
Assembly station 2       6.62       1     300     0.74     0.55       1       0  55.95  (Rep 2)
Assembly station 2       6.61       1     300     0.74     0.56       1       0  56.14  (Rep 3)
Assembly station 2       6.61       1     300     0.74     0.56       1       0  56.11  (Rep 4)
Assembly station 2       6.63       1     300     0.74     0.56       1       0  56.34  (Rep 5)
Assembly station 2       6.61       1     300     0.75     0.56       1       0  56.70  (Rep 6)
Assembly station 2       6.61       1     300     0.73     0.55       1       0  55.75  (Rep 7)
Assembly station 2       6.61       1     300     0.73     0.55       1       0  55.88  (Rep 8)
Assembly station 2       6.62       1     300     0.73     0.55       1       0  55.67  (Rep 9)
Assembly station 2       6.60       1     300     0.73     0.55       1       0  55.91  (Rep 10)
Assembly station 2       6.61       1     300     0.74     0.56       1       0  56.08  (Average)
Assembly station 2       0.00       0       0     0.00     0.00       0       0   0.31  (Std. Dev.)
Assembly station 2       6.60       1     300     0.73     0.55       1       0  55.67  (Min)
Assembly station 2       6.63       1     300     0.75     0.56       1       0  56.70  (Max)

Assembly station 3       6.60       1     300     0.91     0.68       1       0  68.95  (Rep 1)
Assembly station 3       6.62       1     300     0.91     0.68       1       0  68.85  (Rep 2)
Assembly station 3       6.61       1     300     0.91     0.68       1       0  68.88  (Rep 3)
Assembly station 3       6.61       1     300     0.90     0.68       1       0  68.73  (Rep 4)
Assembly station 3       6.63       1     300     0.91     0.68       1       0  68.78  (Rep 5)
Assembly station 3       6.61       1     300     0.91     0.69       1       0  69.03  (Rep 6)
Assembly station 3       6.61       1     300     0.91     0.68       1       0  68.80  (Rep 7)
```

Assembly station 3	6.61	1	300	0.91	0.68	1	0	68.98	(Rep 8)
Assembly station 3	6.62	1	300	0.91	0.68	1	0	68.82	(Rep 9)
Assembly station 3	6.60	1	300	0.91	0.68	1	0	68.96	(Rep 10)
Assembly station 3	6.61	1	300	0.91	0.68	1	0	68.88	(Average)
Assembly station 3	0.00	0	0	0.00	0.00	0	0	0.10	(Std. Dev.)
Assembly station 3	6.60	1	300	0.90	0.68	1	0	68.73	(Min)
Assembly station 3	6.63	1	300	0.91	0.69	1	0	69.03	(Max)
Assembly station 4	6.60	1	300	0.77	0.58	1	0	58.45	(Rep 1)
Assembly station 4	6.62	1	300	0.79	0.60	1	0	60.04	(Rep 2)
Assembly station 4	6.61	1	300	0.79	0.59	1	0	59.88	(Rep 3)
Assembly station 4	6.61	1	300	0.76	0.58	1	0	58.08	(Rep 4)
Assembly station 4	6.63	1	300	0.80	0.60	1	0	60.37	(Rep 5)
Assembly station 4	6.61	1	300	0.77	0.58	1	0	58.39	(Rep 6)
Assembly station 4	6.61	1	300	0.78	0.58	1	0	58.95	(Rep 7)
Assembly station 4	6.61	1	300	0.79	0.60	1	0	60.01	(Rep 8)
Assembly station 4	6.62	1	300	0.79	0.59	1	0	59.89	(Rep 9)
Assembly station 4	6.60	1	300	0.77	0.58	1	0	58.98	(Rep 10)
Assembly station 4	6.61	1	300	0.78	0.59	1	0	59.30	(Average)
Assembly station 4	0.00	0	0	0.01	0.00	0	0	0.83	(Std. Dev.)
Assembly station 4	6.60	1	300	0.76	0.58	1	0	58.08	(Min)
Assembly station 4	6.63	1	300	0.80	0.60	1	0	60.37	(Max)
Assembly station 5	6.60	1	300	0.92	0.70	1	0	70.38	(Rep 1)
Assembly station 5	6.62	1	300	0.96	0.72	1	0	72.58	(Rep 2)
Assembly station 5	6.61	1	300	0.95	0.72	1	0	72.09	(Rep 3)
Assembly station 5	6.61	1	300	0.92	0.70	1	0	70.15	(Rep 4)
Assembly station 5	6.63	1	300	0.95	0.71	1	0	71.96	(Rep 5)
Assembly station 5	6.61	1	300	0.93	0.70	1	0	70.58	(Rep 6)
Assembly station 5	6.61	1	300	0.94	0.71	1	0	71.39	(Rep 7)
Assembly station 5	6.61	1	300	0.96	0.72	1	0	72.58	(Rep 8)
Assembly station 5	6.62	1	300	0.95	0.71	1	0	71.97	(Rep 9)
Assembly station 5	6.60	1	300	0.94	0.71	1	0	71.25	(Rep 10)
Assembly station 5	6.61	1	300	0.94	0.71	1	0	71.49	(Average)
Assembly station 5	0.00	0	0	0.01	0.00	0	0	0.89	(Std. Dev.)
Assembly station 5	6.60	1	300	0.92	0.70	1	0	70.15	(Min)
Assembly station 5	6.63	1	300	0.96	0.72	1	0	72.58	(Max)
Assembly station 6	6.60	1	300	1.03	0.78	1	0	78.10	(Rep 1)
Assembly station 6	6.62	1	300	1.07	0.80	1	0	80.90	(Rep 2)
Assembly station 6	6.61	1	300	1.05	0.79	1	0	79.79	(Rep 3)
Assembly station 6	6.61	1	300	1.03	0.77	1	0	77.84	(Rep 4)
Assembly station 6	6.63	1	300	1.05	0.79	1	0	79.71	(Rep 5)
Assembly station 6	6.61	1	300	1.03	0.78	1	0	78.04	(Rep 6)
Assembly station 6	6.61	1	300	1.04	0.78	1	0	78.90	(Rep 7)
Assembly station 6	6.61	1	300	1.06	0.80	1	0	80.48	(Rep 8)
Assembly station 6	6.62	1	300	1.05	0.79	1	0	79.77	(Rep 9)
Assembly station 6	6.60	1	300	1.05	0.79	1	0	79.57	(Rep 10)
Assembly station 6	6.61	1	300	1.04	0.79	1	0	79.31	(Average)
Assembly station 6	0.00	0	0	0.01	0.01	0	0	1.05	(Std. Dev.)
Assembly station 6	6.60	1	300	1.03	0.77	1	0	77.84	(Min)
Assembly station 6	6.63	1	300	1.07	0.80	1	0	80.90	(Max)
Assembly station 7	6.60	1	300	1.23	0.93	1	0	93.36	(Rep 1)
Assembly station 7	6.62	1	300	1.23	0.93	1	0	93.34	(Rep 2)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.33	(Rep 3)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.26	(Rep 4)
Assembly station 7	6.63	1	300	1.23	0.93	1	0	93.34	(Rep 5)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.27	(Rep 6)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.30	(Rep 7)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.30	(Rep 8)
Assembly station 7	6.62	1	300	1.23	0.93	1	0	93.34	(Rep 9)
Assembly station 7	6.60	1	300	1.23	0.93	1	0	93.31	(Rep 10)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.31	(Average)
Assembly station 7	0.00	0	0	0.00	0.00	0	0	0.03	(Std. Dev.)
Assembly station 7	6.60	1	300	1.23	0.93	1	0	93.26	(Min)
Assembly station 7	6.63	1	300	1.23	0.93	1	0	93.36	(Max)

Assembly station 8	6.60	1	300	0.68	0.51	1	0	51.80	(Rep 1)
Assembly station 8	6.62	1	300	0.68	0.51	1	0	51.52	(Rep 2)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.63	(Rep 3)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.59	(Rep 4)
Assembly station 8	6.63	1	300	0.68	0.51	1	0	51.60	(Rep 5)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.86	(Rep 6)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.71	(Rep 7)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.54	(Rep 8)
Assembly station 8	6.62	1	300	0.68	0.51	1	0	51.67	(Rep 9)
Assembly station 8	6.60	1	300	0.68	0.51	1	0	51.58	(Rep 10)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.65	(Average)
Assembly station 8	0.00	0	0	0.00	0.00	0	0	0.11	(Std. Dev.)
Assembly station 8	6.60	1	300	0.68	0.51	1	0	51.52	(Min)
Assembly station 8	6.63	1	300	0.68	0.51	1	0	51.86	(Max)

Assembly station 9	6.60	1	300	0.94	0.71	1	0	71.49	(Rep 1)
Assembly station 9	6.62	1	300	0.94	0.71	1	0	71.47	(Rep 2)
Assembly station 9	6.61	1	300	0.94	0.71	1	0	71.71	(Rep 3)
Assembly station 9	6.61	1	300	0.94	0.71	1	0	71.63	(Rep 4)
Assembly station 9	6.63	1	300	0.94	0.71	1	0	71.49	(Rep 5)
Assembly station 9	6.61	1	300	0.95	0.71	1	0	71.91	(Rep 6)
Assembly station 9	6.61	1	300	0.95	0.71	1	0	71.84	(Rep 7)
Assembly station 9	6.61	1	300	0.94	0.71	1	0	71.73	(Rep 8)
Assembly station 9	6.62	1	300	0.95	0.71	1	0	71.70	(Rep 9)
Assembly station 9	6.60	1	300	0.94	0.71	1	0	71.76	(Rep 10)
Assembly station 9	6.61	1	300	0.94	0.71	1	0	71.67	(Average)
Assembly station 9	0.00	0	0	0.00	0.00	0	0	0.15	(Std. Dev.)
Assembly station 9	6.60	1	300	0.94	0.71	1	0	71.47	(Min)
Assembly station 9	6.63	1	300	0.95	0.71	1	0	71.91	(Max)

Assembly station 10	6.60	1	300	0.82	0.62	1	0	62.09	(Rep 1)
Assembly station 10	6.62	1	300	0.81	0.61	1	0	61.41	(Rep 2)
Assembly station 10	6.61	1	300	0.81	0.61	1	0	61.65	(Rep 3)
Assembly station 10	6.61	1	300	0.81	0.61	1	0	61.71	(Rep 4)
Assembly station 10	6.63	1	300	0.81	0.61	1	0	61.44	(Rep 5)
Assembly station 10	6.61	1	300	0.81	0.61	1	0	61.79	(Rep 6)
Assembly station 10	6.61	1	300	0.81	0.61	1	0	61.37	(Rep 7)
Assembly station 10	6.61	1	300	0.81	0.61	1	0	61.51	(Rep 8)
Assembly station 10	6.62	1	300	0.81	0.61	1	0	61.42	(Rep 9)
Assembly station 10	6.60	1	300	0.82	0.62	1	0	62.04	(Rep 10)
Assembly station 10	6.61	1	300	0.81	0.61	1	0	61.64	(Average)
Assembly station 10	0.00	0	0	0.00	0.00	0	0	0.26	(Std. Dev.)
Assembly station 10	6.60	1	300	0.81	0.61	1	0	61.37	(Min)
Assembly station 10	6.63	1	300	0.82	0.62	1	0	62.09	(Max)

Assembly station 11	6.60	1	300	0.11	0.08	1	0	8.49	(Rep 1)
Assembly station 11	6.62	1	300	0.10	0.08	1	0	8.01	(Rep 2)
Assembly station 11	6.61	1	300	0.10	0.08	1	0	8.25	(Rep 3)
Assembly station 11	6.61	1	300	0.11	0.08	1	0	8.49	(Rep 4)
Assembly station 11	6.63	1	300	0.10	0.08	1	0	8.14	(Rep 5)
Assembly station 11	6.61	1	300	0.11	0.08	1	0	8.48	(Rep 6)
Assembly station 11	6.61	1	300	0.10	0.08	1	0	8.22	(Rep 7)
Assembly station 11	6.61	1	300	0.10	0.07	1	0	7.92	(Rep 8)
Assembly station 11	6.62	1	300	0.10	0.07	1	0	7.61	(Rep 9)
Assembly station 11	6.60	1	300	0.10	0.08	1	0	8.29	(Rep 10)
Assembly station 11	6.61	1	300	0.10	0.08	1	0	8.19	(Average)
Assembly station 11	0.00	0	0	0.00	0.00	0	0	0.28	(Std. Dev.)
Assembly station 11	6.60	1	300	0.10	0.07	1	0	7.61	(Min)
Assembly station 11	6.63	1	300	0.11	0.08	1	0	8.49	(Max)

Experiment 2 - Results: Line Balancing (Multifunction Employee): 'L', Setup Time: 'L' and Quality Control: 'H'

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation
Programming\Assembly line 3 (LLH).MOD
Date: Sep/25/2007   Time: 12:16:18 PM
--------------------------------------------------------------------------------
Scenario       : Normal Run
Replication    : All
Period         : Final Report (0 sec to 7.03445 hr Elapsed: 7.03445 hr)
Simulation Time : 7.04175 hr (Std. Dev. 0.00
--------------------------------------------------------------------------------


LOCATIONS

                                           Average
Location             Scheduled             Total   Minutes   Average  Maximum   Current
Name                     Hours  Capacity  Entries  Per Entry  Contents  Contents  Contents  % Util
-------------------- --------- -------- ------- --------- -------- -------- -------- ------
Assembly station 1       7.03      200      300      0.82     0.58       1        0    0.29  (Rep 1)
Assembly station 1       7.03      200      300      0.82     0.58       1        0    0.29  (Rep 2)
Assembly station 1       7.03      200      300      0.82     0.58       1        0    0.29  (Rep 3)
Assembly station 1       7.04      200      300      0.82     0.58       1        0    0.29  (Rep 4)
Assembly station 1       7.04      200      300      0.82     0.58       1        0    0.29  (Rep 5)
Assembly station 1       7.04      200      300      0.83     0.59       1        0    0.30  (Rep 6)
Assembly station 1       7.03      200      300      0.82     0.58       1        0    0.29  (Rep 7)
Assembly station 1       7.04      200      300      0.82     0.58       1        0    0.29  (Rep 8)
Assembly station 1       7.04      200      300      0.82     0.58       1        0    0.29  (Rep 9)
Assembly station 1       7.05      200      300      0.82     0.58       1        0    0.29  (Rep 10)
Assembly station 1       7.04      200      300      0.82     0.58       1        0    0.29  (Average)
Assembly station 1       0.00        0        0      0.00     0.00       0        0    0.00  (Std. Dev.)
Assembly station 1       7.03      200      300      0.82     0.58       1        0    0.29  (Min)
Assembly station 1       7.05      200      300      0.83     0.59       1        0    0.30  (Max)

Assembly station 2       7.03        1      300      0.82     0.58       1        0   58.81  (Rep 1)
Assembly station 2       7.03        1      300      0.82     0.58       1        0   58.67  (Rep 2)
Assembly station 2       7.03        1      300      0.82     0.58       1        0   58.96  (Rep 3)
Assembly station 2       7.04        1      300      0.82     0.58       1        0   58.20  (Rep 4)
Assembly station 2       7.04        1      300      0.82     0.58       1        0   58.39  (Rep 5)
Assembly station 2       7.04        1      300      0.82     0.58       1        0   58.82  (Rep 6)
Assembly station 2       7.03        1      300      0.82     0.58       1        0   58.50  (Rep 7)
Assembly station 2       7.04        1      300      0.82     0.58       1        0   58.82  (Rep 8)
Assembly station 2       7.04        1      300      0.82     0.58       1        0   58.75  (Rep 9)
Assembly station 2       7.05        1      300      0.82     0.58       1        0   58.69  (Rep 10)
Assembly station 2       7.04        1      300      0.82     0.58       1        0   58.66  (Average)
Assembly station 2       0.00        0        0      0.00     0.00       0        0    0.23  (Std. Dev.)
Assembly station 2       7.03        1      300      0.82     0.58       1        0   58.20  (Min)
Assembly station 2       7.05        1      300      0.82     0.58       1        0   58.96  (Max)

Assembly station 3       7.03        1      300      0.99     0.70       1        0   70.68  (Rep 1)
Assembly station 3       7.03        1      300      0.99     0.70       1        0   70.76  (Rep 2)
Assembly station 3       7.03        1      300      0.99     0.70       1        0   70.60  (Rep 3)
Assembly station 3       7.04        1      300      0.99     0.70       1        0   70.53  (Rep 4)
Assembly station 3       7.04        1      300      0.99     0.70       1        0   70.60  (Rep 5)
Assembly station 3       7.04        1      300      0.99     0.70       1        0   70.69  (Rep 6)
Assembly station 3       7.03        1      300      0.99     0.70       1        0   70.63  (Rep 7)
Assembly station 3       7.04        1      300      0.99     0.70       1        0   70.42  (Rep 8)
Assembly station 3       7.04        1      300      0.99     0.70       1        0   70.61  (Rep 9)
Assembly station 3       7.05        1      300      0.99     0.70       1        0   70.51  (Rep 10)
Assembly station 3       7.04        1      300      0.99     0.70       1        0   70.60  (Average)
Assembly station 3       0.00        0        0      0.00     0.00       0        0    0.10  (Std. Dev.)
Assembly station 3       7.03        1      300      0.99     0.70       1        0   70.42  (Min)
Assembly station 3       7.05        1      300      0.99     0.70       1        0   70.76  (Max)
```

Assembly station 4	7.03	1	300	0.84	0.60	1	0	60.24	(Rep 1)
Assembly station 4	7.03	1	300	0.84	0.60	1	0	60.19	(Rep 2)
Assembly station 4	7.03	1	300	0.84	0.60	1	0	60.24	(Rep 3)
Assembly station 4	7.04	1	300	0.85	0.60	1	0	60.42	(Rep 4)
Assembly station 4	7.04	1	300	0.85	0.61	1	0	61.02	(Rep 5)
Assembly station 4	7.04	1	300	0.84	0.59	1	0	59.77	(Rep 6)
Assembly station 4	7.03	1	300	0.84	0.59	1	0	59.90	(Rep 7)
Assembly station 4	7.04	1	300	0.85	0.60	1	0	60.86	(Rep 8)
Assembly station 4	7.04	1	300	0.84	0.60	1	0	60.12	(Rep 9)
Assembly station 4	7.05	1	300	0.87	0.61	1	0	61.92	(Rep 10)
Assembly station 4	7.04	1	300	0.85	0.60	1	0	60.47	(Average)
Assembly station 4	0.00	0	0	0.00	0.00	0	0	0.64	(Std. Dev.)
Assembly station 4	7.03	1	300	0.84	0.59	1	0	59.77	(Min)
Assembly station 4	7.05	1	300	0.87	0.61	1	0	61.92	(Max)
Assembly station 5	7.03	1	300	1.01	0.72	1	0	72.22	(Rep 1)
Assembly station 5	7.03	1	300	1.01	0.71	1	0	71.92	(Rep 2)
Assembly station 5	7.03	1	300	1.01	0.72	1	0	72.05	(Rep 3)
Assembly station 5	7.04	1	300	1.02	0.72	1	0	72.53	(Rep 4)
Assembly station 5	7.04	1	300	1.02	0.72	1	0	72.83	(Rep 5)
Assembly station 5	7.04	1	300	1.00	0.71	1	0	71.65	(Rep 6)
Assembly station 5	7.03	1	300	0.99	0.70	1	0	70.99	(Rep 7)
Assembly station 5	7.04	1	300	1.02	0.72	1	0	72.99	(Rep 8)
Assembly station 5	7.04	1	300	1.01	0.72	1	0	72.22	(Rep 9)
Assembly station 5	7.05	1	300	1.03	0.73	1	0	73.45	(Rep 10)
Assembly station 5	7.04	1	300	1.01	0.72	1	0	72.29	(Average)
Assembly station 5	0.00	0	0	0.01	0.00	0	0	0.70	(Std. Dev.)
Assembly station 5	7.03	1	300	0.99	0.70	1	0	70.99	(Min)
Assembly station 5	7.05	1	300	1.03	0.73	1	0	73.45	(Max)
Assembly station 6	7.03	1	300	1.11	0.79	1	0	79.50	(Rep 1)
Assembly station 6	7.03	1	300	1.12	0.79	1	0	79.62	(Rep 2)
Assembly station 6	7.03	1	300	1.12	0.79	1	0	79.93	(Rep 3)
Assembly station 6	7.04	1	300	1.13	0.80	1	0	80.20	(Rep 4)
Assembly station 6	7.04	1	300	1.13	0.80	1	0	80.83	(Rep 5)
Assembly station 6	7.04	1	300	1.11	0.78	1	0	78.98	(Rep 6)
Assembly station 6	7.03	1	300	1.11	0.79	1	0	79.36	(Rep 7)
Assembly station 6	7.04	1	300	1.13	0.80	1	0	80.31	(Rep 8)
Assembly station 6	7.04	1	300	1.13	0.80	1	0	80.27	(Rep 9)
Assembly station 6	7.05	1	300	1.14	0.81	1	0	81.26	(Rep 10)
Assembly station 6	7.04	1	300	1.12	0.80	1	0	80.03	(Average)
Assembly station 6	0.00	0	0	0.01	0.00	0	0	0.69	(Std. Dev.)
Assembly station 6	7.03	1	300	1.11	0.78	1	0	78.98	(Min)
Assembly station 6	7.05	1	300	1.14	0.81	1	0	81.26	(Max)
Assembly station 7	7.03	1	300	1.31	0.93	1	0	93.58	(Rep 1)
Assembly station 7	7.03	1	300	1.31	0.93	1	0	93.57	(Rep 2)
Assembly station 7	7.03	1	300	1.31	0.93	1	0	93.56	(Rep 3)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.54	(Rep 4)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.59	(Rep 5)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.57	(Rep 6)
Assembly station 7	7.03	1	300	1.31	0.93	1	0	93.56	(Rep 7)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.56	(Rep 8)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.57	(Rep 9)
Assembly station 7	7.05	1	300	1.31	0.93	1	0	93.59	(Rep 10)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.57	(Average)
Assembly station 7	0.00	0	0	0.00	0.00	0	0	0.02	(Std. Dev.)
Assembly station 7	7.03	1	300	1.31	0.93	1	0	93.54	(Min)
Assembly station 7	7.05	1	300	1.31	0.93	1	0	93.59	(Max)
Assembly station 8	7.03	1	300	0.76	0.54	1	0	54.48	(Rep 1)
Assembly station 8	7.03	1	300	0.76	0.54	1	0	54.37	(Rep 2)
Assembly station 8	7.03	1	300	0.76	0.54	1	0	54.41	(Rep 3)
Assembly station 8	7.04	1	300	0.76	0.54	1	0	54.02	(Rep 4)
Assembly station 8	7.04	1	300	0.76	0.54	1	0	54.49	(Rep 5)
Assembly station 8	7.04	1	300	0.76	0.54	1	0	54.37	(Rep 6)

```
Assembly station 8      7.03    1   300    0.76    0.54     1     0  54.60  (Rep 7)
Assembly station 8      7.04    1   300    0.76    0.54     1     0  54.33  (Rep 8)
Assembly station 8      7.04    1   300    0.76    0.54     1     0  54.59  (Rep 9)
Assembly station 8      7.05    1   300    0.76    0.54     1     0  54.34  (Rep 10)
Assembly station 8      7.04    1   300    0.76    0.54     1     0  54.40  (Average)
Assembly station 8      0.00    0     0   0.00    0.00     0     0   0.17  (Std. Dev.)
Assembly station 8      7.03    1   300    0.76    0.54     1     0  54.02  (Min)
Assembly station 8      7.05    1   300    0.76    0.54     1     0  54.60  (Max)

Assembly station 9      7.03    1   300    0.94    0.67     1     0  67.26  (Rep 1)
Assembly station 9      7.03    1   300    0.94    0.67     1     0  67.32  (Rep 2)
Assembly station 9      7.03    1   300    0.94    0.67     1     0  67.31  (Rep 3)
Assembly station 9      7.04    1   300    0.94    0.67     1     0  67.14  (Rep 4)
Assembly station 9      7.04    1   300    0.94    0.67     1     0  67.20  (Rep 5)
Assembly station 9      7.04    1   300    0.94    0.67     1     0  67.24  (Rep 6)
Assembly station 9      7.03    1   300    0.95    0.67     1     0  67.62  (Rep 7)
Assembly station 9      7.04    1   300    0.95    0.67     1     0  67.46  (Rep 8)
Assembly station 9      7.04    1   300    0.94    0.67     1     0  67.19  (Rep 9)
Assembly station 9      7.05    1   300    0.94    0.67     1     0  67.05  (Rep 10)
Assembly station 9      7.04    1   300    0.94    0.67     1     0  67.28  (Average)
Assembly station 9      0.00    0     0   0.00    0.00     0     0   0.16  (Std. Dev.)
Assembly station 9      7.03    1   300    0.94    0.67     1     0  67.05  (Min)
Assembly station 9      7.05    1   300    0.95    0.67     1     0  67.62  (Max)

Assembly station 10      7.03    1   300    0.81    0.57     1     0  57.95  (Rep 1)
Assembly station 10      7.03    1   300    0.81    0.57     1     0  57.61  (Rep 2)
Assembly station 10      7.03    1   300    0.81    0.57     1     0  57.80  (Rep 3)
Assembly station 10      7.04    1   300    0.81    0.57     1     0  57.73  (Rep 4)
Assembly station 10      7.04    1   300    0.81    0.57     1     0  57.66  (Rep 5)
Assembly station 10      7.04    1   300    0.81    0.57     1     0  57.96  (Rep 6)
Assembly station 10      7.03    1   300    0.81    0.58     1     0  58.31  (Rep 7)
Assembly station 10      7.04    1   300    0.81    0.57     1     0  57.80  (Rep 8)
Assembly station 10      7.04    1   300    0.81    0.57     1     0  57.72  (Rep 9)
Assembly station 10      7.05    1   300    0.81    0.57     1     0  57.46  (Rep 10)
Assembly station 10      7.04    1   300    0.81    0.57     1     0  57.80  (Average)
Assembly station 10      0.00    0     0   0.00    0.00     0     0   0.23  (Std. Dev.)
Assembly station 10      7.03    1   300    0.81    0.57     1     0  57.46  (Min)
Assembly station 10      7.05    1   300    0.81    0.58     1     0  58.31  (Max)

Assembly station 11      7.03    1   300    0.09    0.07     1     0   7.09  (Rep 1)
Assembly station 11      7.03    1   300    0.09    0.06     1     0   6.97  (Rep 2)
Assembly station 11      7.03    1   300    0.09    0.06     1     0   6.58  (Rep 3)
Assembly station 11      7.04    1   300    0.09    0.06     1     0   6.88  (Rep 4)
Assembly station 11      7.04    1   300    0.09    0.06     1     0   6.83  (Rep 5)
Assembly station 11      7.04    1   300    0.09    0.06     1     0   6.48  (Rep 6)
Assembly station 11      7.03    1   300    0.09    0.06     1     0   6.66  (Rep 7)
Assembly station 11      7.04    1   300    0.09    0.06     1     0   6.70  (Rep 8)
Assembly station 11      7.04    1   300    0.09    0.06     1     0   6.73  (Rep 9)
Assembly station 11      7.05    1   300    0.09    0.07     1     0   7.07  (Rep 10)
Assembly station 11      7.04    1   300    0.09    0.06     1     0   6.80  (Average)
Assembly station 11      0.00    0     0   0.00    0.00     0     0   0.20  (Std. Dev.)
Assembly station 11      7.03    1   300    0.09    0.06     1     0   6.48  (Min)
Assembly station 11      7.05    1   300    0.09    0.07     1     0   7.09  (Max)
```

Experiment 3 - Results: Line Balancing (Multifunction Employee): ‘L’, Setup Time: ‘H’ and Quality Control: ‘L’

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation
Programming\Assembly line 3 (LHL).MOD
Date: Sep/25/2007   Time: 11:42:39 AM
--------------------------------------------------------------------------------
```

```
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 6.609933333 hr Elapsed: 6.609933333 hr)
Simulation Time : 6.61475 hr (Std. Dev. 0.00
-------------------------------------------------------------------------------


LOCATIONS

                                       Average
Location             Scheduled           Total   Minutes   Average  Maximum   Current
Name                     Hours  Capacity  Entries  Per Entry  Contents  Contents  Contents  % Util
-------------------- --------- -------- ------- --------- -------- -------- -------- ------
Assembly station 1        6.60      200     300      0.74     0.56        1        0   0.28  (Rep 1)
Assembly station 1        6.61      200     300      0.73     0.55        1        0   0.28  (Rep 2)
Assembly station 1        6.60      200     300      0.74     0.56        1        0   0.28  (Rep 3)
Assembly station 1        6.61      200     300      0.74     0.55        1        0   0.28  (Rep 4)
Assembly station 1        6.62      200     300      0.74     0.56        1        0   0.28  (Rep 5)
Assembly station 1        6.62      200     300      0.74     0.56        1        0   0.28  (Rep 6)
Assembly station 1        6.60      200     300      0.74     0.56        1        0   0.28  (Rep 7)
Assembly station 1        6.62      200     300      0.74     0.55        1        0   0.28  (Rep 8)
Assembly station 1        6.61      200     300      0.74     0.56        1        0   0.28  (Rep 9)
Assembly station 1        6.61      200     300      0.74     0.56        1        0   0.28  (Rep 10)
Assembly station 1        6.61      200     300      0.74     0.56        1        0   0.28  (Average)
Assembly station 1        0.00        0       0      0.00     0.00        0        0   0.00  (Std. Dev.)
Assembly station 1        6.60      200     300      0.73     0.55        1        0   0.28  (Min)
Assembly station 1        6.62      200     300      0.74     0.56        1        0   0.28  (Max)

Assembly station 2        6.60        1     300      0.74     0.56        1        0  56.30  (Rep 1)
Assembly station 2        6.61        1     300      0.74     0.56        1        0  56.16  (Rep 2)
Assembly station 2        6.60        1     300      0.74     0.56        1        0  56.04  (Rep 3)
Assembly station 2        6.61        1     300      0.74     0.55        1        0  55.96  (Rep 4)
Assembly station 2        6.62        1     300      0.74     0.56        1        0  56.50  (Rep 5)
Assembly station 2        6.62        1     300      0.75     0.56        1        0  56.60  (Rep 6)
Assembly station 2        6.60        1     300      0.74     0.56        1        0  56.39  (Rep 7)
Assembly station 2        6.62        1     300      0.74     0.56        1        0  56.08  (Rep 8)
Assembly station 2        6.61        1     300      0.74     0.56        1        0  56.22  (Rep 9)
Assembly station 2        6.61        1     300      0.73     0.55        1        0  55.63  (Rep 10)
Assembly station 2        6.61        1     300      0.74     0.56        1        0  56.19  (Average)
Assembly station 2        0.00        0       0      0.00     0.00        0        0   0.28  (Std. Dev.)
Assembly station 2        6.60        1     300      0.73     0.55        1        0  55.63  (Min)
Assembly station 2        6.62        1     300      0.75     0.56        1        0  56.60  (Max)

Assembly station 3        6.60        1     300      0.93     0.71        1        0  71.07  (Rep 1)
Assembly station 3        6.61        1     300      0.93     0.70        1        0  70.36  (Rep 2)
Assembly station 3        6.60        1     300      0.93     0.70        1        0  70.63  (Rep 3)
Assembly station 3        6.61        1     300      0.93     0.70        1        0  70.55  (Rep 4)
Assembly station 3        6.62        1     300      0.94     0.70        1        0  71.00  (Rep 5)
Assembly station 3        6.62        1     300      0.93     0.70        1        0  70.59  (Rep 6)
Assembly station 3        6.60        1     300      0.93     0.70        1        0  70.45  (Rep 7)
Assembly station 3        6.62        1     300      0.93     0.70        1        0  70.95  (Rep 8)
Assembly station 3        6.61        1     300      0.93     0.70        1        0  70.60  (Rep 9)
Assembly station 3        6.61        1     300      0.93     0.70        1        0  70.54  (Rep 10)
Assembly station 3        6.61        1     300      0.93     0.70        1        0  70.67  (Average)
Assembly station 3        0.00        0       0      0.00     0.00        0        0   0.24  (Std. Dev.)
Assembly station 3        6.60        1     300      0.93     0.70        1        0  70.36  (Min)
Assembly station 3        6.62        1     300      0.94     0.71        1        0  71.07  (Max)

Assembly station 4        6.60        1     300      0.86     0.65        1        0  65.54  (Rep 1)
Assembly station 4        6.61        1     300      0.85     0.64        1        0  64.48  (Rep 2)
Assembly station 4        6.60        1     300      0.85     0.64        1        0  64.80  (Rep 3)
Assembly station 4        6.61        1     300      0.85     0.64        1        0  64.82  (Rep 4)
Assembly station 4        6.62        1     300      0.86     0.65        1        0  65.38  (Rep 5)
Assembly station 4        6.62        1     300      0.85     0.64        1        0  64.74  (Rep 6)
Assembly station 4        6.60        1     300      0.85     0.65        1        0  65.02  (Rep 7)
Assembly station 4        6.62        1     300      0.86     0.65        1        0  65.35  (Rep 8)
Assembly station 4        6.61        1     300      0.86     0.65        1        0  65.05  (Rep 9)
```

Assembly station 4	6.61	1	300	0.85	0.64	1	0	64.96	(Rep 10)
Assembly station 4	6.61	1	300	0.86	0.65	1	0	65.01	(Average)
Assembly station 4	0.00	0	0	0.00	0.00	0	0	0.33	(Std. Dev.)
Assembly station 4	6.60	1	300	0.85	0.64	1	0	64.48	(Min)
Assembly station 4	6.62	1	300	0.86	0.65	1	0	65.54	(Max)
Assembly station 5	6.60	1	300	0.97	0.73	1	0	73.49	(Rep 1)
Assembly station 5	6.61	1	300	0.96	0.73	1	0	73.05	(Rep 2)
Assembly station 5	6.60	1	300	0.95	0.72	1	0	72.60	(Rep 3)
Assembly station 5	6.61	1	300	0.96	0.72	1	0	72.86	(Rep 4)
Assembly station 5	6.62	1	300	0.97	0.73	1	0	73.32	(Rep 5)
Assembly station 5	6.62	1	300	0.96	0.73	1	0	73.18	(Rep 6)
Assembly station 5	6.60	1	300	0.95	0.72	1	0	72.61	(Rep 7)
Assembly station 5	6.62	1	300	0.97	0.73	1	0	73.90	(Rep 8)
Assembly station 5	6.61	1	300	0.96	0.73	1	0	73.02	(Rep 9)
Assembly station 5	6.61	1	300	0.96	0.73	1	0	73.34	(Rep 10)
Assembly station 5	6.61	1	300	0.96	0.73	1	0	73.14	(Average)
Assembly station 5	0.00	0	0	0.00	0.00	0	0	0.40	(Std. Dev.)
Assembly station 5	6.60	1	300	0.95	0.72	1	0	72.60	(Min)
Assembly station 5	6.62	1	300	0.97	0.73	1	0	73.90	(Max)
Assembly station 6	6.60	1	300	1.04	0.78	1	0	78.76	(Rep 1)
Assembly station 6	6.61	1	300	1.03	0.78	1	0	78.37	(Rep 2)
Assembly station 6	6.60	1	300	1.02	0.77	1	0	77.48	(Rep 3)
Assembly station 6	6.61	1	300	1.03	0.78	1	0	78.02	(Rep 4)
Assembly station 6	6.62	1	300	1.04	0.78	1	0	78.74	(Rep 5)
Assembly station 6	6.62	1	300	1.04	0.78	1	0	78.86	(Rep 6)
Assembly station 6	6.60	1	300	1.02	0.77	1	0	77.49	(Rep 7)
Assembly station 6	6.62	1	300	1.04	0.79	1	0	79.04	(Rep 8)
Assembly station 6	6.61	1	300	1.03	0.78	1	0	78.31	(Rep 9)
Assembly station 6	6.61	1	300	1.03	0.78	1	0	78.48	(Rep 10)
Assembly station 6	6.61	1	300	1.03	0.78	1	0	78.36	(Average)
Assembly station 6	0.00	0	0	0.00	0.00	0	0	0.55	(Std. Dev.)
Assembly station 6	6.60	1	300	1.02	0.77	1	0	77.48	(Min)
Assembly station 6	6.62	1	300	1.04	0.79	1	0	79.04	(Max)
Assembly station 7	6.60	1	300	1.23	0.93	1	0	93.38	(Rep 1)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.35	(Rep 2)
Assembly station 7	6.60	1	300	1.23	0.93	1	0	93.31	(Rep 3)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.29	(Rep 4)
Assembly station 7	6.62	1	300	1.23	0.93	1	0	93.34	(Rep 5)
Assembly station 7	6.62	1	300	1.23	0.93	1	0	93.29	(Rep 6)
Assembly station 7	6.60	1	300	1.23	0.93	1	0	93.31	(Rep 7)
Assembly station 7	6.62	1	300	1.23	0.93	1	0	93.30	(Rep 8)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.33	(Rep 9)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.31	(Rep 10)
Assembly station 7	6.61	1	300	1.23	0.93	1	0	93.32	(Average)
Assembly station 7	0.00	0	0	0.00	0.00	0	0	0.03	(Std. Dev.)
Assembly station 7	6.60	1	300	1.23	0.93	1	0	93.29	(Min)
Assembly station 7	6.62	1	300	1.23	0.93	1	0	93.38	(Max)
Assembly station 8	6.60	1	300	0.68	0.51	1	0	51.59	(Rep 1)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.58	(Rep 2)
Assembly station 8	6.60	1	300	0.68	0.52	1	0	52.09	(Rep 3)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.68	(Rep 4)
Assembly station 8	6.62	1	300	0.68	0.51	1	0	51.61	(Rep 5)
Assembly station 8	6.62	1	300	0.68	0.51	1	0	51.68	(Rep 6)
Assembly station 8	6.60	1	300	0.68	0.51	1	0	51.72	(Rep 7)
Assembly station 8	6.62	1	300	0.68	0.51	1	0	51.66	(Rep 8)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.48	(Rep 9)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.77	(Rep 10)
Assembly station 8	6.61	1	300	0.68	0.51	1	0	51.68	(Average)
Assembly station 8	0.00	0	0	0.00	0.00	0	0	0.16	(Std. Dev.)
Assembly station 8	6.60	1	300	0.68	0.51	1	0	51.48	(Min)
Assembly station 8	6.62	1	300	0.68	0.52	1	0	52.09	(Max)
Assembly station 9	6.60	1	300	0.94	0.71	1	0	71.77	(Rep 1)

```
Assembly station 9     6.61    1    300    0.95    0.71    1    0   71.82  (Rep 2)
Assembly station 9     6.60    1    300    0.95    0.71    1    0   71.88  (Rep 3)
Assembly station 9     6.61    1    300    0.94    0.71    1    0   71.75  (Rep 4)
Assembly station 9     6.62    1    300    0.94    0.71    1    0   71.50  (Rep 5)
Assembly station 9     6.62    1    300    0.95    0.71    1    0   71.74  (Rep 6)
Assembly station 9     6.60    1    300    0.94    0.71    1    0   71.86  (Rep 7)
Assembly station 9     6.62    1    300    0.94    0.71    1    0   71.58  (Rep 8)
Assembly station 9     6.61    1    300    0.94    0.71    1    0   71.61  (Rep 9)
Assembly station 9     6.61    1    300    0.94    0.71    1    0   71.72  (Rep 10)
Assembly station 9     6.61    1    300    0.94    0.71    1    0   71.72  (Average)
Assembly station 9     0.00    0      0   0.00    0.00    0     0   0.12  (Std. Dev.)
Assembly station 9     6.60    1    300    0.94    0.71    1    0   71.50  (Min)
Assembly station 9     6.62    1    300    0.95    0.71    1    0   71.88  (Max)

Assembly station 10     6.60    1    300    0.81    0.61    1    0   61.72  (Rep 1)
Assembly station 10     6.61    1    300    0.82    0.62    1    0   62.02  (Rep 2)
Assembly station 10     6.60    1    300    0.81    0.61    1    0   61.84  (Rep 3)
Assembly station 10     6.61    1    300    0.80    0.60    1    0   60.76  (Rep 4)
Assembly station 10     6.62    1    300    0.81    0.61    1    0   61.26  (Rep 5)
Assembly station 10     6.62    1    300    0.82    0.62    1    0   62.23  (Rep 6)
Assembly station 10     6.60    1    300    0.81    0.61    1    0   61.86  (Rep 7)
Assembly station 10     6.62    1    300    0.82    0.62    1    0   62.19  (Rep 8)
Assembly station 10     6.61    1    300    0.81    0.61    1    0   61.85  (Rep 9)
Assembly station 10     6.61    1    300    0.81    0.61    1    0   61.64  (Rep 10)
Assembly station 10     6.61    1    300    0.81    0.61    1    0   61.74  (Average)
Assembly station 10     0.00    0      0   0.00    0.00    0     0   0.44  (Std. Dev.)
Assembly station 10     6.60    1    300    0.80    0.60    1    0   60.76  (Min)
Assembly station 10     6.62    1    300    0.82    0.62    1    0   62.23  (Max)

Assembly station 11     6.60    1    300    0.10    0.07    1    0    7.71  (Rep 1)
Assembly station 11     6.61    1    300    0.10    0.08    1    0    8.06  (Rep 2)
Assembly station 11     6.60    1    300    0.09    0.07    1    0    7.50  (Rep 3)
Assembly station 11     6.61    1    300    0.11    0.08    1    0    8.44  (Rep 4)
Assembly station 11     6.62    1    300    0.11    0.08    1    0    8.65  (Rep 5)
Assembly station 11     6.62    1    300    0.10    0.07    1    0    7.72  (Rep 6)
Assembly station 11     6.60    1    300    0.11    0.08    1    0    8.44  (Rep 7)
Assembly station 11     6.62    1    300    0.11    0.08    1    0    8.59  (Rep 8)
Assembly station 11     6.61    1    300    0.10    0.08    1    0    8.24  (Rep 9)
Assembly station 11     6.61    1    300    0.10    0.08    1    0    8.26  (Rep 10)
Assembly station 11     6.61    1    300    0.10    0.08    1    0    8.16  (Average)
Assembly station 11     0.00    0      0   0.00    0.00    0     0   0.40  (Std. Dev.)
Assembly station 11     6.60    1    300    0.09    0.07    1    0    7.50  (Min)
Assembly station 11     6.62    1    300    0.11    0.08    1    0    8.65  (Max)
```

Experiment 4 - Results: Line Balancing (Multifunction Employee): 'L', Setup Time: 'H' and Quality Control: 'H

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation
Programming\Assembly line 3 (LHH).MOD
Date: Sep/25/2007   Time: 12:49:38 PM
--------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 7.042866667 hr Elapsed: 7.042866667 hr)
Simulation Time : 7.042983333 hr (Std. Dev. 0.01
--------------------------------------------------------------------------------
```

```
LOCATIONS

                                      Average
Location             Scheduled            Total   Minutes   Average   Maximum   Current
Name                     Hours  Capacity  Entries  Per Entry  Contents  Contents  Contents  % Util
--------------------  ---------  --------  -------  ---------  --------  --------  --------  ------
Assembly station 1        7.04      200      300      0.82      0.58        1       0    0.29  (Rep 1)
Assembly station 1        7.03      200      300      0.82      0.58        1       0    0.29  (Rep 2)
Assembly station 1        7.02      200      300      0.82      0.58        1       0    0.29  (Rep 3)
Assembly station 1        7.04      200      300      0.82      0.58        1       0    0.29  (Rep 4)
Assembly station 1        7.06      200      300      0.82      0.58        1       0    0.29  (Rep 5)
Assembly station 1        7.05      200      300      0.82      0.58        1       0    0.29  (Rep 6)
Assembly station 1        7.03      200      300      0.82      0.58        1       0    0.29  (Rep 7)
Assembly station 1        7.05      200      300      0.82      0.58        1       0    0.29  (Rep 8)
Assembly station 1        7.03      200      300      0.82      0.58        1       0    0.29  (Rep 9)
Assembly station 1        7.04      200      300      0.82      0.58        1       0    0.29  (Rep 10)
Assembly station 1        7.04      200      300      0.82      0.58        1       0    0.29  (Average)
Assembly station 1        0.01        0        0      0.00      0.00        0       0    0.00  (Std. Dev.)
Assembly station 1        7.02      200      300      0.82      0.58        1       0    0.29  (Min)
Assembly station 1        7.06      200      300      0.82      0.58        1       0    0.29  (Max)

Assembly station 2        7.04        1      300      0.82      0.58        1       0   58.71  (Rep 1)
Assembly station 2        7.03        1      300      0.82      0.58        1       0   58.55  (Rep 2)
Assembly station 2        7.02        1      300      0.82      0.58        1       0   58.91  (Rep 3)
Assembly station 2        7.04        1      300      0.82      0.58        1       0   58.44  (Rep 4)
Assembly station 2        7.06        1      300      0.82      0.58        1       0   58.65  (Rep 5)
Assembly station 2        7.05        1      300      0.83      0.58        1       0   58.80  (Rep 6)
Assembly station 2        7.03        1      300      0.82      0.58        1       0   58.37  (Rep 7)
Assembly station 2        7.05        1      300      0.82      0.58        1       0   58.50  (Rep 8)
Assembly station 2        7.03        1      300      0.82      0.58        1       0   58.51  (Rep 9)
Assembly station 2        7.04        1      300      0.82      0.58        1       0   58.37  (Rep 10)
Assembly station 2        7.04        1      300      0.82      0.58        1       0   58.58  (Average)
Assembly station 2        0.01        0        0      0.00      0.00        0       0    0.18  (Std. Dev.)
Assembly station 2        7.02        1      300      0.82      0.58        1       0   58.37  (Min)
Assembly station 2        7.06        1      300      0.83      0.58        1       0   58.91  (Max)

Assembly station 3        7.04        1      300      1.00      0.71        1       0   71.43  (Rep 1)
Assembly station 3        7.03        1      300      1.00      0.71        1       0   71.69  (Rep 2)
Assembly station 3        7.02        1      300      1.00      0.71        1       0   71.31  (Rep 3)
Assembly station 3        7.04        1      300      1.00      0.71        1       0   71.48  (Rep 4)
Assembly station 3        7.06        1      300      1.01      0.71        1       0   71.85  (Rep 5)
Assembly station 3        7.05        1      300      1.01      0.71        1       0   71.77  (Rep 6)
Assembly station 3        7.03        1      300      1.00      0.71        1       0   71.51  (Rep 7)
Assembly station 3        7.05        1      300      1.00      0.71        1       0   71.37  (Rep 8)
Assembly station 3        7.03        1      300      0.99      0.71        1       0   71.02  (Rep 9)
Assembly station 3        7.04        1      300      1.01      0.71        1       0   71.92  (Rep 10)
Assembly station 3        7.04        1      300      1.00      0.71        1       0   71.53  (Average)
Assembly station 3        0.01        0        0      0.00      0.00        0       0    0.28  (Std. Dev.)
Assembly station 3        7.02        1      300      0.99      0.71        1       0   71.02  (Min)
Assembly station 3        7.06        1      300      1.01      0.71        1       0   71.92  (Max)

Assembly station 4        7.04        1      300      0.93      0.66        1       0   66.07  (Rep 1)
Assembly station 4        7.03        1      300      0.93      0.66        1       0   66.25  (Rep 2)
Assembly station 4        7.02        1      300      0.92      0.66        1       0   66.12  (Rep 3)
Assembly station 4        7.04        1      300      0.93      0.66        1       0   66.20  (Rep 4)
Assembly station 4        7.06        1      300      0.94      0.66        1       0   66.70  (Rep 5)
Assembly station 4        7.05        1      300      0.93      0.66        1       0   66.51  (Rep 6)
Assembly station 4        7.03        1      300      0.93      0.66        1       0   66.27  (Rep 7)
Assembly station 4        7.05        1      300      0.93      0.66        1       0   66.10  (Rep 8)
Assembly station 4        7.03        1      300      0.92      0.65        1       0   65.74  (Rep 9)
Assembly station 4        7.04        1      300      0.93      0.66        1       0   66.59  (Rep 10)
Assembly station 4        7.04        1      300      0.93      0.66        1       0   66.25  (Average)
Assembly station 4        0.01        0        0      0.00      0.00        0       0    0.28  (Std. Dev.)
Assembly station 4        7.02        1      300      0.92      0.65        1       0   65.74  (Min)
Assembly station 4        7.06        1      300      0.94      0.66        1       0   66.70  (Max)

Assembly station 5        7.04        1      300      1.04      0.73        1       0   73.99  (Rep 1)
```

Assembly station 5	7.03	1	300	1.04	0.73	1	0	73.97	(Rep 2)
Assembly station 5	7.02	1	300	1.02	0.73	1	0	73.19	(Rep 3)
Assembly station 5	7.04	1	300	1.04	0.74	1	0	74.03	(Rep 4)
Assembly station 5	7.06	1	300	1.06	0.75	1	0	75.61	(Rep 5)
Assembly station 5	7.05	1	300	1.05	0.75	1	0	75.00	(Rep 6)
Assembly station 5	7.03	1	300	1.04	0.73	1	0	73.94	(Rep 7)
Assembly station 5	7.05	1	300	1.04	0.74	1	0	74.23	(Rep 8)
Assembly station 5	7.03	1	300	1.03	0.73	1	0	73.37	(Rep 9)
Assembly station 5	7.04	1	300	1.05	0.74	1	0	74.97	(Rep 10)
Assembly station 5	7.04	1	300	1.04	0.74	1	0	74.23	(Average)
Assembly station 5	0.01	0	0	0.01	0.00	0	0	0.75	(Std. Dev.)
Assembly station 5	7.02	1	300	1.02	0.73	1	0	73.19	(Min)
Assembly station 5	7.06	1	300	1.06	0.75	1	0	75.61	(Max)
Assembly station 6	7.04	1	300	1.11	0.79	1	0	79.01	(Rep 1)
Assembly station 6	7.03	1	300	1.11	0.79	1	0	79.09	(Rep 2)
Assembly station 6	7.02	1	300	1.10	0.78	1	0	78.58	(Rep 3)
Assembly station 6	7.04	1	300	1.11	0.79	1	0	79.42	(Rep 4)
Assembly station 6	7.06	1	300	1.14	0.80	1	0	80.88	(Rep 5)
Assembly station 6	7.05	1	300	1.13	0.80	1	0	80.08	(Rep 6)
Assembly station 6	7.03	1	300	1.11	0.79	1	0	79.13	(Rep 7)
Assembly station 6	7.05	1	300	1.12	0.79	1	0	79.57	(Rep 8)
Assembly station 6	7.03	1	300	1.10	0.78	1	0	78.33	(Rep 9)
Assembly station 6	7.04	1	300	1.13	0.80	1	0	80.43	(Rep 10)
Assembly station 6	7.04	1	300	1.11	0.79	1	0	79.45	(Average)
Assembly station 6	0.01	0	0	0.01	0.00	0	0	0.81	(Std. Dev.)
Assembly station 6	7.02	1	300	1.10	0.78	1	0	78.33	(Min)
Assembly station 6	7.06	1	300	1.14	0.80	1	0	80.88	(Max)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.61	(Rep 1)
Assembly station 7	7.03	1	300	1.31	0.93	1	0	93.58	(Rep 2)
Assembly station 7	7.02	1	300	1.31	0.93	1	0	93.54	(Rep 3)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.54	(Rep 4)
Assembly station 7	7.06	1	300	1.32	0.93	1	0	93.60	(Rep 5)
Assembly station 7	7.05	1	300	1.32	0.93	1	0	93.57	(Rep 6)
Assembly station 7	7.03	1	300	1.31	0.93	1	0	93.56	(Rep 7)
Assembly station 7	7.05	1	300	1.31	0.93	1	0	93.55	(Rep 8)
Assembly station 7	7.03	1	300	1.31	0.93	1	0	93.58	(Rep 9)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.58	(Rep 10)
Assembly station 7	7.04	1	300	1.31	0.93	1	0	93.57	(Average)
Assembly station 7	0.01	0	0	0.00	0.00	0	0	0.02	(Std. Dev.)
Assembly station 7	7.02	1	300	1.31	0.93	1	0	93.54	(Min)
Assembly station 7	7.06	1	300	1.32	0.93	1	0	93.61	(Max)
Assembly station 8	7.04	1	300	0.76	0.54	1	0	54.36	(Rep 1)
Assembly station 8	7.03	1	300	0.76	0.54	1	0	54.43	(Rep 2)
Assembly station 8	7.02	1	300	0.76	0.54	1	0	54.46	(Rep 3)
Assembly station 8	7.04	1	300	0.76	0.54	1	0	54.56	(Rep 4)
Assembly station 8	7.06	1	300	0.76	0.54	1	0	54.40	(Rep 5)
Assembly station 8	7.05	1	300	0.76	0.54	1	0	54.35	(Rep 6)
Assembly station 8	7.03	1	300	0.76	0.54	1	0	54.43	(Rep 7)
Assembly station 8	7.05	1	300	0.76	0.54	1	0	54.47	(Rep 8)
Assembly station 8	7.03	1	300	0.76	0.54	1	0	54.68	(Rep 9)
Assembly station 8	7.04	1	300	0.76	0.54	1	0	54.28	(Rep 10)
Assembly station 8	7.04	1	300	0.76	0.54	1	0	54.44	(Average)
Assembly station 8	0.01	0	0	0.00	0.00	0	0	0.11	(Std. Dev.)
Assembly station 8	7.02	1	300	0.76	0.54	1	0	54.28	(Min)
Assembly station 8	7.06	1	300	0.76	0.54	1	0	54.68	(Max)
Assembly station 9	7.04	1	300	0.94	0.67	1	0	67.32	(Rep 1)
Assembly station 9	7.03	1	300	0.94	0.67	1	0	67.45	(Rep 2)
Assembly station 9	7.02	1	300	0.94	0.67	1	0	67.32	(Rep 3)
Assembly station 9	7.04	1	300	0.94	0.67	1	0	67.10	(Rep 4)
Assembly station 9	7.06	1	300	0.94	0.67	1	0	67.01	(Rep 5)
Assembly station 9	7.05	1	300	0.94	0.67	1	0	67.12	(Rep 6)
Assembly station 9	7.03	1	300	0.94	0.67	1	0	67.37	(Rep 7)
Assembly station 9	7.05	1	300	0.94	0.67	1	0	67.14	(Rep 8)

```
Assembly station 9      7.03    1   300    0.94    0.67     1      0  67.45  (Rep 9)
Assembly station 9      7.04    1   300    0.94    0.67     1      0  67.23  (Rep 10)
Assembly station 9      7.04    1   300    0.94    0.67     1      0  67.25  (Average)
Assembly station 9      0.01    0     0    0.00    0.00     0      0   0.15  (Std. Dev.)
Assembly station 9      7.02    1   300    0.94    0.67     1      0  67.01  (Min)
Assembly station 9      7.06    1   300    0.94    0.67     1      0  67.45  (Max)

Assembly station 10     7.04    1   300    0.81    0.57     1      0  57.65  (Rep 1)
Assembly station 10     7.03    1   300    0.81    0.57     1      0  57.76  (Rep 2)
Assembly station 10     7.02    1   300    0.81    0.58     1      0  58.12  (Rep 3)
Assembly station 10     7.04    1   300    0.81    0.58     1      0  58.01  (Rep 4)
Assembly station 10     7.06    1   300    0.81    0.57     1      0  57.61  (Rep 5)
Assembly station 10     7.05    1   300    0.81    0.57     1      0  57.57  (Rep 6)
Assembly station 10     7.03    1   300    0.81    0.58     1      0  58.06  (Rep 7)
Assembly station 10     7.05    1   300    0.81    0.57     1      0  57.86  (Rep 8)
Assembly station 10     7.03    1   300    0.81    0.57     1      0  57.99  (Rep 9)
Assembly station 10     7.04    1   300    0.81    0.57     1      0  57.87  (Rep 10)
Assembly station 10     7.04    1   300    0.81    0.57     1      0  57.85  (Average)
Assembly station 10     0.01    0     0    0.00    0.00     0      0   0.20  (Std. Dev.)
Assembly station 10     7.02    1   300    0.81    0.57     1      0  57.57  (Min)
Assembly station 10     7.06    1   300    0.81    0.58     1      0  58.12  (Max)

Assembly station 11     7.04    1   300    0.10    0.07     1      0   7.17  (Rep 1)
Assembly station 11     7.03    1   300    0.08    0.06     1      0   6.23  (Rep 2)
Assembly station 11     7.02    1   300    0.09    0.06     1      0   6.58  (Rep 3)
Assembly station 11     7.04    1   300    0.09    0.06     1      0   6.61  (Rep 4)
Assembly station 11     7.06    1   300    0.09    0.06     1      0   6.67  (Rep 5)
Assembly station 11     7.05    1   300    0.09    0.06     1      0   6.73  (Rep 6)
Assembly station 11     7.03    1   300    0.09    0.06     1      0   6.50  (Rep 7)
Assembly station 11     7.05    1   300    0.09    0.06     1      0   6.98  (Rep 8)
Assembly station 11     7.03    1   300    0.09    0.06     1      0   6.92  (Rep 9)
Assembly station 11     7.04    1   300    0.10    0.07     1      0   7.37  (Rep 10)
Assembly station 11     7.04    1   300    0.09    0.06     1      0   6.78  (Average)
Assembly station 11     0.01    0     0    0.00    0.00     0      0   0.34  (Std. Dev.)
Assembly station 11     7.02    1   300    0.08    0.06     1      0   6.23  (Min)
Assembly station 11     7.06    1   300    0.10    0.07     1      0   7.37  (Max)
```

Experiment 5- Results: Line Balancing (Multifunction Employee): ‘H’, Setup Time: ‘L’ and Quality Control: ‘L’

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation
Programming\Assembly line 3 (HLL).MOD
Date: Sep/25/2007   Time: 11:22:43 AM
--------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 4.99385 hr Elapsed: 4.99385 hr)
Simulation Time : 4.995183333 hr (Std. Dev. 0.00
--------------------------------------------------------------------------------


LOCATIONS

                                        Average
Location             Scheduled           Total   Minutes   Average  Maximum  Current
Name                    Hours  Capacity  Entries Per Entry Contents Contents Contents % Util
-------------------- --------- -------- ------- --------- -------- -------- -------- ------
Assembly station 1      4.99      200     300     0.74     0.74      1      0   0.37  (Rep 1)
Assembly station 1      4.99      200     300     0.74     0.74      1      0   0.37  (Rep 2)
Assembly station 1      4.99      200     300     0.74     0.74      1      0   0.37  (Rep 3)
Assembly station 1      4.99      200     300     0.74     0.74      1      0   0.37  (Rep 4)
```

Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Rep 5)
Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Rep 6)
Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Rep 7)
Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Rep 8)
Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Rep 9)
Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Rep 10)
Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Average)
Assembly station 1	0.00	0	0	0.00	0.00	0	0	0.00	(Std. Dev.)
Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Min)
Assembly station 1	4.99	200	300	0.74	0.74	1	0	0.37	(Max)
Assembly station 2	4.99	1	300	0.73	0.73	1	0	73.81	(Rep 1)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.27	(Rep 2)
Assembly station 2	4.99	1	300	0.73	0.73	1	0	73.79	(Rep 3)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.12	(Rep 4)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.65	(Rep 5)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.45	(Rep 6)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.48	(Rep 7)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.37	(Rep 8)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.71	(Rep 9)
Assembly station 2	4.99	1	300	0.73	0.74	1	0	74.05	(Rep 10)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.27	(Average)
Assembly station 2	0.00	0	0	0.00	0.00	0	0	0.32	(Std. Dev.)
Assembly station 2	4.99	1	300	0.73	0.73	1	0	73.79	(Min)
Assembly station 2	4.99	1	300	0.74	0.74	1	0	74.71	(Max)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.31	(Rep 1)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.15	(Rep 2)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.36	(Rep 3)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.47	(Rep 4)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.29	(Rep 5)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.40	(Rep 6)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.23	(Rep 7)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.36	(Rep 8)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.28	(Rep 9)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.29	(Rep 10)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.31	(Average)
Assembly station 3	0.00	0	0	0.00	0.00	0	0	0.09	(Std. Dev.)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.15	(Min)
Assembly station 3	4.99	1	300	0.73	0.73	1	0	73.47	(Max)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.14	(Rep 1)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.18	(Rep 2)
Assembly station 4	4.99	1	300	0.73	0.74	1	0	74.05	(Rep 3)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.17	(Rep 4)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.16	(Rep 5)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.13	(Rep 6)
Assembly station 4	4.99	1	300	0.73	0.74	1	0	74.11	(Rep 7)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.09	(Rep 8)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.09	(Rep 9)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.15	(Rep 10)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.13	(Average)
Assembly station 4	0.00	0	0	0.00	0.00	0	0	0.04	(Std. Dev.)
Assembly station 4	4.99	1	300	0.73	0.74	1	0	74.05	(Min)
Assembly station 4	4.99	1	300	0.74	0.74	1	0	74.18	(Max)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.63	(Rep 1)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.52	(Rep 2)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.68	(Rep 3)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.50	(Rep 4)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.45	(Rep 5)
Assembly station 5	4.99	1	300	0.72	0.72	1	0	72.07	(Rep 6)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.47	(Rep 7)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.56	(Rep 8)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.47	(Rep 9)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.64	(Rep 10)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.60	(Average)

Assembly station 5	0.00	0	0	0.00	0.00	0	0	0.18	(Std. Dev.)
Assembly station 5	4.99	1	300	0.71	0.71	1	0	71.45	(Min)
Assembly station 5	4.99	1	300	0.72	0.72	1	0	72.07	(Max)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.25	(Rep 1)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.34	(Rep 2)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.22	(Rep 3)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.27	(Rep 4)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.20	(Rep 5)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.27	(Rep 6)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.33	(Rep 7)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.18	(Rep 8)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.10	(Rep 9)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.22	(Rep 10)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.24	(Average)
Assembly station 6	0.00	0	0	0.00	0.00	0	0	0.07	(Std. Dev.)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.10	(Min)
Assembly station 6	4.99	1	300	0.74	0.74	1	0	74.34	(Max)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.09	(Rep 1)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.07	(Rep 2)
Assembly station A	4.99	1	300	0.51	0.51	1	0	51.96	(Rep 3)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.08	(Rep 4)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.11	(Rep 5)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.16	(Rep 6)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.16	(Rep 7)
Assembly station A	4.99	1	300	0.51	0.51	1	0	51.93	(Rep 8)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.12	(Rep 9)
Assembly station A	4.99	1	300	0.51	0.51	1	0	51.91	(Rep 10)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.06	(Average)
Assembly station A	0.00	0	0	0.00	0.00	0	0	0.09	(Std. Dev.)
Assembly station A	4.99	1	300	0.51	0.51	1	0	51.91	(Min)
Assembly station A	4.99	1	300	0.52	0.52	1	0	52.16	(Max)
Assembly station 7	4.99	1	300	0.63	0.63	1	0	63.10	(Rep 1)
Assembly station 7	4.99	1	300	0.63	0.63	1	0	63.12	(Rep 2)
Assembly station 7	4.99	1	300	0.62	0.62	1	0	62.82	(Rep 3)
Assembly station 7	4.99	1	300	0.62	0.62	1	0	63.00	(Rep 4)
Assembly station 7	4.99	1	300	0.62	0.62	1	0	62.96	(Rep 5)
Assembly station 7	4.99	1	300	0.63	0.63	1	0	63.18	(Rep 6)
Assembly station 7	4.99	1	300	0.62	0.62	1	0	62.98	(Rep 7)
Assembly station 7	4.99	1	300	0.63	0.63	1	0	63.06	(Rep 8)
Assembly station 7	4.99	1	300	0.62	0.62	1	0	62.91	(Rep 9)
Assembly station 7	4.99	1	300	0.63	0.63	1	0	63.13	(Rep 10)
Assembly station 7	4.99	1	300	0.62	0.63	1	0	63.03	(Average)
Assembly station 7	0.00	0	0	0.00	0.00	0	0	0.11	(Std. Dev.)
Assembly station 7	4.99	1	300	0.62	0.62	1	0	62.82	(Min)
Assembly station 7	4.99	1	300	0.63	0.63	1	0	63.18	(Max)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.68	(Rep 1)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.60	(Rep 2)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.71	(Rep 3)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.72	(Rep 4)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.60	(Rep 5)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.89	(Rep 6)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.77	(Rep 7)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.61	(Rep 8)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.62	(Rep 9)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.83	(Rep 10)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.70	(Average)
Assembly station 8	0.00	0	0	0.00	0.00	0	0	0.10	(Std. Dev.)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.60	(Min)
Assembly station 8	4.99	1	300	0.55	0.55	1	0	55.89	(Max)
Assembly station 9	4.99	1	300	0.59	0.59	1	0	59.85	(Rep 1)
Assembly station 9	4.99	1	300	0.59	0.59	1	0	59.57	(Rep 2)
Assembly station 9	4.99	1	300	0.59	0.59	1	0	59.89	(Rep 3)

```
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.59  (Rep 4)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.75  (Rep 5)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.65  (Rep 6)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.88  (Rep 7)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.53  (Rep 8)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.94  (Rep 9)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.75  (Rep 10)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.74  (Average)
Assembly station 9      0.00    0     0    0.00    0.00     0     0   0.15  (Std. Dev.)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.53  (Min)
Assembly station 9      4.99    1   300    0.59    0.59     1     0  59.94  (Max)

Assembly station B      4.99    1   300    0.77    0.77     1     0  77.77  (Rep 1)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.74  (Rep 2)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.69  (Rep 3)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.93  (Rep 4)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.86  (Rep 5)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.54  (Rep 6)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.66  (Rep 7)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.74  (Rep 8)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.68  (Rep 9)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.72  (Rep 10)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.73  (Average)
Assembly station B      0.00    0     0    0.00    0.00     0     0   0.11  (Std. Dev.)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.54  (Min)
Assembly station B      4.99    1   300    0.77    0.77     1     0  77.93  (Max)

Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.19  (Rep 1)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  82.00  (Rep 2)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.75  (Rep 3)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.24  (Rep 4)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.99  (Rep 5)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.88  (Rep 6)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.30  (Rep 7)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.28  (Rep 8)
Assembly station 10     4.99    1   300    0.82    0.82     1     0  82.06  (Rep 9)
Assembly station 10     4.99    1   300    0.82    0.82     1     0  82.24  (Rep 10)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.69  (Average)
Assembly station 10     0.00    0     0    0.00    0.00     0     0   0.40  (Std. Dev.)
Assembly station 10     4.99    1   300    0.81    0.81     1     0  81.19  (Min)
Assembly station 10     4.99    1   300    0.82    0.82     1     0  82.24  (Max)

Assembly station 11     4.99    1   300    0.18    0.18     1     0  18.20  (Rep 1)
Assembly station 11     4.99    1   300    0.17    0.17     1     0  17.69  (Rep 2)
Assembly station 11     4.99    1   300    0.18    0.18     1     0  18.05  (Rep 3)
Assembly station 11     4.99    1   300    0.17    0.17     1     0  17.63  (Rep 4)
Assembly station 11     4.99    1   300    0.17    0.17     1     0  17.97  (Rep 5)
Assembly station 11     4.99    1   300    0.17    0.17     1     0  17.04  (Rep 6)
Assembly station 11     4.99    1   300    0.17    0.18     1     0  18.03  (Rep 7)
Assembly station 11     4.99    1   300    0.17    0.17     1     0  17.55  (Rep 8)
Assembly station 11     4.99    1   300    0.18    0.18     1     0  18.20  (Rep 9)
Assembly station 11     4.99    1   300    0.17    0.17     1     0  17.72  (Rep 10)
Assembly station 11     4.99    1   300    0.17    0.17     1     0  17.81  (Average)
Assembly station 11     0.00    0     0    0.00    0.00     0     0   0.36  (Std. Dev.)
Assembly station 11     4.99    1   300    0.17    0.17     1     0  17.04  (Min)
Assembly station 11     4.99    1   300    0.18    0.18     1     0  18.20  (Max)
```

Experiment 6- Results: Line Balancing (Multifunction Employee): 'H', Setup Time: 'L' and Quality Control: 'H'

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation
Programming\Assembly line 3 (HLH).MOD
Date: Sep/25/2007   Time: 12:32:47 PM
```

```
--------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 5.5074 hr Elapsed: 5.5074 hr)
Simulation Time : 5.508266667 hr (Std. Dev. 0.00
--------------------------------------------------------------------------------


LOCATIONS

                                         Average
Location             Scheduled            Total   Minutes   Average  Maximum   Current
Name                     Hours  Capacity  Entries  Per Entry  Contents  Contents  Contents  % Util
---------------------  ---------  --------  -------  ---------  --------  --------  --------  ------
Assembly station 1        5.50     200     300     0.82     0.75      1      0    0.38  (Rep 1)
Assembly station 1        5.50     200     300     0.82     0.74      1      0    0.37  (Rep 2)
Assembly station 1        5.51     200     300     0.82     0.74      1      0    0.37  (Rep 3)
Assembly station 1        5.50     200     300     0.82     0.74      1      0    0.37  (Rep 4)
Assembly station 1        5.50     200     300     0.82     0.75      1      0    0.38  (Rep 5)
Assembly station 1        5.50     200     300     0.82     0.75      1      0    0.38  (Rep 6)
Assembly station 1        5.50     200     300     0.82     0.74      1      0    0.37  (Rep 7)
Assembly station 1        5.50     200     300     0.82     0.74      1      0    0.37  (Rep 8)
Assembly station 1        5.51     200     300     0.82     0.74      1      0    0.37  (Rep 9)
Assembly station 1        5.50     200     300     0.82     0.75      1      0    0.38  (Rep 10)
Assembly station 1        5.50     200     300     0.82     0.74      1      0    0.37  (Average)
Assembly station 1        0.00       0       0     0.00     0.00      0      0    0.00  (Std. Dev.)
Assembly station 1        5.50     200     300     0.82     0.74      1      0    0.37  (Min)
Assembly station 1        5.51     200     300     0.82     0.75      1      0    0.38  (Max)

Assembly station 2        5.50       1     300     0.82     0.74      1      0   74.82  (Rep 1)
Assembly station 2        5.50       1     300     0.82     0.74      1      0   74.52  (Rep 2)
Assembly station 2        5.51       1     300     0.82     0.74      1      0   74.88  (Rep 3)
Assembly station 2        5.50       1     300     0.82     0.75      1      0   75.08  (Rep 4)
Assembly station 2        5.50       1     300     0.82     0.74      1      0   74.62  (Rep 5)
Assembly station 2        5.50       1     300     0.82     0.74      1      0   74.90  (Rep 6)
Assembly station 2        5.50       1     300     0.82     0.75      1      0   75.18  (Rep 7)
Assembly station 2        5.50       1     300     0.82     0.74      1      0   74.72  (Rep 8)
Assembly station 2        5.51       1     300     0.82     0.75      1      0   75.04  (Rep 9)
Assembly station 2        5.50       1     300     0.82     0.74      1      0   74.85  (Rep 10)
Assembly station 2        5.50       1     300     0.82     0.74      1      0   74.86  (Average)
Assembly station 2        0.00       0       0     0.00     0.00      0      0    0.21  (Std. Dev.)
Assembly station 2        5.50       1     300     0.82     0.74      1      0   74.52  (Min)
Assembly station 2        5.51       1     300     0.82     0.75      1      0   75.18  (Max)

Assembly station 3        5.50       1     300     0.81     0.74      1      0   74.05  (Rep 1)
Assembly station 3        5.50       1     300     0.81     0.73      1      0   73.82  (Rep 2)
Assembly station 3        5.51       1     300     0.81     0.73      1      0   73.83  (Rep 3)
Assembly station 3        5.50       1     300     0.81     0.74      1      0   74.02  (Rep 4)
Assembly station 3        5.50       1     300     0.81     0.74      1      0   74.04  (Rep 5)
Assembly station 3        5.50       1     300     0.81     0.74      1      0   74.09  (Rep 6)
Assembly station 3        5.50       1     300     0.81     0.73      1      0   73.78  (Rep 7)
Assembly station 3        5.50       1     300     0.81     0.73      1      0   73.94  (Rep 8)
Assembly station 3        5.51       1     300     0.81     0.74      1      0   74.06  (Rep 9)
Assembly station 3        5.50       1     300     0.81     0.73      1      0   73.85  (Rep 10)
Assembly station 3        5.50       1     300     0.81     0.73      1      0   73.95  (Average)
Assembly station 3        0.00       0       0     0.00     0.00      0      0    0.12  (Std. Dev.)
Assembly station 3        5.50       1     300     0.81     0.73      1      0   73.78  (Min)
Assembly station 3        5.51       1     300     0.81     0.74      1      0   74.09  (Max)

Assembly station 4        5.50       1     300     0.82     0.74      1      0   74.73  (Rep 1)
Assembly station 4        5.50       1     300     0.82     0.74      1      0   74.73  (Rep 2)
Assembly station 4        5.51       1     300     0.82     0.74      1      0   74.65  (Rep 3)
Assembly station 4        5.50       1     300     0.82     0.74      1      0   74.57  (Rep 4)
Assembly station 4        5.50       1     300     0.82     0.74      1      0   74.90  (Rep 5)
Assembly station 4        5.50       1     300     0.82     0.74      1      0   74.80  (Rep 6)
Assembly station 4        5.50       1     300     0.82     0.74      1      0   74.69  (Rep 7)
Assembly station 4        5.50       1     300     0.82     0.74      1      0   74.72  (Rep 8)
```

Assembly station 4	5.51	1	300	0.82	0.74	1	0	74.73	(Rep 9)
Assembly station 4	5.50	1	300	0.82	0.74	1	0	74.83	(Rep 10)
Assembly station 4	5.50	1	300	0.82	0.74	1	0	74.74	(Average)
Assembly station 4	0.00	0	0	0.00	0.00	0	0	0.09	(Std. Dev.)
Assembly station 4	5.50	1	300	0.82	0.74	1	0	74.57	(Min)
Assembly station 4	5.51	1	300	0.82	0.74	1	0	74.90	(Max)
Assembly station 5	5.50	1	300	0.79	0.72	1	0	72.55	(Rep 1)
Assembly station 5	5.50	1	300	0.79	0.72	1	0	72.53	(Rep 2)
Assembly station 5	5.51	1	300	0.79	0.72	1	0	72.47	(Rep 3)
Assembly station 5	5.50	1	300	0.80	0.72	1	0	72.67	(Rep 4)
Assembly station 5	5.50	1	300	0.79	0.72	1	0	72.51	(Rep 5)
Assembly station 5	5.50	1	300	0.79	0.72	1	0	72.61	(Rep 6)
Assembly station 5	5.50	1	300	0.79	0.72	1	0	72.56	(Rep 7)
Assembly station 5	5.50	1	300	0.80	0.72	1	0	72.77	(Rep 8)
Assembly station 5	5.51	1	300	0.79	0.72	1	0	72.37	(Rep 9)
Assembly station 5	5.50	1	300	0.79	0.72	1	0	72.43	(Rep 10)
Assembly station 5	5.50	1	300	0.79	0.72	1	0	72.55	(Average)
Assembly station 5	0.00	0	0	0.00	0.00	0	0	0.12	(Std. Dev.)
Assembly station 5	5.50	1	300	0.79	0.72	1	0	72.37	(Min)
Assembly station 5	5.51	1	300	0.80	0.72	1	0	72.77	(Max)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.83	(Rep 1)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.83	(Rep 2)
Assembly station 6	5.51	1	300	0.82	0.74	1	0	74.93	(Rep 3)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.89	(Rep 4)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.88	(Rep 5)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.95	(Rep 6)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.79	(Rep 7)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.83	(Rep 8)
Assembly station 6	5.51	1	300	0.82	0.74	1	0	74.82	(Rep 9)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.83	(Rep 10)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.86	(Average)
Assembly station 6	0.00	0	0	0.00	0.00	0	0	0.05	(Std. Dev.)
Assembly station 6	5.50	1	300	0.82	0.74	1	0	74.79	(Min)
Assembly station 6	5.51	1	300	0.82	0.74	1	0	74.95	(Max)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.56	(Rep 1)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.84	(Rep 2)
Assembly station A	5.51	1	300	0.59	0.54	1	0	54.38	(Rep 3)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.76	(Rep 4)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.81	(Rep 5)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.66	(Rep 6)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.47	(Rep 7)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.89	(Rep 8)
Assembly station A	5.51	1	300	0.60	0.54	1	0	54.78	(Rep 9)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.73	(Rep 10)
Assembly station A	5.50	1	300	0.60	0.54	1	0	54.69	(Average)
Assembly station A	0.00	0	0	0.00	0.00	0	0	0.17	(Std. Dev.)
Assembly station A	5.50	1	300	0.59	0.54	1	0	54.38	(Min)
Assembly station A	5.51	1	300	0.60	0.54	1	0	54.89	(Max)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.75	(Rep 1)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.61	(Rep 2)
Assembly station 7	5.51	1	300	0.71	0.64	1	0	64.58	(Rep 3)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.69	(Rep 4)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.87	(Rep 5)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.99	(Rep 6)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.73	(Rep 7)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.86	(Rep 8)
Assembly station 7	5.51	1	300	0.71	0.64	1	0	64.68	(Rep 9)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.67	(Rep 10)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.74	(Average)
Assembly station 7	0.00	0	0	0.00	0.00	0	0	0.13	(Std. Dev.)
Assembly station 7	5.50	1	300	0.71	0.64	1	0	64.58	(Min)
Assembly station 7	5.51	1	300	0.71	0.64	1	0	64.99	(Max)

Assembly station 8	5.50	1	300	0.64	0.58	1	0	58.23	(Rep 1)
Assembly station 8	5.50	1	300	0.63	0.58	1	0	58.02	(Rep 2)
Assembly station 8	5.51	1	300	0.64	0.58	1	0	58.29	(Rep 3)
Assembly station 8	5.50	1	300	0.63	0.58	1	0	58.01	(Rep 4)
Assembly station 8	5.50	1	300	0.64	0.58	1	0	58.17	(Rep 5)
Assembly station 8	5.50	1	300	0.64	0.58	1	0	58.44	(Rep 6)
Assembly station 8	5.50	1	300	0.63	0.58	1	0	58.01	(Rep 7)
Assembly station 8	5.50	1	300	0.63	0.58	1	0	58.02	(Rep 8)
Assembly station 8	5.51	1	300	0.64	0.58	1	0	58.18	(Rep 9)
Assembly station 8	5.50	1	300	0.63	0.57	1	0	57.96	(Rep 10)
Assembly station 8	5.50	1	300	0.64	0.58	1	0	58.13	(Average)
Assembly station 8	0.00	0	0	0.00	0.00	0	0	0.16	(Std. Dev.)
Assembly station 8	5.50	1	300	0.63	0.57	1	0	57.96	(Min)
Assembly station 8	5.51	1	300	0.64	0.58	1	0	58.44	(Max)

Assembly station 9	5.50	1	300	0.68	0.61	1	0	61.83	(Rep 1)
Assembly station 9	5.50	1	300	0.68	0.62	1	0	62.10	(Rep 2)
Assembly station 9	5.51	1	300	0.67	0.61	1	0	61.50	(Rep 3)
Assembly station 9	5.50	1	300	0.67	0.61	1	0	61.55	(Rep 4)
Assembly station 9	5.50	1	300	0.68	0.61	1	0	61.78	(Rep 5)
Assembly station 9	5.50	1	300	0.68	0.61	1	0	61.79	(Rep 6)
Assembly station 9	5.50	1	300	0.67	0.61	1	0	61.66	(Rep 7)
Assembly station 9	5.50	1	300	0.67	0.61	1	0	61.64	(Rep 8)
Assembly station 9	5.51	1	300	0.68	0.61	1	0	61.74	(Rep 9)
Assembly station 9	5.50	1	300	0.68	0.61	1	0	61.75	(Rep 10)
Assembly station 9	5.50	1	300	0.68	0.61	1	0	61.73	(Average)
Assembly station 9	0.00	0	0	0.00	0.00	0	0	0.17	(Std. Dev.)
Assembly station 9	5.50	1	300	0.67	0.61	1	0	61.50	(Min)
Assembly station 9	5.51	1	300	0.68	0.62	1	0	62.10	(Max)

Assembly station B	5.50	1	300	0.77	0.70	1	0	70.36	(Rep 1)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.41	(Rep 2)
Assembly station B	5.51	1	300	0.77	0.70	1	0	70.38	(Rep 3)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.55	(Rep 4)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.45	(Rep 5)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.54	(Rep 6)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.41	(Rep 7)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.54	(Rep 8)
Assembly station B	5.51	1	300	0.77	0.70	1	0	70.41	(Rep 9)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.48	(Rep 10)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.45	(Average)
Assembly station B	0.00	0	0	0.00	0.00	0	0	0.07	(Std. Dev.)
Assembly station B	5.50	1	300	0.77	0.70	1	0	70.36	(Min)
Assembly station B	5.51	1	300	0.77	0.70	1	0	70.55	(Max)

Assembly station 10	5.50	1	300	0.81	0.73	1	0	73.63	(Rep 1)
Assembly station 10	5.50	1	300	0.81	0.73	1	0	73.72	(Rep 2)
Assembly station 10	5.51	1	300	0.81	0.73	1	0	73.94	(Rep 3)
Assembly station 10	5.50	1	300	0.82	0.74	1	0	74.47	(Rep 4)
Assembly station 10	5.50	1	300	0.81	0.74	1	0	74.07	(Rep 5)
Assembly station 10	5.50	1	300	0.82	0.74	1	0	74.67	(Rep 6)
Assembly station 10	5.50	1	300	0.81	0.74	1	0	74.29	(Rep 7)
Assembly station 10	5.50	1	300	0.81	0.73	1	0	73.83	(Rep 8)
Assembly station 10	5.51	1	300	0.81	0.74	1	0	74.24	(Rep 9)
Assembly station 10	5.50	1	300	0.81	0.74	1	0	74.12	(Rep 10)
Assembly station 10	5.50	1	300	0.81	0.74	1	0	74.10	(Average)
Assembly station 10	0.00	0	0	0.00	0.00	0	0	0.33	(Std. Dev.)
Assembly station 10	5.50	1	300	0.81	0.73	1	0	73.63	(Min)
Assembly station 10	5.51	1	300	0.82	0.74	1	0	74.67	(Max)

Assembly station 11	5.50	1	300	0.15	0.13	1	0	13.93	(Rep 1)
Assembly station 11	5.50	1	300	0.15	0.13	1	0	13.74	(Rep 2)
Assembly station 11	5.51	1	300	0.15	0.13	1	0	13.92	(Rep 3)
Assembly station 11	5.50	1	300	0.15	0.14	1	0	14.48	(Rep 4)
Assembly station 11	5.50	1	300	0.16	0.14	1	0	14.69	(Rep 5)
Assembly station 11	5.50	1	300	0.14	0.13	1	0	13.57	(Rep 6)
Assembly station 11	5.50	1	300	0.15	0.13	1	0	13.92	(Rep 7)

```
Assembly station 11      5.50     1    300     0.15     0.14      1       0   14.25  (Rep 8)
Assembly station 11      5.51     1    300     0.15     0.14      1       0   14.14  (Rep 9)
Assembly station 11      5.50     1    300     0.15     0.14      1       0   14.36  (Rep 10)
Assembly station 11      5.50     1    300     0.15     0.14      1       0   14.10  (Average)
Assembly station 11      0.00     0      0     0.00     0.00      0       0    0.35  (Std. Dev.)
Assembly station 11      5.50     1    300     0.14     0.13      1       0   13.57  (Min)
Assembly station 11      5.51     1    300     0.16     0.14      1       0   14.69  (Max)
```

Experiment 7 Results: Line Balancing (Multifunction Employee): 'H', Setup Time: 'H' and Quality Control: 'L'

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation
Programming\Assembly line 3 (HHL).MOD
Date: Sep/25/2007   Time: 11:59:56 AM
--------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 5.161966667 hr Elapsed: 5.161966667 hr)
Simulation Time : 5.162233333 hr (Std. Dev. 0.00
--------------------------------------------------------------------------------


LOCATIONS

                                         Average
Location             Scheduled            Total    Minutes   Average  Maximum   Current
Name                     Hours  Capacity  Entries  Per Entry Contents Contents  Contents  % Util
-------------------- --------- -------- ------- --------- -------- -------- -------- ------
Assembly station 1       5.16     200     300     0.74     0.72      1       0    0.36  (Rep 1)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Rep 2)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Rep 3)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Rep 4)
Assembly station 1       5.16     200     300     0.74     0.72      1       0    0.36  (Rep 5)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Rep 6)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Rep 7)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Rep 8)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Rep 9)
Assembly station 1       5.16     200     300     0.74     0.72      1       0    0.36  (Rep 10)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Average)
Assembly station 1       0.00       0       0     0.00     0.00      0       0    0.00  (Std. Dev.)
Assembly station 1       5.16     200     300     0.74     0.71      1       0    0.36  (Min)
Assembly station 1       5.16     200     300     0.74     0.72      1       0    0.36  (Max)

Assembly station 2       5.16       1     300     0.73     0.71      1       0   71.52  (Rep 1)
Assembly station 2       5.16       1     300     0.74     0.72      1       0   72.13  (Rep 2)
Assembly station 2       5.16       1     300     0.73     0.71      1       0   71.14  (Rep 3)
Assembly station 2       5.16       1     300     0.73     0.71      1       0   71.59  (Rep 4)
Assembly station 2       5.16       1     300     0.73     0.71      1       0   71.68  (Rep 5)
Assembly station 2       5.16       1     300     0.74     0.72      1       0   72.41  (Rep 6)
Assembly station 2       5.16       1     300     0.74     0.72      1       0   72.05  (Rep 7)
Assembly station 2       5.16       1     300     0.74     0.71      1       0   71.96  (Rep 8)
Assembly station 2       5.16       1     300     0.74     0.71      1       0   71.93  (Rep 9)
Assembly station 2       5.16       1     300     0.73     0.71      1       0   71.66  (Rep 10)
Assembly station 2       5.16       1     300     0.74     0.71      1       0   71.81  (Average)
Assembly station 2       0.00       0       0     0.00     0.00      0       0    0.36  (Std. Dev.)
Assembly station 2       5.16       1     300     0.73     0.71      1       0   71.14  (Min)
Assembly station 2       5.16       1     300     0.74     0.72      1       0   72.41  (Max)

Assembly station 3       5.16       1     300     0.73     0.70      1       0   70.99  (Rep 1)
Assembly station 3       5.16       1     300     0.73     0.70      1       0   70.88  (Rep 2)
Assembly station 3       5.16       1     300     0.73     0.70      1       0   70.95  (Rep 3)
Assembly station 3       5.16       1     300     0.73     0.71      1       0   71.05  (Rep 4)
Assembly station 3       5.16       1     300     0.73     0.70      1       0   70.88  (Rep 5)
```

Assembly station 3	5.16	1	300	0.73	0.70	1	0	70.90	(Rep 6)
Assembly station 3	5.16	1	300	0.73	0.70	1	0	70.87	(Rep 7)
Assembly station 3	5.16	1	300	0.73	0.71	1	0	71.11	(Rep 8)
Assembly station 3	5.16	1	300	0.73	0.70	1	0	70.93	(Rep 9)
Assembly station 3	5.16	1	300	0.73	0.70	1	0	70.85	(Rep 10)
Assembly station 3	5.16	1	300	0.73	0.70	1	0	70.94	(Average)
Assembly station 3	0.00	0	0	0.00	0.00	0	0	0.09	(Std. Dev.)
Assembly station 3	5.16	1	300	0.73	0.70	1	0	70.85	(Min)
Assembly station 3	5.16	1	300	0.73	0.71	1	0	71.11	(Max)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.71	(Rep 1)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.82	(Rep 2)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.77	(Rep 3)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.74	(Rep 4)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.80	(Rep 5)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.73	(Rep 6)
Assembly station 4	5.16	1	300	0.73	0.71	1	0	71.62	(Rep 7)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.66	(Rep 8)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.68	(Rep 9)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.70	(Rep 10)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.72	(Average)
Assembly station 4	0.00	0	0	0.00	0.00	0	0	0.06	(Std. Dev.)
Assembly station 4	5.16	1	300	0.73	0.71	1	0	71.62	(Min)
Assembly station 4	5.16	1	300	0.74	0.71	1	0	71.82	(Max)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.19	(Rep 1)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.24	(Rep 2)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.32	(Rep 3)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.35	(Rep 4)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.28	(Rep 5)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.64	(Rep 6)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.16	(Rep 7)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.28	(Rep 8)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.25	(Rep 9)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.27	(Rep 10)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.30	(Average)
Assembly station 5	0.00	0	0	0.00	0.00	0	0	0.13	(Std. Dev.)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.16	(Min)
Assembly station 5	5.16	1	300	0.71	0.69	1	0	69.64	(Max)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.86	(Rep 1)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.84	(Rep 2)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.71	(Rep 3)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.81	(Rep 4)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.84	(Rep 5)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.88	(Rep 6)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.86	(Rep 7)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.82	(Rep 8)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.69	(Rep 9)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.91	(Rep 10)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.82	(Average)
Assembly station 6	0.00	0	0	0.00	0.00	0	0	0.07	(Std. Dev.)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.69	(Min)
Assembly station 6	5.16	1	300	0.74	0.71	1	0	71.91	(Max)
Assembly station A	5.16	1	300	0.51	0.50	1	0	50.32	(Rep 1)
Assembly station A	5.16	1	300	0.51	0.50	1	0	50.31	(Rep 2)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.38	(Rep 3)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.52	(Rep 4)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.44	(Rep 5)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.45	(Rep 6)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.44	(Rep 7)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.36	(Rep 8)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.45	(Rep 9)
Assembly station A	5.16	1	300	0.51	0.50	1	0	50.36	(Rep 10)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.40	(Average)
Assembly station A	0.00	0	0	0.00	0.00	0	0	0.07	(Std. Dev.)

Assembly station A	5.16	1	300	0.51	0.50	1	0	50.31	(Min)
Assembly station A	5.16	1	300	0.52	0.50	1	0	50.52	(Max)
Assembly station 7	5.16	1	300	0.63	0.61	1	0	61.04	(Rep 1)
Assembly station 7	5.16	1	300	0.62	0.61	1	0	61.01	(Rep 2)
Assembly station 7	5.16	1	300	0.62	0.60	1	0	60.81	(Rep 3)
Assembly station 7	5.16	1	300	0.62	0.60	1	0	60.94	(Rep 4)
Assembly station 7	5.16	1	300	0.63	0.61	1	0	61.04	(Rep 5)
Assembly station 7	5.16	1	300	0.63	0.61	1	0	61.14	(Rep 6)
Assembly station 7	5.16	1	300	0.62	0.60	1	0	60.95	(Rep 7)
Assembly station 7	5.16	1	300	0.62	0.60	1	0	60.88	(Rep 8)
Assembly station 7	5.16	1	300	0.62	0.60	1	0	60.98	(Rep 9)
Assembly station 7	5.16	1	300	0.63	0.61	1	0	61.09	(Rep 10)
Assembly station 7	5.16	1	300	0.62	0.60	1	0	60.99	(Average)
Assembly station 7	0.00	0	0	0.00	0.00	0	0	0.10	(Std. Dev.)
Assembly station 7	5.16	1	300	0.62	0.60	1	0	60.81	(Min)
Assembly station 7	5.16	1	300	0.63	0.61	1	0	61.14	(Max)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.84	(Rep 1)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.90	(Rep 2)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.90	(Rep 3)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.88	(Rep 4)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.68	(Rep 5)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.95	(Rep 6)
Assembly station 8	5.16	1	300	0.55	0.54	1	0	54.22	(Rep 7)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	54.00	(Rep 8)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.82	(Rep 9)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.86	(Rep 10)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.90	(Average)
Assembly station 8	0.00	0	0	0.00	0.00	0	0	0.14	(Std. Dev.)
Assembly station 8	5.16	1	300	0.55	0.53	1	0	53.68	(Min)
Assembly station 8	5.16	1	300	0.55	0.54	1	0	54.22	(Max)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.95	(Rep 1)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.71	(Rep 2)
Assembly station 9	5.16	1	300	0.60	0.58	1	0	58.17	(Rep 3)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.78	(Rep 4)
Assembly station 9	5.16	1	300	0.59	0.58	1	0	58.00	(Rep 5)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.90	(Rep 6)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.90	(Rep 7)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.71	(Rep 8)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.99	(Rep 9)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.70	(Rep 10)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.88	(Average)
Assembly station 9	0.00	0	0	0.00	0.00	0	0	0.15	(Std. Dev.)
Assembly station 9	5.16	1	300	0.59	0.57	1	0	57.70	(Min)
Assembly station 9	5.16	1	300	0.60	0.58	1	0	58.17	(Max)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.21	(Rep 1)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.18	(Rep 2)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.18	(Rep 3)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.38	(Rep 4)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.36	(Rep 5)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.17	(Rep 6)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.06	(Rep 7)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.35	(Rep 8)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.16	(Rep 9)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.33	(Rep 10)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.24	(Average)
Assembly station B	0.00	0	0	0.00	0.00	0	0	0.11	(Std. Dev.)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.06	(Min)
Assembly station B	5.16	1	300	0.77	0.75	1	0	75.38	(Max)
Assembly station 10	5.16	1	300	0.81	0.79	1	0	79.21	(Rep 1)
Assembly station 10	5.16	1	300	0.81	0.78	1	0	78.92	(Rep 2)
Assembly station 10	5.16	1	300	0.80	0.78	1	0	78.30	(Rep 3)
Assembly station 10	5.16	1	300	0.80	0.78	1	0	78.46	(Rep 4)

```
Assembly station 10    5.16    1   300    0.82    0.79     1     0  79.46  (Rep 5)
Assembly station 10    5.16    1   300    0.81    0.79     1     0  79.35  (Rep 6)
Assembly station 10    5.16    1   300    0.81    0.78     1     0  78.60  (Rep 7)
Assembly station 10    5.16    1   300    0.81    0.78     1     0  78.89  (Rep 8)
Assembly station 10    5.16    1   300    0.81    0.78     1     0  78.93  (Rep 9)
Assembly station 10    5.16    1   300    0.81    0.79     1     0  79.14  (Rep 10)
Assembly station 10    5.16    1   300    0.81    0.78     1     0  78.93  (Average)
Assembly station 10    0.00    0     0    0.00    0.00     0     0   0.38  (Std. Dev.)
Assembly station 10    5.16    1   300    0.80    0.78     1     0  78.30  (Min)
Assembly station 10    5.16    1   300    0.82    0.79     1     0  79.46  (Max)

Assembly station 11    5.16    1   300    0.17    0.17     1     0  17.13  (Rep 1)
Assembly station 11    5.16    1   300    0.18    0.17     1     0  17.45  (Rep 2)
Assembly station 11    5.16    1   300    0.18    0.18     1     0  18.02  (Rep 3)
Assembly station 11    5.16    1   300    0.17    0.17     1     0  17.17  (Rep 4)
Assembly station 11    5.16    1   300    0.17    0.17     1     0  17.31  (Rep 5)
Assembly station 11    5.16    1   300    0.17    0.16     1     0  16.78  (Rep 6)
Assembly station 11    5.16    1   300    0.17    0.17     1     0  17.06  (Rep 7)
Assembly station 11    5.16    1   300    0.17    0.16     1     0  16.81  (Rep 8)
Assembly station 11    5.16    1   300    0.18    0.17     1     0  17.72  (Rep 9)
Assembly station 11    5.16    1   300    0.17    0.17     1     0  17.37  (Rep 10)
Assembly station 11    5.16    1   300    0.17    0.17     1     0  17.28  (Average)
Assembly station 11    0.00    0     0    0.00    0.00     0     0   0.39  (Std. Dev.)
Assembly station 11    5.16    1   300    0.17    0.16     1     0  16.78  (Min)
Assembly station 11    5.16    1   300    0.18    0.18     1     0  18.02  (Max)
```

Experiment 8- Results: Line Balancing (Multifunction Employee): 'H', Setup Time: 'H' and Quality Control: 'H'

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case Studies - Denso\DMUK Assembly Line 3\Simulation
Programming\Assembly line 3 (HHH).MOD
Date: Sep/25/2007   Time: 01:03:34 PM
--------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 5.57675 hr Elapsed: 5.57675 hr)
Simulation Time : 5.576066667 hr (Std. Dev. 0.00
--------------------------------------------------------------------------------


LOCATIONS

                                     Average
Location            Scheduled          Total   Minutes   Average  Maximum   Current
Name                    Hours Capacity Entries Per Entry Contents Contents  Contents  % Util
-------------------- --------- -------- ------- --------- -------- -------- -------- ------
Assembly station 1      5.57     200    300     0.82    0.74      1      0   0.37  (Rep 1)
Assembly station 1      5.57     200    300     0.82    0.74      1      0   0.37  (Rep 2)
Assembly station 1      5.57     200    300     0.82    0.74      1      0   0.37  (Rep 3)
Assembly station 1      5.58     200    300     0.82    0.74      1      0   0.37  (Rep 4)
Assembly station 1      5.57     200    300     0.82    0.74      1      0   0.37  (Rep 5)
Assembly station 1      5.57     200    300     0.82    0.74      1      0   0.37  (Rep 6)
Assembly station 1      5.57     200    300     0.82    0.73      1      0   0.37  (Rep 7)
Assembly station 1      5.57     200    300     0.82    0.74      1      0   0.37  (Rep 8)
Assembly station 1      5.57     200    300     0.82    0.73      1      0   0.37  (Rep 9)
Assembly station 1      5.57     200    300     0.82    0.74      1      0   0.37  (Rep 10)
Assembly station 1      5.57     200    300     0.82    0.74      1      0   0.37  (Average)
Assembly station 1      0.00       0      0     0.00    0.00      0      0   0.00  (Std. Dev.)
Assembly station 1      5.57     200    300     0.82    0.73      1      0   0.37  (Min)
Assembly station 1      5.58     200    300     0.82    0.74      1      0   0.37  (Max)

Assembly station 2      5.57       1    300     0.82    0.73      1      0  73.55  (Rep 1)
```

Assembly station 2	5.57	1	300	0.82	0.74	1	0	74.26	(Rep 2)
Assembly station 2	5.57	1	300	0.81	0.73	1	0	73.30	(Rep 3)
Assembly station 2	5.58	1	300	0.82	0.73	1	0	73.71	(Rep 4)
Assembly station 2	5.57	1	300	0.82	0.74	1	0	74.30	(Rep 5)
Assembly station 2	5.57	1	300	0.82	0.73	1	0	73.95	(Rep 6)
Assembly station 2	5.57	1	300	0.82	0.73	1	0	73.86	(Rep 7)
Assembly station 2	5.57	1	300	0.82	0.73	1	0	73.90	(Rep 8)
Assembly station 2	5.57	1	300	0.82	0.74	1	0	74.30	(Rep 9)
Assembly station 2	5.57	1	300	0.82	0.73	1	0	73.66	(Rep 10)
Assembly station 2	5.57	1	300	0.82	0.73	1	0	73.88	(Average)
Assembly station 2	0.00	0	0	0.00	0.00	0	0	0.34	(Std. Dev.)
Assembly station 2	5.57	1	300	0.81	0.73	1	0	73.30	(Min)
Assembly station 2	5.58	1	300	0.82	0.74	1	0	74.30	(Max)
Assembly station 3	5.57	1	300	0.81	0.73	1	0	73.23	(Rep 1)
Assembly station 3	5.57	1	300	0.81	0.73	1	0	73.05	(Rep 2)
Assembly station 3	5.57	1	300	0.81	0.72	1	0	72.99	(Rep 3)
Assembly station 3	5.58	1	300	0.81	0.72	1	0	72.94	(Rep 4)
Assembly station 3	5.57	1	300	0.81	0.73	1	0	73.19	(Rep 5)
Assembly station 3	5.57	1	300	0.81	0.73	1	0	73.11	(Rep 6)
Assembly station 3	5.57	1	300	0.81	0.73	1	0	73.08	(Rep 7)
Assembly station 3	5.57	1	300	0.81	0.72	1	0	72.97	(Rep 8)
Assembly station 3	5.57	1	300	0.81	0.73	1	0	73.15	(Rep 9)
Assembly station 3	5.57	1	300	0.81	0.73	1	0	73.01	(Rep 10)
Assembly station 3	5.57	1	300	0.81	0.73	1	0	73.07	(Average)
Assembly station 3	0.00	0	0	0.00	0.00	0	0	0.10	(Std. Dev.)
Assembly station 3	5.57	1	300	0.81	0.72	1	0	72.94	(Min)
Assembly station 3	5.58	1	300	0.81	0.73	1	0	73.23	(Max)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.81	(Rep 1)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.89	(Rep 2)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.78	(Rep 3)
Assembly station 4	5.58	1	300	0.82	0.73	1	0	73.69	(Rep 4)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.92	(Rep 5)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.83	(Rep 6)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.84	(Rep 7)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.86	(Rep 8)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.82	(Rep 9)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.84	(Rep 10)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.83	(Average)
Assembly station 4	0.00	0	0	0.00	0.00	0	0	0.06	(Std. Dev.)
Assembly station 4	5.57	1	300	0.82	0.73	1	0	73.69	(Min)
Assembly station 4	5.58	1	300	0.82	0.73	1	0	73.92	(Max)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.61	(Rep 1)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.63	(Rep 2)
Assembly station 5	5.57	1	300	0.80	0.71	1	0	71.77	(Rep 3)
Assembly station 5	5.58	1	300	0.79	0.71	1	0	71.65	(Rep 4)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.67	(Rep 5)
Assembly station 5	5.57	1	300	0.80	0.71	1	0	71.98	(Rep 6)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.55	(Rep 7)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.46	(Rep 8)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.66	(Rep 9)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.62	(Rep 10)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.66	(Average)
Assembly station 5	0.00	0	0	0.00	0.00	0	0	0.14	(Std. Dev.)
Assembly station 5	5.57	1	300	0.79	0.71	1	0	71.46	(Min)
Assembly station 5	5.58	1	300	0.80	0.71	1	0	71.98	(Max)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.99	(Rep 1)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.88	(Rep 2)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.94	(Rep 3)
Assembly station 6	5.58	1	300	0.82	0.73	1	0	73.85	(Rep 4)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.98	(Rep 5)
Assembly station 6	5.57	1	300	0.82	0.74	1	0	74.05	(Rep 6)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.97	(Rep 7)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.96	(Rep 8)

Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.95	(Rep 9)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.87	(Rep 10)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.94	(Average)
Assembly station 6	0.00	0	0	0.00	0.00	0	0	0.06	(Std. Dev.)
Assembly station 6	5.57	1	300	0.82	0.73	1	0	73.85	(Min)
Assembly station 6	5.58	1	300	0.82	0.74	1	0	74.05	(Max)

Assembly station A	5.57	1	300	0.60	0.53	1	0	53.95	(Rep 1)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.14	(Rep 2)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.02	(Rep 3)
Assembly station A	5.58	1	300	0.60	0.54	1	0	54.01	(Rep 4)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.06	(Rep 5)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.16	(Rep 6)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.00	(Rep 7)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.09	(Rep 8)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.05	(Rep 9)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.17	(Rep 10)
Assembly station A	5.57	1	300	0.60	0.54	1	0	54.06	(Average)
Assembly station A	0.00	0	0	0.00	0.00	0	0	0.07	(Std. Dev.)
Assembly station A	5.57	1	300	0.60	0.53	1	0	53.95	(Min)
Assembly station A	5.58	1	300	0.60	0.54	1	0	54.17	(Max)

Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.87	(Rep 1)
Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.76	(Rep 2)
Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.85	(Rep 3)
Assembly station 7	5.58	1	300	0.71	0.63	1	0	63.85	(Rep 4)
Assembly station 7	5.57	1	300	0.71	0.64	1	0	64.03	(Rep 5)
Assembly station 7	5.57	1	300	0.71	0.64	1	0	64.01	(Rep 6)
Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.95	(Rep 7)
Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.89	(Rep 8)
Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.85	(Rep 9)
Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.82	(Rep 10)
Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.89	(Average)
Assembly station 7	0.00	0	0	0.00	0.00	0	0	0.08	(Std. Dev.)
Assembly station 7	5.57	1	300	0.71	0.63	1	0	63.76	(Min)
Assembly station 7	5.58	1	300	0.71	0.64	1	0	64.03	(Max)

Assembly station 8	5.57	1	300	0.64	0.57	1	0	57.42	(Rep 1)
Assembly station 8	5.57	1	300	0.63	0.57	1	0	57.36	(Rep 2)
Assembly station 8	5.57	1	300	0.64	0.57	1	0	57.55	(Rep 3)
Assembly station 8	5.58	1	300	0.64	0.57	1	0	57.37	(Rep 4)
Assembly station 8	5.57	1	300	0.64	0.57	1	0	57.54	(Rep 5)
Assembly station 8	5.57	1	300	0.64	0.57	1	0	57.42	(Rep 6)
Assembly station 8	5.57	1	300	0.63	0.56	1	0	56.96	(Rep 7)
Assembly station 8	5.57	1	300	0.63	0.57	1	0	57.31	(Rep 8)
Assembly station 8	5.57	1	300	0.64	0.57	1	0	57.42	(Rep 9)
Assembly station 8	5.57	1	300	0.64	0.57	1	0	57.39	(Rep 10)
Assembly station 8	5.57	1	300	0.63	0.57	1	0	57.37	(Average)
Assembly station 8	0.00	0	0	0.00	0.00	0	0	0.16	(Std. Dev.)
Assembly station 8	5.57	1	300	0.63	0.56	1	0	56.96	(Min)
Assembly station 8	5.58	1	300	0.64	0.57	1	0	57.55	(Max)

Assembly station 9	5.57	1	300	0.68	0.61	1	0	61.18	(Rep 1)
Assembly station 9	5.57	1	300	0.68	0.61	1	0	61.01	(Rep 2)
Assembly station 9	5.57	1	300	0.67	0.60	1	0	60.93	(Rep 3)
Assembly station 9	5.58	1	300	0.67	0.60	1	0	60.85	(Rep 4)
Assembly station 9	5.57	1	300	0.68	0.61	1	0	61.15	(Rep 5)
Assembly station 9	5.57	1	300	0.68	0.61	1	0	61.39	(Rep 6)
Assembly station 9	5.57	1	300	0.67	0.60	1	0	60.92	(Rep 7)
Assembly station 9	5.57	1	300	0.68	0.61	1	0	61.05	(Rep 8)
Assembly station 9	5.57	1	300	0.68	0.61	1	0	61.03	(Rep 9)
Assembly station 9	5.57	1	300	0.68	0.61	1	0	61.05	(Rep 10)
Assembly station 9	5.57	1	300	0.68	0.61	1	0	61.06	(Average)
Assembly station 9	0.00	0	0	0.00	0.00	0	0	0.15	(Std. Dev.)
Assembly station 9	5.57	1	300	0.67	0.60	1	0	60.85	(Min)
Assembly station 9	5.58	1	300	0.68	0.61	1	0	61.39	(Max)

Assembly station B	5.57	1	300	0.77	0.69	1	0	69.51	(Rep 1)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.60	(Rep 2)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.44	(Rep 3)
Assembly station B	5.58	1	300	0.77	0.69	1	0	69.59	(Rep 4)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.68	(Rep 5)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.64	(Rep 6)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.70	(Rep 7)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.61	(Rep 8)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.64	(Rep 9)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.65	(Rep 10)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.61	(Average)
Assembly station B	0.00	0	0	0.00	0.00	0	0	0.08	(Std. Dev.)
Assembly station B	5.57	1	300	0.77	0.69	1	0	69.44	(Min)
Assembly station B	5.58	1	300	0.77	0.69	1	0	69.70	(Max)

Assembly station 10	5.57	1	300	0.81	0.72	1	0	72.94	(Rep 1)
Assembly station 10	5.57	1	300	0.81	0.73	1	0	73.09	(Rep 2)
Assembly station 10	5.57	1	300	0.81	0.72	1	0	72.67	(Rep 3)
Assembly station 10	5.58	1	300	0.81	0.72	1	0	72.90	(Rep 4)
Assembly station 10	5.57	1	300	0.81	0.73	1	0	73.32	(Rep 5)
Assembly station 10	5.57	1	300	0.80	0.72	1	0	72.57	(Rep 6)
Assembly station 10	5.57	1	300	0.81	0.72	1	0	72.99	(Rep 7)
Assembly station 10	5.57	1	300	0.82	0.73	1	0	73.78	(Rep 8)
Assembly station 10	5.57	1	300	0.81	0.73	1	0	73.21	(Rep 9)
Assembly station 10	5.57	1	300	0.80	0.72	1	0	72.57	(Rep 10)
Assembly station 10	5.57	1	300	0.81	0.73	1	0	73.00	(Average)
Assembly station 10	0.00	0	0	0.00	0.00	0	0	0.37	(Std. Dev.)
Assembly station 10	5.57	1	300	0.80	0.72	1	0	72.57	(Min)
Assembly station 10	5.58	1	300	0.82	0.73	1	0	73.78	(Max)

Assembly station 11	5.57	1	300	0.15	0.13	1	0	13.89	(Rep 1)
Assembly station 11	5.57	1	300	0.16	0.14	1	0	14.46	(Rep 2)
Assembly station 11	5.57	1	300	0.16	0.14	1	0	14.42	(Rep 3)
Assembly station 11	5.58	1	300	0.16	0.14	1	0	14.57	(Rep 4)
Assembly station 11	5.57	1	300	0.16	0.14	1	0	14.80	(Rep 5)
Assembly station 11	5.57	1	300	0.16	0.14	1	0	14.55	(Rep 6)
Assembly station 11	5.57	1	300	0.15	0.14	1	0	14.30	(Rep 7)
Assembly station 11	5.57	1	300	0.16	0.14	1	0	14.43	(Rep 8)
Assembly station 11	5.57	1	300	0.15	0.13	1	0	13.80	(Rep 9)
Assembly station 11	5.57	1	300	0.16	0.14	1	0	14.62	(Rep 10)
Assembly station 11	5.57	1	300	0.16	0.14	1	0	14.38	(Average)
Assembly station 11	0.00	0	0	0.00	0.00	0	0	0.32	(Std. Dev.)
Assembly station 11	5.57	1	300	0.15	0.13	1	0	13.80	(Min)
Assembly station 11	5.58	1	300	0.16	0.14	1	0	14.80	(Max)

APPENDIX – 4

TYPICAL SIMULATION PROGRAMMING AND RESULTS OF RISANE LTD. CASE STUDY

SIMULATION PROGRAMMING

Experiment 1 : Setup time elimination plans: 'H, Group technology – 1: 'H', Innovation and investment plans: 'H' and Group technology – 2: 'H'

```
********************************************************************************
*                                                                              *
*                         Formatted Listing of Model:                          *
*     E:\PhD-Uni Computer\Case studies - Risane\Simulation-test-4\HHHH.MOD     *
*                                                                              *
********************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Meters


********************************************************************************
*                                  Locations                                   *
********************************************************************************

  Name                  Cap Units Stats       Rules      Cost
  --------------------- --- ----- ----------- ---------- ------------
  Raw_material_storage  38  1     Time Series Oldest, ,
  Laminator             1   1     Time Series Oldest, ,
  Laminated_reel_pallet 38  1     Time Series Oldest, ,
  Sheeting_machine      1   1     Time Series Oldest, ,
  Sheets_pallet         38  1     Time Series Oldest, ,
  Loading_bay           1   1     Time Series Oldest, ,
  Printing_press        1   1     Time Series Oldest, ,
  Unloading_bay         1   1     Time Series Oldest, ,
  Sammy_machine         1   1     Time Series Oldest, ,
  Pressed_sheet_pallet  38  1     Time Series Oldest, ,
  Packing_tabel         1   1     Time Series Oldest, ,
  Finished_pallet       38  1     Time Series Oldest, ,


********************************************************************************
*                                   Entities                                   *
********************************************************************************

  Name             Speed (mpm)  Stats       Cost
  ---------------- ------------ ----------- ------------
  Sheets           50           Time Series
  WIP              50           Time Series
  Finished_inserts 50           Time Series


********************************************************************************
*                                Path Networks                                 *
********************************************************************************

  Name     Type        T/S              From     To       BI   Dist/Time
Speed Factor
  -------- ----------- ---------------- -------- -------- ---- ---------------- --
----------
  Net1     Passing     Speed & Distance N1       N2       Bi   2.0              1
                                        N1       N3       Bi   2.0              1
                                        N1       N4       Bi   5.0              1
  Net2     Passing     Speed & Distance N1       N2       Bi   15               1
                                        N1       N3       Bi   1.0              1
                                        N1       N4       Bi   2.0              1
                                        N4       N5       Bi   10.0             1
  Net3     Passing     Time             N1       N2       Bi   N(153, 12.5) min
                                        N2       N3       Bi   N(153, 12.5) min
                                        N3       N1       Bi   2 min
  Net4     Passing     Speed & Distance N1       N2       Bi   2.0             1
                                        N1       N3       Bi   2.0             1
                                        N1       N4       Bi   50.0            1
  Net5     Passing     Speed & Distance N1       N2       Bi   2.0             1
                                        N1       N3       Bi   1.0             1
                                        N1       N4       Bi   2.0             1


********************************************************************************
*                                  Interfaces                                  *
********************************************************************************

  Net        Node       Location
  ---------- ---------- --------------------
  Net1       N2         Raw_material_storage
             N3         Laminator
             N4         Laminated_reel_pallet
  Net2       N2         Laminated_reel_pallet
             N3         Sheeting_machine
             N4         Sheets_pallet
             N5         Loading_bay
  Net3       N1         Loading_bay
             N2         Printing_press
             N3         Unloading_bay
  Net4       N2         Unloading_bay
             N3         Sammy_machine
             N4         Pressed_sheet_pallet
  Net5       N2         Pressed_sheet_pallet
             N3         Packing_tabel
             N4         Finished_pallet


********************************************************************************
*                                  Resources                                   *
********************************************************************************

                               Res     Ent
  Name       Units Stats    Search  Search Path       Motion        Cost
  ---------- ----- -------- ------- ------ ---------- ------------- ------------
  Operator_1 1     By Unit  Closest Oldest Net1       Empty: 50 mpm
                                           Home: N1   Full: 50 mpm
                                           (Return)

  Operator_2 1     By Unit  Closest Oldest Net2       Empty: 50 mpm
                                           Home: N1   Full: 50 mpm
                                           (Return)

  Operator_3 1     By Unit  Closest Oldest Net4       Empty: 50 mpm
                                           Home: N1   Full: 50 mpm
                                           (Return)

  Operator_4 1     By Unit  Closest Oldest Net5       Empty: 50 mpm
                                           Home: N1   Full: 50 mpm
                                           (Return)

  Truck      1     By Unit  Closest Oldest Net3
                                           Home: N1


********************************************************************************
*                                  Processing                                  *
********************************************************************************

                                                  Process
Routing

 Entity           Location              Operation            Blk  Output
Destination           Rule      Move Logic
 ---------------- -------------------- ------------------    ---- ----------------
-------------------- -------  ------------
```

```
 Sheets          Raw_material_storage                       1    Sheets
Laminator            FIRST 1  MOVE WITH Operator_1 THEN FREE

 Sheets          Laminator             WAIT N(256, 9.43) MIN


 Sheets          Laminator                                  1    Sheets
Laminated_reel_pallet FIRST 1  MOVE WITH Operator_1 THEN FREE

 Sheets          Laminated_reel_pallet                      1    Sheets
Sheeting_machine     FIRST 1  MOVE WITH Operator_2 THEN FREE

 Sheets          Sheeting_machine      WAIT N(117, 3.43) MIN


 Sheets          Sheeting_machine                           1    Sheets
Sheets_pallet        FIRST 1  MOVE WITH Operator_2 THEN FREE

 Sheets          Sheets_pallet         ACCUM 38
                                       GROUP 38 AS WIP

 WIP             Sheets_pallet                              1    WIP
Loading_bay          FIRST 1  MOVE WITH Operator_2 THEN FREE

 WIP             Loading_bay           WAIT N(61.2, 7.39) MIN
 WIP             Loading_bay                                1    WIP
Printing_press       FIRST 1  MOVE WITH Truck THEN FREE

 WIP             Printing_press        WAIT 935 MIN
 WIP             Printing_press                             1    WIP
Unloading_bay        FIRST 1  MOVE WITH Truck THEN FREE


 WIP             Unloading_bay         WAIT N(61.2, 7.39) MIN
 WIP             Unloading_bay         UNGROUP

 Sheets          Unloading_bay                              1    Sheets
Sammy_machine        FIRST 1  MOVE WITH Operator_3 THEN FREE

 Sheets          Sammy_machine         WAIT N(42.2, 1.54) MIN
 Sheets          Sammy_machine                              1    Sheets
Pressed_sheet_pallet  FIRST 1  MOVE WITH Operator_3 THEN FREE

 Sheets          Pressed_sheet_pallet                       1    Sheets
Packing_tabel        FIRST 1  MOVE WITH Operator_4 THEN FREE

 Sheets          Packing_tabel         WAIT N(169, 4.8) MIN
 Sheets          Packing_tabel                              1    Sheets
Finished_pallet      FIRST 1  MOVE WITH Operator_4 THEN FREE

 Sheets          Finished_pallet       ACCUM 38
                                       GROUP 38 AS Finished_inserts


 Finished_inserts Finished_pallet                           1    Finished_inserts
EXIT                 FIRST 1


********************************************************************************
*                                    Arrivals                                  *
********************************************************************************

  Entity   Location             Qty each   First Time Occurrences Frequency  Logic
  -------- -------------------- ---------- ---------- ----------- ---------- -----
-------
  Sheets   Raw_material_storage 2                     38          258
```

SIMULATION EXPERIMENT RESULTS

Experiment 1 – Results : Setup time elimination plans: 'H, Group technology – 1: 'H', Innovation and investment plans: 'H' and Group technology – 2: 'H'

```
--------------------------------------------------------------------------------
General Report
Output from E:\PhD-Uni Computer\Case studies - Risane\Simulation-test-4\HHHH.MOD
Date: Oct/08/2007   Time: 10:33:23 AM
--------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : All
Period          : Final Report (0 sec to 462.1626833 hr Elapsed: 462.1626833 hr)
Simulation Time : 462.0844667 hr (Std. Dev. 1.29
--------------------------------------------------------------------------------


LOCATIONS

                                                       Average
Location               Scheduled              Total    Minutes   Average   Maximum   Current
Name                       Hours  Capacity  Entries  Per Entry  Contents  Contents  Contents
% Util
---------------------  ---------  --------  -------  ---------  --------  --------  --------
------
Raw material storage      462.16        38       76    4801.82     13.16        38         0
34.63  (Rep 1)
Raw material storage      460.13        38       76    4828.14     13.29        38         0
34.98  (Rep 2)
Raw material storage      463.78        38       76    4839.32     13.21        38         0
34.78  (Rep 3)
Raw material storage      460.61        38       76    4785.52     13.15        38         0
34.63  (Rep 4)
Raw material storage      462.86        38       76    4818.06     13.18        38         0
34.70  (Rep 5)
Raw material storage      462.41        38       76    4787.47     13.11        38         0
34.51  (Rep 6)
Raw material storage      460.73        38       76    4788.56     13.16        38         0
34.64  (Rep 7)
Raw material storage      461.61        38       76    4762.24     13.06        38         0
34.39  (Rep 8)
Raw material storage      462.67        38       76    4836.50     13.24        38         0
34.84  (Rep 9)
Raw material storage      463.82        38       76    4886.48     13.34        38         0
35.12  (Rep 10)
Raw material storage      462.08        38       76    4813.41     13.19        38         0
34.72  (Average)
Raw material storage        1.29         0        0      35.90      0.08         0         0
0.22  (Std. Dev.)

Laminator                 462.16         1       76     255.41      0.70         1         0
70.00  (Rep 1)
Laminator                 460.13         1       76     254.56      0.70         1         0
70.08  (Rep 2)
Laminator                 463.78         1       76     256.16      0.69         1         0
69.96  (Rep 3)
Laminator                 460.61         1       76     254.89      0.70         1         0
70.09  (Rep 4)
Laminator                 462.86         1       76     255.63      0.69         1         0
69.95  (Rep 5)
Laminator                 462.41         1       76     255.98      0.70         1         0
70.12  (Rep 6)
Laminator                 460.73         1       76     254.47      0.69         1         0
69.96  (Rep 7)
Laminator                 461.61         1       76     255.45      0.70         1         0
70.10  (Rep 8)
Laminator                 462.67         1       76     255.85      0.70         1         0
70.05  (Rep 9)
Laminator                 463.82         1       76     257.01      0.70         1         0
70.19  (Rep 10)
Laminator                 462.08         1       76     255.54      0.70         1         0
70.05  (Average)
Laminator                   1.29         0        0       0.77      0.00         0         0
0.08  (Std. Dev.)
```

```
Laminated reel pallet     462.16        38        76        0.30       0.00          1          0
0.00  (Rep 1)
Laminated reel pallet     460.13        38        76        0.30       0.00          1          0
0.00  (Rep 2)
Laminated reel pallet     463.78        38        76        0.30       0.00          1          0
0.00  (Rep 3)
Laminated reel pallet     460.61        38        76        0.30       0.00          1          0
0.00  (Rep 4)
Laminated reel pallet     462.86        38        76        0.30       0.00          1          0
0.00  (Rep 5)
Laminated reel pallet     462.41        38        76        0.30       0.00          1          0
0.00  (Rep 6)
Laminated reel pallet     460.73        38        76        0.30       0.00          1          0
0.00  (Rep 7)
Laminated reel pallet     461.61        38        76        0.30       0.00          1          0
0.00  (Rep 8)
Laminated reel pallet     462.67        38        76        0.30       0.00          1          0
0.00  (Rep 9)
Laminated reel pallet     463.82        38        76        0.30       0.00          1          0
0.00  (Rep 10)
Laminated reel pallet     462.08        38        76        0.30       0.00          1          0
0.00  (Average)
Laminated reel pallet       1.29         0         0        0.00       2.29          0          0
0.00  (Std. Dev.)

Sheeting machine          462.16         1        76      116.84       0.32          1          0
32.02  (Rep 1)
Sheeting machine          460.13         1        76      117.35       0.32          1          0
32.30  (Rep 2)
Sheeting machine          463.78         1        76      117.42       0.32          1          0
32.07  (Rep 3)
Sheeting machine          460.61         1        76      117.26       0.32          1          0
32.25  (Rep 4)
Sheeting machine          462.86         1        76      117.43       0.32          1          0
32.14  (Rep 5)
Sheeting machine          462.41         1        76      117.06       0.32          1          0
32.07  (Rep 6)
Sheeting machine          460.73         1        76      117.14       0.32          1          0
32.21  (Rep 7)
Sheeting machine          461.61         1        76      117.22       0.32          1          0
32.17  (Rep 8)
Sheeting machine          462.67         1        76      116.80       0.31          1          0
31.98  (Rep 9)
Sheeting machine          463.82         1        76      116.86       0.31          1          0
31.91  (Rep 10)
Sheeting machine          462.08         1        76      117.14       0.32          1          0
32.11  (Average)
Sheeting machine            1.29         0         0        0.24       0.00          0          0
0.12  (Std. Dev.)

Sheets pallet             462.16        38        76     4731.17      12.96         38          0
34.12  (Rep 1)
Sheets pallet             460.13        38        76     4703.54      12.94         38          0
34.07  (Rep 2)
Sheets pallet             463.78        38        76     4764.95      13.01         38          0
34.25  (Rep 3)
Sheets pallet             460.61        38        76     4732.51      13.01         38          0
34.25  (Rep 4)
Sheets pallet             462.86        38        76     4741.35      12.97         38          0
34.14  (Rep 5)
Sheets pallet             462.41        38        76     4752.96      13.01         38          0
34.26  (Rep 6)
Sheets pallet             460.73        38        76     4720.28      12.97         38          0
34.15  (Rep 7)
Sheets pallet             461.61        38        76     4739.58      13.00         38          0
34.22  (Rep 8)
Sheets pallet             462.67        38        76     4729.15      12.94         38          0
34.07  (Rep 9)
Sheets pallet             463.82        38        76     4755.04      12.98         38          0
34.17  (Rep 10)
Sheets pallet             462.08        38        76     4737.05      12.98         38          0
34.17  (Average)
Sheets pallet               1.29         0         0       17.95       0.02          0          0
0.07  (Std. Dev.)

Loading bay               462.16         1         2       62.28       0.00          1          0
0.45  (Rep 1)
Loading bay               460.13         1         2       59.06       0.00          1          0
0.43  (Rep 2)
Loading bay               463.78         1         2       62.27       0.00          1          0
0.45  (Rep 3)
Loading bay               460.61         1         2       70.81       0.00          1          0
0.51  (Rep 4)
```

```
Loading bay               462.86         1        2      65.54      0.00         1         0
0.47  (Rep 5)
Loading bay               462.41         1        2      72.18      0.00         1         0
0.52  (Rep 6)
Loading bay               460.73         1        2      72.81      0.00         1         0
0.53  (Rep 7)
Loading bay               461.61         1        2      54.67      0.00         1         0
0.39  (Rep 8)
Loading bay               462.67         1        2      52.31      0.00         1         0
0.38  (Rep 9)
Loading bay               463.82         1        2      68.35      0.00         1         0
0.49  (Rep 10)
Loading bay               462.08         1        2      64.03      0.00         1         0
0.46  (Average)
Loading bay                 1.29         0        0       7.19      0.00         0         0
0.05  (Std. Dev.)

Printing press            462.16         1        2     935.00      0.06         1         0
6.74  (Rep 1)
Printing press            460.13         1        2     935.00      0.06         1         0
6.77  (Rep 2)
Printing press            463.78         1        2     935.00      0.06         1         0
6.72  (Rep 3)
Printing press            460.61         1        2     935.00      0.06         1         0
6.77  (Rep 4)
Printing press            462.86         1        2     935.00      0.06         1         0
6.73  (Rep 5)
Printing press            462.41         1        2     935.00      0.06         1         0
6.74  (Rep 6)
Printing press            460.73         1        2     935.00      0.06         1         0
6.76  (Rep 7)
Printing press            461.61         1        2     935.00      0.06         1         0
6.75  (Rep 8)
Printing press            462.67         1        2     935.00      0.06         1         0
6.74  (Rep 9)
Printing press            463.82         1        2     935.00      0.06         1         0
6.72  (Rep 10)
Printing press            462.08         1        2     935.00      0.06         1         0
6.74  (Average)
Printing press              1.29         0        0       0.00      0.00         0         0
0.02  (Std. Dev.)

Unloading bay             462.16         1        2    1708.23      0.12         1         0
12.32  (Rep 1)
Unloading bay             460.13         1        2    1685.43      0.12         1         0
12.21  (Rep 2)
Unloading bay             463.78         1        2    1714.20      0.12         1         0
12.32  (Rep 3)
Unloading bay             460.61         1        2    1710.46      0.12         1         0
12.38  (Rep 4)
Unloading bay             462.86         1        2    1693.70      0.12         1         0
12.20  (Rep 5)
Unloading bay             462.41         1        2    1699.68      0.12         1         0
12.25  (Rep 6)
Unloading bay             460.73         1        2    1707.42      0.12         1         0
12.35  (Rep 7)
Unloading bay             461.61         1        2    1693.38      0.12         1         0
12.23  (Rep 8)
Unloading bay             462.67         1        2    1706.14      0.12         1         0
12.29  (Rep 9)
Unloading bay             463.82         1        2    1701.63      0.12         1         0
12.23  (Rep 10)
Unloading bay             462.08         1        2    1702.03      0.12         1         0
12.28  (Average)
Unloading bay               1.29         0        0       8.99      0.00         0         0
0.06  (Std. Dev.)

Sammy machine             462.16         1       76      42.37      0.11         1         0
11.61  (Rep 1)
Sammy machine             460.13         1       76      41.83      0.11         1         0
11.52  (Rep 2)
Sammy machine             463.78         1       76      42.29      0.11         1         0
11.55  (Rep 3)
Sammy machine             460.61         1       76      42.46      0.11         1         0
11.68  (Rep 4)
Sammy machine             462.86         1       76      42.30      0.11         1         0
11.58  (Rep 5)
Sammy machine             462.41         1       76      42.19      0.11         1         0
11.56  (Rep 6)
Sammy machine             460.73         1       76      42.32      0.11         1         0
11.64  (Rep 7)
Sammy machine             461.61         1       76      42.02      0.11         1         0
11.53  (Rep 8)
```

```
Sammy machine           462.67         1        76       42.17       0.11          1          0
11.54  (Rep 9)
Sammy machine           463.82         1        76       42.12       0.11          1          0
11.50  (Rep 10)
Sammy machine           462.08         1        76       42.21       0.11          1          0
11.57  (Average)
Sammy machine             1.29         0         0        0.18       0.00          0          0
0.06  (Std. Dev.)

Pressed sheet pallet    462.16        38        76     2325.03       6.37         28          0
16.77  (Rep 1)
Pressed sheet pallet    460.13        38        76     2325.03       6.40         28          0
16.84  (Rep 2)
Pressed sheet pallet    463.78        38        76     2324.61       6.34         28          0
16.71  (Rep 3)
Pressed sheet pallet    460.61        38        76     2292.21       6.30         28          0
16.59  (Rep 4)
Pressed sheet pallet    462.86        38        76     2317.84       6.34         28          0
16.69  (Rep 5)
Pressed sheet pallet    462.41        38        76     2298.18       6.29         28          0
16.57  (Rep 6)
Pressed sheet pallet    460.73        38        76     2291.71       6.30         28          0
16.58  (Rep 7)
Pressed sheet pallet    461.61        38        76     2299.73       6.31         28          0
16.61  (Rep 8)
Pressed sheet pallet    462.67        38        76     2315.78       6.33         28          0
16.68  (Rep 9)
Pressed sheet pallet    463.82        38        76     2289.05       6.25         28          0
16.45  (Rep 10)
Pressed sheet pallet    462.08        38        76     2307.92       6.32         28          0
16.65  (Average)
Pressed sheet pallet      1.29         0         0       15.09       0.04          0          0
0.11  (Std. Dev.)

Packing tabel           462.16         1        76      169.41       0.46          1          0
46.43  (Rep 1)
Packing tabel           460.13         1        76      169.69       0.46          1          0
46.71  (Rep 2)
Packing tabel           463.78         1        76      169.66       0.46          1          0
46.34  (Rep 3)
Packing tabel           460.61         1        76      168.84       0.46          1          0
46.43  (Rep 4)
Packing tabel           462.86         1        76      169.91       0.46          1          0
46.50  (Rep 5)
Packing tabel           462.41         1        76      168.26       0.46          1          0
46.09  (Rep 6)
Packing tabel           460.73         1        76      168.06       0.46          1          0
46.21  (Rep 7)
Packing tabel           461.61         1        76      168.54       0.46          1          0
46.25  (Rep 8)
Packing tabel           462.67         1        76      169.45       0.46          1          0
46.39  (Rep 9)
Packing tabel           463.82         1        76      167.77       0.45          1          0
45.82  (Rep 10)
Packing tabel           462.08         1        76      168.96       0.46          1          0
46.32  (Average)
Packing tabel             1.29         0         0        0.76       0.00          0          0
0.25  (Std. Dev.)

Finished pallet         462.16        38        76     3127.04       8.57         38          0
22.55  (Rep 1)
Finished pallet         460.13        38        76     3147.09       8.66         38          0
22.80  (Rep 2)
Finished pallet         463.78        38        76     3139.02       8.57         38          0
22.56  (Rep 3)
Finished pallet         460.61        38        76     3136.47       8.62         38          0
22.70  (Rep 4)
Finished pallet         462.86        38        76     3153.11       8.62         38          0
22.71  (Rep 5)
Finished pallet         462.41        38        76     3114.90       8.53         38          0
22.45  (Rep 6)
Finished pallet         460.73        38        76     3109.59       8.54         38          0
22.50  (Rep 7)
Finished pallet         461.61        38        76     3126.79       8.57         38          0
22.58  (Rep 8)
Finished pallet         462.67        38        76     3140.80       8.59         38          0
22.63  (Rep 9)
Finished pallet         463.82        38        76     3108.93       8.49         38          0
22.34  (Rep 10)
Finished pallet         462.08        38        76     3130.38       8.58         38          0
22.58  (Average)
Finished pallet           1.29         0         0       15.53       0.05          0          0
0.13  (Std. Dev.)
```

APPENDIX – 5

AHP ANALYSIS :

DENSO MANUFACTURING (UK) LTD.

AHP ANALYSIS

RELATIVE RANKING – 1

Step 1: Enter data to the pairwise comparison table

- ***Step 1.1***: Enter geometric means of pairwise comparison responses (*e.g. W_1 is the average of 20 responses given for the customer-financial perspective pairing: 3, 4, 2, ½, ½, ½, ½, 2, ½, 4, 1, 2, 2, 2, 2, 2, 1, 2, 3, 2, that is 1.825*).
- ***Step 1.2***: Calculate and enter values for reciprocity axiom; i.e. when $\mathcal{F}_{ij}$ is a comparison judgements for column *i* and row *j*; then, $\mathcal{F}_{ji} = 1/ \mathcal{F}_{ij}$. (*e.g. when $\mathcal{F}_{ij} = W_1 = 1.825$, then, $\mathcal{F}_{ji} = 1/ \mathcal{F}_{ij} = 1/ W_1 = 1/1.825 = 0.548$*).
- ***Step 1.3***: Calculate sum of each column (*e.g. S_1 is sum of column 1: 1.000, 0.548, 0.496, 0.484, 0.349, 0.574, 0.430, that is 3.881*).

Pair-wise Comparisons of the Extended BSC Perspectives

Step 1.2
Reciprocity Axiom
($1/W_1$, e.g: 1/1.825)

Step 1.1
Geometric mean of pairwise comparison responses (W_1)

	Performance Pair-Wise Comparison						
Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective
Customer Perspective	1.000	1.825	2.017	2.067	2.867	1.742	2.325
Financial Perspective	0.548	1.000	1.875	1.917	2.550	1.850	2.550
Internal Business Processes Perspective	0.496	0.533	1.000	1.375	1.908	1.108	1.925
Employee Perspective	0.484	0.522	0.727	1.000	2.117	1.317	1.725
Supplier Perspective	0.349	0.392	0.524	0.472	1.000	0.704	1.208
Innovation and Growth Perspective	0.574	0.541	0.902	0.759	1.420	1.000	1.817
External Environmental Groups Perspective	0.430	0.392	0.519	0.580	0.828	0.550	1.000
SUM	**3.881**	**5.205**	**7.565**	**8.170**	**12.689**	**8.271**	**12.550**

Step 1.3
Sum of the column (S_1)

Step 2: Normalise the comparison

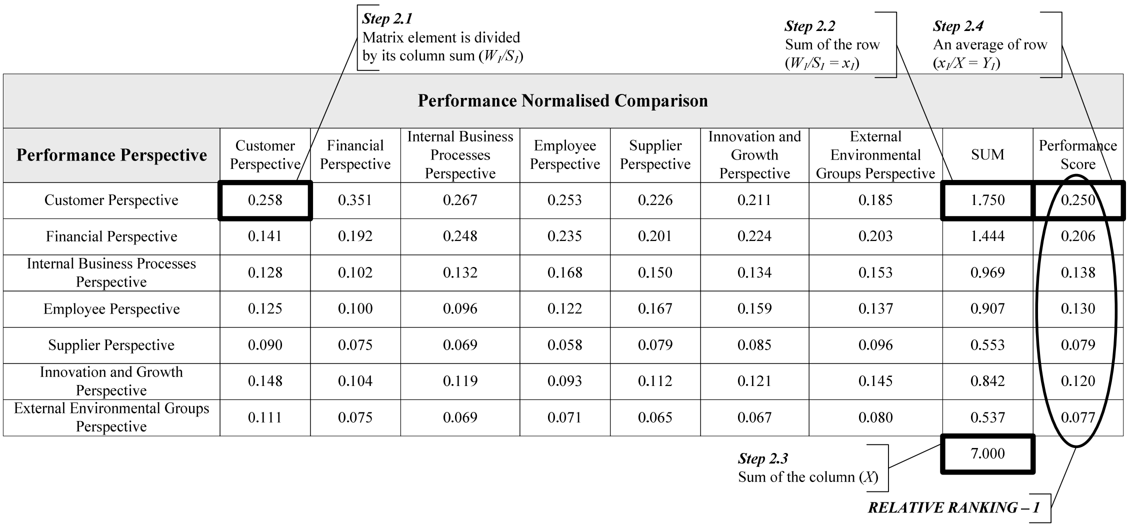
- ***Step 2.1***: Divide each element of the matrix by its column sum (*e.g. The first element in the normalised matrix is $W_1/S_1 = 1.000/3.881 = 0.258$*).

- ***Step 2.2***: Calculate sum of each row (*e.g.* x_1 *is sum of row 1: 0.258, 0.351, 0.267, 0.253, 0.226, 0.211, 0.185, that is 1.750*).

- ***Step 2.3***: Add up row sums (*e.g.* X *is* $\sum_{i=1}^{7} x_i$; *i.e. sum of 1.750, 1.444, 0.969, 0.907, 0.553, 0.842, 0.537, that is 7.000; X should be equal to number of alternatives*).

- ***Step 2.4:*** Calculate average of each row. This is the performance score for each alternative element (*e.g. Performance score of customer perspective =* $Y_1 = x_1/X = 1.750/7.000 = 0.250$). This performance score column is also called Relative Ranking – 1. It is transferred to the weight column of the overall evaluation table.

Pairwise Normalised Comparisons of the Extended BSC Perspectives



Step 2.1
Matrix element is divided by its column sum (W_1/S_1)

Step 2.2
Sum of the row ($W_1/S_1 = x_1$)

Step 2.4
An average of row ($x_1/X = Y_1$)

Performance Normalised Comparison									
Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective	SUM	Performance Score
Customer Perspective	0.258	0.351	0.267	0.253	0.226	0.211	0.185	1.750	0.250
Financial Perspective	0.141	0.192	0.248	0.235	0.201	0.224	0.203	1.444	0.206
Internal Business Processes Perspective	0.128	0.102	0.132	0.168	0.150	0.134	0.153	0.969	0.138
Employee Perspective	0.125	0.100	0.096	0.122	0.167	0.159	0.137	0.907	0.130
Supplier Perspective	0.090	0.075	0.069	0.058	0.079	0.085	0.096	0.553	0.079
Innovation and Growth Perspective	0.148	0.104	0.119	0.093	0.112	0.121	0.145	0.842	0.120
External Environmental Groups Perspective	0.111	0.075	0.069	0.071	0.065	0.067	0.080	0.537	0.077
								7.000	

Step 2.3
Sum of the column (X)

RELATIVE RANKING – 1

Step 3: Consistency calculations

- ***Step 3.1***: Multiply each element of the comparison matrix by the equivalent performance score vector value to obtain a new vector. (*e.g. The first element of the first row of new vector is 1.000* x *0.250 = 0.250 and the second element of the first row is 1.825* x *0.206 = 0.376 and so on*)

- ***Step 3.2***: Calculate sum of each row (*e.g.* Z_1 *is sum of row 1: 0.250, 0.376, 0.279, 0.268, 0.226, 0.209, 0.178; that is 1.787*).

The sum column can be calculated in one step (replacing step 3.1 and 3.2) by matrix multiplication of the comparison matrix with the performance score vector.

$$New\ vector = \begin{bmatrix} 1 & W_{12} & W_{13} & .... & W_{17} \\ 1/W_{12} & 1 & W_{23} & .... & W_{27} \\ 1/W_{13} & 1/W_{23} & 1 & .... & W_{37} \\ .... & .... & .... & .... & .... \\ 1/W_{17} & 1/W_{27} & 1/W_{37} & .... & 1 \end{bmatrix} . \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ .... \\ Y_7 \end{bmatrix}$$

- ***Step 3.3***: Divide the sum of the first row of the new vector (Z_1) by the first component (row) of the performance score vector (Y_1) and the sum of second component (row) of new vector by the second component of the performance score vector and so on (*e.g.* α_1 *is the first component in last column* = Z_1/Y_1 = *1.787/0.250 = 7.150 and* $\alpha_2 = Z_2/Y_2$ = *1.470/0.206 = 7.150 and so on*)

- ***Step 3.4***: Calculate λ_{max}, that is an average of α value column. (*Here* λ_{max} = *(7.150+7.130+7.098+7.074+7.070+7.070+7.083)/7 = 7.096*)

- ***Step 3.5***: Calculate consistency index (*CI*) (*Here* $CI=(\lambda_{max}–n)/(n–1)$= *(7.096–7.000)/(7.000–1.000) = 0.016, where n is number of alternatives; in other words n=X*)

- ***Step 3.6***: Calculate consistency ratio (*CR*), which is the ratio between consistency index (*CI*) and random index (*RI*). The appropriate *RI* for seven alternatives is 1.32 (*Here CR = CI/RI = 0.016/1.32 = 0.012*)

Consistency Calculations for Extended BSC Perspectives

Step 3.1
Multiply matrix of comparison by performance score vector to obtain new vector

Step 3.2
Sum of the row (Z_1)

Step 3.3
Ratio between sum of the row and performance score ($Z_1/Y_1=\alpha_1$)

	Performance Normalised Comparison								
Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective	SUM	SUM ÷ Performance Score
Customer Perspective	0.250	0.376	0.279	0.268	0.226	0.209	0.178	1.787	7.150
Financial Perspective	0.137	0.206	0.259	0.248	0.201	0.222	0.196	1.470	7.130
Internal Business Processes Perspective	0.124	0.110	0.138	0.178	0.151	0.133	0.148	0.982	7.098
Employee Perspective	0.121	0.108	0.101	0.130	0.167	0.158	0.132	0.916	7.074
Supplier Perspective	0.087	0.081	0.073	0.061	0.079	0.085	0.093	0.558	7.070
Innovation and Growth Perspective	0.144	0.111	0.125	0.098	0.112	0.120	0.139	0.850	7.070
External Environmental Groups Perspective	0.108	0.081	0.072	0.075	0.065	0.066	0.077	0.544	7.083

RELATIVE RANKINGS – 2

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Customer Perspective

Performance Pair-Wise Comparison				
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control
Line Balancing	1.000	2.800	1.500	0.607
Setup Time	0.357	1.000	0.533	0.357
Multifunction Employee	0.667	1.875	1.000	0.473
Quality Control	1.648	2.804	2.113	1.000
SUM	**3.672**	**8.479**	**5.146**	**2.437**

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	Performance Score
Line Balancing	0.272	0.330	0.291	0.249	1.143	0.286
Setup Time	0.097	0.118	0.104	0.146	0.465	0.116
Multifunction Employee	0.182	0.221	0.194	0.194	0.791	0.198
Quality Control	0.449	0.331	0.411	0.410	1.600	0.400
					4.000	

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	SUM ÷ Performance Score
Line Balancing	0.286	0.326	0.297	0.243	1.151	4.027
Setup Time	0.102	0.116	0.106	0.143	0.467	4.012
Multifunction Employee	0.191	0.218	0.198	0.189	0.796	4.023
Quality Control	0.471	0.326	0.418	0.400	1.615	4.037

$\lambda_{max} = 4.025$

CI = 0.008

CR = 0.009

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Financial Perspective

Performance Pair-Wise Comparison				
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control
Line Balancing	1.000	2.900	0.867	1.107
Setup Time	0.345	1.000	0.757	0.407
Multifunction Employee	1.154	1.322	1.000	1.007
Quality Control	0.904	2.459	0.993	1.000
SUM	**3.402**	**7.681**	**3.617**	**3.520**

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	Performance Score
Line Balancing	0.294	0.378	0.240	0.314	1.226	0.306
Setup Time	0.101	0.130	0.209	0.116	0.556	0.139
Multifunction Employee	0.339	0.172	0.276	0.286	1.074	0.268
Quality Control	0.266	0.320	0.275	0.284	1.145	0.286
					4.000	

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	SUM ÷ Performance Score
Line Balancing	0.306	0.403	0.233	0.317	1.259	4.109
Setup Time	0.106	0.139	0.203	0.116	0.564	4.057
Multifunction Employee	0.354	0.184	0.268	0.288	1.094	4.075
Quality Control	0.277	0.342	0.267	0.286	1.172	4.095

$\lambda_{max} = 4.084$

CI = 0.028

CR = 0.031

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Internal Business Processes Perspective

Performance Pair-Wise Comparison				
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control
Line Balancing	1.000	1.885	0.949	1.233
Setup Time	0.531	1.000	0.776	1.115
Multifunction Employee	1.054	1.289	1.000	1.147
Quality Control	0.811	0.897	0.872	1.000
SUM	**3.395**	**5.070**	**3.596**	**4.496**

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	Performance Score
Line Balancing	0.295	0.372	0.264	0.274	1.204	0.301
Setup Time	0.156	0.197	0.216	0.248	0.817	0.204
Multifunction Employee	0.310	0.254	0.278	0.255	1.098	0.274
Quality Control	0.239	0.177	0.242	0.222	0.880	0.220
					4.000	

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	SUM ÷ Performance Score
Line Balancing	0.301	0.385	0.260	0.271	1.218	4.045
Setup Time	0.160	0.204	0.213	0.245	0.822	4.026
Multifunction Employee	0.317	0.263	0.274	0.253	1.108	4.036
Quality Control	0.244	0.183	0.239	0.220	0.887	4.028

λ_{max} = 4.034

CI = 0.011

CR = 0.013

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Employee Perspective

Performance Pair-Wise Comparison				
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control
Line Balancing	1.000	2.200	0.789	1.478
Setup Time	0.455	1.000	0.628	1.222
Multifunction Employee	1.268	1.593	1.000	1.806
Quality Control	0.677	0.818	0.554	1.000
SUM	**3.399**	**5.611**	**2.971**	**5.506**

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	Performance Score
Line Balancing	0.294	0.392	0.266	0.268	1.220	0.305
Setup Time	0.134	0.178	0.211	0.222	0.745	0.186
Multifunction Employee	0.373	0.284	0.337	0.328	1.321	0.330
Quality Control	0.199	0.146	0.186	0.182	0.713	0.178
					4.000	

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	SUM ÷ Performance Score
Line Balancing	0.305	0.410	0.261	0.263	1.239	4.061
Setup Time	0.139	0.186	0.207	0.218	0.750	4.027
Multifunction Employee	0.387	0.297	0.330	0.322	1.336	4.043
Quality Control	0.206	0.152	0.183	0.178	0.720	4.040

λ_{max} = 4.043

CI = 0.014

CR = 0.016

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Supplier Perspective

Performance Pair-Wise Comparison				
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control
Line Balancing	1.000	3.000	1.111	0.361
Setup Time	0.333	1.000	0.333	0.261
Multifunction Employee	0.900	3.000	1.000	0.389
Quality Control	2.769	3.830	2.571	1.000
SUM	**5.003**	**10.830**	**5.016**	**2.011**

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	Performance Score
Line Balancing	0.200	0.277	0.222	0.180	0.878	0.219
Setup Time	0.067	0.092	0.066	0.130	0.355	0.089
Multifunction Employee	0.180	0.277	0.199	0.193	0.850	0.212
Quality Control	0.554	0.354	0.513	0.497	1.917	0.479
					4.000	

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	SUM ÷ Performance Score
Line Balancing	0.219	0.266	0.236	0.173	0.895	4.078
Setup Time	0.073	0.089	0.071	0.125	0.358	4.030
Multifunction Employee	0.198	0.266	0.212	0.186	0.863	4.062
Quality Control	0.608	0.340	0.546	0.479	1.973	4.118

λ_{max} = 4.072

CI = 0.024

CR = 0.027

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Innovation and Growth Perspective

Performance Pair-Wise Comparison				
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control
Line Balancing	1.000	2.667	1.833	1.194
Setup Time	0.375	1.000	0.389	0.389
Multifunction Employee	0.545	2.571	1.000	0.611
Quality Control	0.837	2.571	1.636	1.000
SUM	**2.758**	**8.810**	**4.859**	**3.194**

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	Performance Score
Line Balancing	0.363	0.303	0.377	0.374	1.417	0.354
Setup Time	0.136	0.114	0.080	0.122	0.451	0.113
Multifunction Employee	0.198	0.292	0.206	0.191	0.887	0.222
Quality Control	0.304	0.292	0.337	0.313	1.245	0.311
					4.000	

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	SUM ÷ Performance Score
Line Balancing	0.354	0.301	0.406	0.372	1.433	4.047
Setup Time	0.133	0.113	0.086	0.121	0.453	4.015
Multifunction Employee	0.193	0.290	0.222	0.190	0.895	4.038
Quality Control	0.296	0.290	0.363	0.311	1.261	4.049

$\lambda_{max} = 4.037$

CI = 0.012

CR = 0.014

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the External Socio-Environmental Groups Perspective

Performance Pair-Wise Comparison				
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control
Line Balancing	1.000	1.778	0.944	0.417
Setup Time	0.563	1.000	1.167	0.333
Multifunction Employee	1.059	0.857	1.000	0.361
Quality Control	2.400	3.000	2.769	1.000
SUM	**5.021**	**6.635**	**5.880**	**2.111**

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	Performance Score
Line Balancing	0.199	0.268	0.161	0.197	0.825	0.206
Setup Time	0.112	0.151	0.198	0.158	0.619	0.155
Multifunction Employee	0.211	0.129	0.170	0.171	0.681	0.170
Quality Control	0.478	0.452	0.471	0.474	1.875	0.469
					4.000	

Performance Normalised Comparison						
JIT Variable	Line Balancing	Setup Time	Multifunction Employee	Quality Control	SUM	SUM ÷ Performance Score
Line Balancing	0.206	0.275	0.161	0.195	0.838	4.060
Setup Time	0.116	0.155	0.199	0.156	0.626	4.043
Multifunction Employee	0.218	0.133	0.170	0.169	0.691	4.055
Quality Control	0.495	0.464	0.472	0.469	1.900	4.053

λ_{max} = 4.053

CI = 0.018

CR = 0.020

APPENDIX – 6

AHP ANALYSIS :

RISANE LTD.

AHP ANALYSIS

RELATIVE RANKING – 1

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of the Extended BSC Perspectives

Performance Pair-Wise Comparison

Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective
Customer Perspective	1.000	1.917	2.472	2.708	2.889	1.306	2.722
Financial Perspective	0.522	1.000	1.589	2.139	2.875	1.333	1.750
Internal Business Processes Perspective	0.404	.629	1.000	1.583	1.958	0.908	2.833
Employee Perspective	0.369	0.468	0.632	1.000	1.542	0.317	1.500
Supplier Perspective	0.346	0.348	0.511	0.649	1.000	0.872	1.764
Innovation and Growth Perspective	0.766	0.750	1.101	3.158	1.146	1.000	3.167
External Environmental Groups Perspective	0.367	0.571	0.353	0.667	0.567	0.316	1.000
SUM	**3.775**	**5.683**	**7.657**	**11.904**	**11.997**	**6.052**	**14.736**

Performance Normalised Comparison

Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective	SUM	Performance Score
Customer Perspective	0.265	0.337	0.323	0.228	0.241	0.216	0.185	1.794	0.256
Financial Perspective	0.138	0.176	0.208	0.180	0.240	0.220	0.119	1.280	0.183
Internal Business Processes Perspective	0.107	0.111	0.131	0.133	0.164	0.150	0.192	0.987	0.141
Employee Perspective	0.098	0.082	0.082	0.084	0.129	0.052	0.102	0.629	0.090
Supplier Perspective	0.092	0.061	0.067	0.054	0.083	0.144	0.120	0.621	0.089
Innovation and Growth Perspective	0.203	0.132	0.144	0.265	0.096	0.165	0.215	1.220	0.174
External Environmental Groups Perspective	0.097	0.101	0.046	0.056	0.047	0.052	0.068	0.467	0.067
								7.000	

Performance Normalised Comparison

Performance Perspective	Customer Perspective	Financial Perspective	Internal Business Processes Perspective	Employee Perspective	Supplier Perspective	Innovation and Growth Perspective	External Environmental Groups Perspective	SUM	SUM ÷ Performance Score
Customer Perspective	0.256	0.351	0.349	0.244	0.256	0.228	0.182	1.865	7.276
Financial Perspective	0.134	0.183	0.224	0.192	0.255	0.232	0.117	1.337	7.312
Internal Business Processes Perspective	0.104	0.115	0.141	0.142	0.174	0.158	0.189	1.024	7.256
Employee Perspective	0.095	0.086	0.089	0.090	0.137	0.055	0.100	0.651	7.244
Supplier Perspective	0.089	0.064	0.072	0.058	0.089	0.152	0.118	0.641	7.223
Innovation and Growth Perspective	0.196	0.137	0.155	0.284	0.102	0.174	0.211	1.260	7.232
External Environmental Groups Perspective	0.094	0.105	0.050	0.060	0.050	0.055	0.067	0.481	7.198

$$\lambda_{max} = 7.249$$

$$CI = 0.041$$

$$CR = 0.031$$

RELATIVE RANKINGS – 2

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Customer Perspective

Performance Pair-Wise Comparison				
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2
Setup Time Elimination Plans	1.000	0.250	0.200	0.250
Group Technology - 1	4.000	1.000	1.000	2.000
Innovation and Investment Plans	5.000	1.000	1.000	2.000
Group Technology - 2	4.000	0.500	0.500	1.000
SUM	**14.000**	**2.750**	**2.700**	**5.250**

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	Performance Score
Setup Time Elimination Plans	0.071	0.091	0.074	0.048	0.284	0.071
Group Technology - 1	0.286	0.364	0.370	0.381	1.401	0.350
Innovation and Investment Plans	0.357	0.364	0.370	0.381	1.472	0.368
Group Technology - 2	0.286	0.182	0.185	0.190	0.843	0.211
					4.000	

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	SUM ÷ Performance Score
Setup Time Elimination Plans	0.071	0.088	0.074	0.053	0.285	4.012
Group Technology - 1	0.284	0.350	0.368	0.422	1.424	4.066
Innovation and Investment Plans	0.355	0.350	0.368	0.422	1.495	4.062
Group Technology - 2	0.284	0.175	0.184	0.211	0.854	4.051

$\lambda_{max} = 4.048$

$CI = 0.016$

$CR = 0.018$

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Financial Perspective

Performance Pair-Wise Comparison

JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2
Setup Time Elimination Plans	1.000	0.417	1.000	0.333
Group Technology - 1	2.400	1.000	1.000	1.250
Innovation and Investment Plans	1.000	1.000	1.000	0.667
Group Technology - 2	3.000	0.800	1.500	1.000
SUM	**7.400**	**3.217**	**4.500**	**3.250**

Performance Normalised Comparison

JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	Performance Score
Setup Time Elimination Plans	0.135	0.130	0.222	0.103	0.589	0.147
Group Technology - 1	0.324	0.311	0.222	0.385	1.242	0.311
Innovation and Investment Plans	0.135	0.311	0.222	0.205	0.873	0.218
Group Technology - 2	0.405	0.249	0.333	0.308	1.295	0.324
					4.000	

Performance Normalised Comparison

JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	SUM ÷ Performance Score
Setup Time Elimination Plans	0.147	0.129	0.218	0.108	0.603	4.092
Group Technology - 1	0.354	0.311	0.218	0.405	1.287	4.146
Innovation and Investment Plans	0.147	0.311	0.218	0.216	0.892	4.086
Group Technology - 2	0.442	0.248	0.328	0.324	1.342	4.144

$\lambda_{max} = 4.117$

$CI = 0.039$

$CR = 0.043$

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Internal Business Processes Perspective

Performance Pair-Wise Comparison				
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2
Setup Time Elimination Plans	1.000	0.667	1.250	0.750
Group Technology - 1	1.500	1.000	0.750	1.600
Innovation and Investment Plans	0.800	1.333	1.000	0.500
Group Technology - 2	1.333	0.625	2.000	1.000
SUM	**4.633**	**3.625**	**5.000**	**3.850**

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	Performance Score
Setup Time Elimination Plans	0.216	0.184	0.250	0.195	0.845	0.211
Group Technology - 1	0.324	0.276	0.150	0.416	1.165	0.291
Innovation and Investment Plans	0.173	0.368	0.200	0.130	0.870	0.218
Group Technology - 2	0.288	0.172	0.400	0.260	1.120	0.280
					4.000	

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	SUM ÷ Performance Score
Setup Time Elimination Plans	0.211	0.194	0.272	0.210	0.887	4.203
Group Technology - 1	0.317	0.291	0.163	0.448	1.219	4.185
Innovation and Investment Plans	0.169	0.388	0.218	0.140	0.915	4.205
Group Technology - 2	0.282	0.182	0.435	0.280	1.179	4.210

$$\lambda_{max} = 4.117$$

$$CI = 0.039$$

$$CR = 0.043$$

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Employee Perspective

Performance Pair-Wise Comparison				
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2
Setup Time Elimination Plans	1.000	0.267	1.500	1.600
Group Technology - 1	3.750	1.000	1.500	2.625
Innovation and Investment Plans	0.667	0.667	1.000	0.750
Group Technology - 2	0.625	0.381	1.333	1.000
SUM	**6.042**	**2.314**	**5.333**	**5.975**

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	Performance Score
Setup Time Elimination Plans	0.166	0.115	0.281	0.268	0.830	0.207
Group Technology - 1	0.621	0.432	0.281	0.439	1.773	0.443
Innovation and Investment Plans	0.110	0.288	0.188	0.126	0.711	0.178
Group Technology - 2	0.103	0.165	0.250	0.167	0.685	0.171
					4.000	

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	SUM ÷ Performance Score
Setup Time Elimination Plans	0.207	0.118	0.267	0.274	0.867	4.178
Group Technology - 1	0.778	0.443	0.267	0.450	1.938	4.371
Innovation and Investment Plans	0.138	0.296	0.178	0.129	0.740	4.162
Group Technology - 2	0.130	0.169	0.237	0.171	0.707	4.126

$\lambda_{max} = 4.209$

$CI = 0.070$

$CR = 0.077$

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Supplier Perspective

Performance Pair-Wise Comparison

JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2
Setup Time Elimination Plans	1.000	1.000	0.333	0.333
Group Technology - 1	1.000	1.000	0.333	1.000
Innovation and Investment Plans	3.000	1.000	1.000	1.000
Group Technology - 2	3.000	1.000	1.000	1.000
SUM	**8.000**	**6.000**	**2.667**	**3.333**

Performance Normalised Comparison

JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	Performance Score
Setup Time Elimination Plans	0.125	0.167	0.125	1.000	0.517	0.129
Group Technology - 1	0.125	0.167	0.125	0.300	0.717	0.179
Innovation and Investment Plans	0.375	0.500	0.375	0.300	1.550	0.388
Group Technology - 2	0.375	0.167	0.375	0.300	1.217	0.304
					4.000	

Performance Normalised Comparison

JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	SUM ÷ Performance Score
Setup Time Elimination Plans	0.129	0.179	0.129	0.101	0.539	4.172
Group Technology - 1	0.129	0.179	0.129	0.304	0.742	4.140
Innovation and Investment Plans	0.388	0.538	0.388	0.304	1.617	4.172
Group Technology - 2	0.388	0.179	0.388	0.304	1.258	4.137

$\lambda_{max} = 4.155$

$CI = 0.052$

$CR = 0.057$

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the Innovation and Growth Perspective

Performance Pair-Wise Comparison				
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2
Setup Time Elimination Plans	1.000	1.667	0.292	1.167
Group Technology - 1	0.600	1.000	0.333	1.667
Innovation and Investment Plans	3.429	3.429	1.000	2.000
Group Technology - 2	0.857	0.600	0.500	1.000
SUM	**5.886**	**6.695**	**2.083**	**5.833**

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	Performance Score
Setup Time Elimination Plans	0.170	0.249	0.140	0.200	0.759	0.190
Group Technology - 1	0.102	0.149	0.140	0.286	0.677	0.169
Innovation and Investment Plans	0.583	0.512	0.480	0.343	1.917	0.479
Group Technology - 2	0.146	0.090	0.240	0.171	0.647	0.162
					4.000	

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	SUM ÷ Performance Score
Setup Time Elimination Plans	0.190	0.282	0.140	0.189	0.800	4.218
Group Technology - 1	0.114	0.169	0.140	0.269	0.692	4.091
Innovation and Investment Plans	0.650	0.580	0.479	0.323	2.033	4.242
Group Technology - 2	0.163	0.102	0.240	0.162	0.666	4.117

$$\lambda_{max} = 4.167$$

$$CI = 0.056$$

$$CR = 0.062$$

Pair-wise Comparisons, Pair-wise Normalised Comparisons and Consistency Calculations of JIT Variables with Respect to the External Socio-Environmental Groups Perspective

Performance Pair-Wise Comparison				
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2
Setup Time Elimination Plans	1.000	0.225	0.625	0.225
Group Technology - 1	4.444	1.000	2.000	1.600
Innovation and Investment Plans	1.600	0.500	1.000	1.000
Group Technology - 2	4.444	0.625	1.000	1.000
SUM	**11.489**	**2.350**	**4.625**	**3.825**

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	Performance Score
Setup Time Elimination Plans	0.087	0.096	0.135	0.059	0.377	0.094
Group Technology - 1	0.387	0.426	0.432	0.418	1.663	0.416
Innovation and Investment Plans	0.139	0.213	0.216	0.261	0.830	0.207
Group Technology - 2	0.387	0.266	0.216	0.261	1.130	0.283
					4.000	

Performance Normalised Comparison						
JIT Variable	Setup Time Elimination Plans	Group Technology - 1	Innovation and Investment Plans	Group Technology - 2	SUM	SUM ÷ Performance Score
Setup Time Elimination Plans	0.094	0.094	0.130	0.064	0.381	4.045
Group Technology - 1	0.419	0.416	0.415	0.452	1.701	4.092
Innovation and Investment Plans	0.151	0.208	0.207	0.283	0.849	4.091
Group Technology - 2	0.419	0.260	0.207	0.283	1.169	4.135

$\lambda_{max} = 4.091$

$CI = 0.030$

$CR = 0.034$

APPENDIX – 7

TYPICAL INFORMAL INTERVIEW AND DISCUSSION TRANSCRIPTION

INFORMAL INTERVIEW/DISCUSSION WITH MANAGING DIRECTOR - OPERATIONS AND SALES AT RISANE LTD.

Q: Can you give me an introduction to this company?

A: Risane Ltd. is four years old, myself and Managing Director – 2 (Innovations) set the company up. I am a scientist/engineer and Risane is a development company built around development and innovation of new products, development of new machines to make the products, and then making the products themselves. Interesting actually that when we started we, Risane, were not going to make anything; the idea was that we were going to be an ideas company and we would develop products and processes and sell those ideas to other companies. Then, we found out that other companies were not quick enough to take on those ideas, and we decided very quickly to start manufacturing ourselves. Now we are so much a manufacturing company. It was never planned that way.

Because our business is innovation, the key to our business is flexibility. What we try to do is to develop new products, which other people have not developed yet based on customer requirements. We then go back to the customer to ensure we got it right and then later on we sell it to the customer.

We do not charge for our development process at all; the only way we make our money is if we make the product and we sell it to the customer. Being that every thing we make is unique, we have a process, which nobody else has. From a manufacturing point of view, flexibility is very important, but so also is adaptability. We need to be able to quickly change from one process to another process. We do not want to invest too much time making a process better and better if at the end of the day all that process could do is make that particular product, because we know in a year’s time or two that product will be obsolete. Basically, our whole business is built around making our own product obsolete before somebody else makes it obsolete. So we are very careful about going too deeply into manufacturing a particular product because we will likely change it at some point. There are one or two exceptions, because there are some products, which look to be long term. We might stick with those products for a while but basically that is how it works.

We offer a different kind of service to our customers compared to our competitors. Our competitors like to state a lead-time to be a week, two weeks, month or whatever it might be; how our lead-time works is we ask our customers when they want the product and we try to work our way around that the best we can. Though sometimes when we are busy or if it is a new product and we do not have the expertise, then we do a lead-time. But generally speaking we always deliver on time to the customer requirements. We are trying to change how manufacturing business works; people think lead-time is something hideous. We do not like the idea of lead-time; we have them, obviously. We do not believe we should be talking to our customers about lead-time which are hours; we only talk to them about lead-times, which are days.

We have created some sense of reliability with our customers in terms of flexibility and short lead times. This is good in a way, because our competitors cannot compete, but bad in a way because we have made life difficult for ourselves.

Q: What are the lead-times of major items?

A: It all depends on the product in question, but generally we try to meet the day the customer wants it.

Q: Have you ever delivered products to your customers before due date?

A: We have done in the past; but they do not like it, so we generally deliver on time.

Q: Who are your suppliers?

A: Our main suppliers are absorbent material suppliers, which are basically paper mills. Our biggest supplier is a company called (ABC Company) in Vancouver. They make these materials and things like nappies. We have other suppliers in the South of Italy, France, China and Denmark. We normally prefer Vancouver because of the weakness of the Dollar.

Q: How many weeks does it normally take to receive orders?

A: Typically six weeks from Vancouver. But what we do is to work on a bulk ordering system. We place bigger orders over a six month period. We work with them on a shipping timetable so that at any one time there may be one container here, one container on the water, one container across Vancouver by train, and a few of them in a Vancouver warehouse waiting to be shipped. So we operate a continuous shipping method, which is ok.

Q: How often do your deliveries come through?

A: Normally we have containers coming through every day or two. A container is made of six pallets, each of four levels. So it is a very bulky material.

Q: How many days will your stocks be here?

A: We have too much stock at the moment. We probably have enough stock to run for six weeks. It does vary from material to material because some materials are fast moving.

Q: Do you put pressure on your suppliers in terms of delivery deadlines?

A: Yes we do put pressure, but it does not work at the moment. Paper mills are a very traditional business and they do not work like the rest of other businesses. The way they work is, you have it when they are ready to give it to you no matter the amount of pressure you put on them. They are big business, supplying to bigger players in the nappies and hygiene industry and we are of no consequence because we are small. When we spend one million pounds it is of no consequence to them. In some other materials that we need like the boxes for packaging, then, yes we can add pressure and they will deliver when we want, but for these companies who happen to be our major suppliers it just does not happen like that, I am afraid.

Q: So you always try to keep buffer stocks?

A: Exactly.

Q: How many stores do you have?

A: We have three units.

Q: So you have to move stocks between the factory and warehouse?

A: Yes, generally speaking, we bring our stock from the warehouse to our main unit on a daily or two day basis. The amount we carry per time is about a container load.

Q: Can you explain about your customers and your relationship with them?

A: Basically our key measure is keeping the customers happy, though our business is very demanding and things change very quickly. For example, the market requirement might change in terms of packaging as we get towards the summer; the sun comes out, barbeque and all that and thus packaging requirements change and we have to respond very quickly. So flexibility is very important and satisfying our customers is very important in terms of service, quality, on-time delivery, flexibility, value, and hygiene standards. Everything we do is built around customer service. Customer satisfaction is a soft measure. The way we do it is very qualitative rather than quantitative, and we do quantify some of the measures but it is very soft. Sometimes almost intangibly soft in the sense that you can talk to a customer and get a good feeling about what they feel about you, but you can never really write it down or turn it into questionnaires, even when you know that they will actually buy form you. So it is a very soft measure.

Q: Let's talk about employees. Are they flexible in your production process?

A: Sure, because of the nature of our business, flexibility is so important. So we demand flexibility from our employees as well as adaptability and working on own initiative. If someone with initiative is working in the process, there would not be any need for management telling them what to do. They look at what they are doing, use their recent training, think about the process and do it better so that when they go to a new thing they quickly learn and so on. Really we try and bring in people trained to be adaptable to different things rather than knowledgeable about certain things. We train them to do lots of different things. One thing we found out in this business is that in a local community, there are some who are very good and others who are mediocre. What you find is that we build the business around the background of the very good people. They are the people we rely on to do the different things we need to do; then we fill up with lesser able people who perform certain tasks. But we do move people around continuously from process to process because they are multi-skilled and we are very flexible about moving people from one place to another. So, people coming here can expect to move around.

Q: How many shifts do you have?

A: We have a 24-hour day, three-shift system running, five days; the 24 hours is divided into 7am to 3pm, 3pm to 11pm and 11pm to 7am. So it is a morning shift, afternoon shift and night shift.

Q: How many workers and administrative staff do you have?

A: We have about 20 per shift plus a shift engineer and a shift leader making it about 65 in the factory and about 20 or so administrators, including customer service, sales, financial, development, engineers, manufacturing management, quality and so on.

Q: Can you explain about the equipment and machinery and their capability?

A: Indeed, some of the reasons we are so special is because we not only develop the product but we also develop the processes to make the product. We have a very good engineering team who can do all the assembly and so on to make the machinery. As a result of that the machines we make are bespoke to what we do. Now we are very aware that a certain machine will do a certain job for a certain period of time, so we make the machinery in modules so that we can roll one out and roll another in to do a different thing. Hence the machinery are made to be multifunctional. Though not always the case, that is the general philosophy. Plus in a way we try and use the same type of components of machinery, so that should we need to rebuild the machinery and make something else out of it we can. The machines are very simple, straightforward and temporary.

Q: Do you have an automated system or a manually operated system?

A: It is manually operated largely, again because of the nature of the business we are in which we need our machines to be flexible. We tend to build them to do what we need them to do, and we make them in such a way that we can modify them to do something else. And quite often we build a prototype machine, which is designed to see if in fact it will work and then when the business takes off we use the prototype to make the product. In fact we have some machines now, which are still prototypes, which we use for manufacture. Because they were quite successful, we have not turned them from prototype to actual. We do not need them to be changed because they are doing what they are meant to do. So, generally speaking, for new products we do them in the manual way until we ascertain whether the business is going in the right direction.

Q: Do you have a continuous improvement process implemented in your plant?

A: We try to improve our products all the time to satisfy the next level. Even if it does not seem to need improving we will always try to change and improve it. It is only when we know that the product as it stands will not satisfy the customer anymore, because they have moved to different field that we now stop. And there are not many products that we have stopped because, generally speaking, the continuous improvement process will recoup the product and more than found. Everything we make now will be different compared to six months ago though some of those differences will may only be small changes. We have a system we call platform products or derivative products. Basically when we develop a completely new product we call that a platform product, but when we improve on an existing product we call that a derivative product. Many platform products give rise to lots and lots of derivative products, with changes that could be in terms of materials, processes or machinery. An important aspect of the product development process is planning and we talk to the suppliers to get an idea of the latest materials; then we get them here to try them out. We do not like to waste too much time doing the planning as we like, be fast in getting the product to market.

Q: Can you explain about quality control?

A: The business that we are in, the food business, is dominated by a particular accreditation standard called the British Food Consortium standard, which has been developed by major supermarkets and retailers.

Q: Who are they?

A: Our final customers are big retailers like ASDA, Morrisons, etc., but we do not normally supply directly to them. We supply to food processors like Kerry Foods, Bernard Matthews, etc.

Q: Have you implemented 100% quality control?

A: No we have not. Well we have in some areas and not in others, basically because it is a voluminous business, which could have about one million units from the plant. You cannot check a million. We have a very comprehensive paper system right through the plan, which can basically aide food traceability, so that we can trace any product right back to its raw materials and back to its process etc. Everything is recorded. Yes, there is a lot of checking going on, but it is not 100%. Generally speaking it's selective sampling. Here, quality control is pretty much everybody so anybody running a particular job will have documentation about the job and also quality checks in the job they are doing. They will have to do the quality checks and record the results on the manufacturing sheets. What we do is train them to do these checks and also monitor them doing them. Then we have a quality controller, for example, who goes round to do additional checks.

Q: What performance measures are used in your company?

A: Customer satisfaction and customer complaints make up some of our soft measures to measure performance; others are accreditation in terms of hygiene. Some of the hard measures include material usage measured in years, scrap rate and so on. Overhead in terms of power usage and consumables, freight (shipping cost), packaging usage, etc., though material usage is number one.

Q: How about production scrap and waste?

A: Yes, we have a 10% scrap rate. We do not measure all the processes right down to the micro-level so we know that we might be a few percentage points above that level. May be 14%.

Q: What are the factors affecting this high scrap level?

A: One is training people; another setting up machines. Another is the nature of the business that we are in, with lots of changeovers from one product to another. Another is machine failure where defective products must be thrown away. Another one is obsolescence, in terms of making more than is needed which then goes into scrap.

Q: How about time? Do you have any issues with total completion time, lead time or delivery delays?

A: Time is a serious issue for us. It is one of the customer service functions. Some processes normally take so much time to run the job. Another issue is in terms of what it costs us; e.g. a two hour job completed in three hours has a cost issue, because labour cost would have increased by 50%. So, labour cost is another big issue for us in performance. Measures and factors which affect this include downtime, setup, efficiency, training, motivation. Our labour cost at the moment is 15% and that is too high as it is supposed to be less than 12%.

Q: Can you talk more about machine setups and efficiency, and their impact on time?

A: That is definitely one of the things but in fact it is not just the machine, because when somebody is running a job, part of the input to the machine is the information they need, which is the manufacturing sheet, the labels, pallets, boxes, and so on. They need the material that goes into that machine. They might feed the machine and maybe go for a break. Then when they come back, they realise the machine has run out of something, which will require the services of the engineer to get the machine up and running again. So there is a lot of input to the process, which we need to study to find out what the mathematical time should be, the actual time, and the difference between both and why there is difference. It is an exercise that we have not been able to do. But we will have to know what is going on. Time is probably the big thing here.

(The researcher was then taken to the factory floor.)

APPENDIX – 8

SUMMARY OF FOCUSED INTERVIEW FINDINGS IN RISANE LTD.

FOCUSED INTERVIEW FINDINGS – RISANE LTD.

Extended BSC Perspective	**Question 1 What does your company think about BSC perspective? Did you consider BSC perspective in the mission and vision statements**	**Question 2 What are the KPIs you have considered and performance targets set in performance measurement of the BSC perspective?**	**Question 3 What are the factors affecting BSC perspective?**
Customer Perspective	***Managing Director (Operations and Sales)***		
	❑ The customers are everything in the company's business model ❑ The company considers every thing as a customer service function ❑ "We delight our customers" reflects the customer perspective in the vision statement ❑ Business objective is to serve the customers and have fun	❑ Number of happy customers ❑ Complaints, quality failures, returns ❑ Delivery performance and delays	❑ Simplicity of business ❑ Hassle free quick communication and response ❑ Range of innovative products for customer needs ❑ Product quality, delivery performance and flexibility
Financial Perspective	***Financial Controller***		
	❑ Risane Ltd. was founded with limited finance ❑ The company's long term strategy is to grow the financial position ❑ The company spends more time and capital on innovation of new products to new markets ❑ "Keep Risane Ltd. ahead of the competition" reflects the financial perspective in this vision statement	❑ Standard profitability measures (gross margin, pre-tax profits, turnover) ❑ Planned to measure variances (material price, labour cost, material usage, labour hours)	❑ Sales and growth of sales ❑ New products (the company earns higher profit margins from new products than old products due to low competition.) ❑ Fixed costs and running costs ❑ Material prices ❑ Manufacturing performance
	Managing Director (Operations and Sales)		
	❑ Risane Ltd. does not have stake holders ❑ Managers closely look after financial situation ❑ Financial performance is stable and Managing Directors are happy to invest	❑ Gross margin ❑ Net profit margin ❑ Sales targets	❑ Happy customer ❑ Competitors ❑ After sales service ❑ Labour and material cost ❑ Manufacturing performance and operation speed ❑ Wastes

Extended BSC Perspective	**Question 1** **What does your company think about BSC perspective? Did you consider BSC perspective in the mission and vision statements**	**Question 2** **What are the KPIs you have considered and performance targets set in performance measurement of the BSC perspective?**	**Question 3** **What are the factors affecting BSC perspective?**
Internal Business Processes Perspective	***Production Manager***		
	❑ Internal business processes are not very efficient and effective ❑ Processes are machine and labour intensive ❑ Developing new machinery to improve process efficiency and reduce scrap ❑ “Continuously improve” reflects the internal business processes perspective in vision statement	❑ Number of products per hour ❑ Number of products from square metre ❑ Weight of scrap ❑ Machine breakdowns	❑ Quality of material ❑ Machine breakdowns ❑ Manpower, training, understanding and communication ❑ Culture ❑ Financial status ❑ Floor space
	Manufacturing Manager		
	❑ Processes are not running at maximum efficiency ❑ Need to implement procedures and policies; company is in the process of introducing new procedures ❑ Internal business processes perspective is mentioned in vision statement, but not in practice	❑ Machine operator time vs. engineering time ❑ Machine lost hours vs. breakdowns ❑ Breakdown and preventive maintenance analysis ❑ Machine availability and stoppage analysis ❑ Operator checks	❑ Individual performance ❑ Communication, training and guidance ❑ Visual control ❑ Under performing machines and individuals ❑ Resources ❑ Supplier issues ❑ Quality of raw materials ❑ New product introduction
Employee Perspective	***Production Manager***		
	❑ Employees are highly valued ❑ Employees need push and more training ❑ Work as a team ❑ “Continuously improve our individual” reflects the employee perspective in vision statement	❑ Number of products per hour ❑ Wastes ❑ Operator idle time	❑ Machine downtimes ❑ Availability of materials ❑ Quality of materials ❑ Floor space ❑ Understanding, communication, culture and literacy
	Hygiene and Quality Controller/Training Manager		
	❑ Employees performance is average ❑ Need more training about products and operating machines ❑ Should improve team work ❑ “Continuously improve our individual and combined performances so that, as a team, working smarter” reflects the employee perspective in vision statement	❑ Customer complaints ❑ Number of defects ❑ Number of products produced over specific time period ❑ Employee turnover rate ❑ Full time and part time employees	❑ Lack of training ❑ Lack of understanding of customer needs ❑ On time delivery to the customers ❑ Lack of communication

Extended BSC Perspective	**Question 1** **What does your company think about BSC perspective? Did you consider BSC perspective in the mission and vision statements**	**Question 2** **What are the KPIs you have considered and performance targets set in performance measurement of the BSC perspective?**	**Question 3** **What are the factors affecting BSC perspective?**
Supplier Perspective	***Managing Director (Operations and Sales)***		
	❑ Company has fairly hard view about suppliers ❑ Suppliers must perform well to satisfy 'Rasine Ltd.' ❑ Not considered in vision statement	❑ Number of suppliers ❑ Delivery of products ❑ Supplier performance questionnaire ❑ Supplier monitoring system	❑ Quality ❑ Good management ❑ Appropriate priorities of supplier
Innovation and Growth Perspective	***Manufacturing Manager***		
	❑ The company need to take the blindfold off and think smarter ❑ "Continuously improve" reflects the innovation and growth perspective in vision statement	❑ Visual control	❑ Lack of capacity of machines ❑ Time to develop new products, processes and machinery ❑ Floor space
	Managing Director (Innovations)		
	❑ Fundamental, constantly innovate ❑ Visionary – selecting the correct ideas ❑ Company has capabilities to convert ideas to reality ❑ Company has capable employees	❑ Happy customers (customer survey and feedback) ❑ Capital spend on innovation	❑ Time ❑ Resources (people/associates) ❑ Financial issues
External Socio-Environmental Groups Perspective	***Hygiene and Quality Controller/Training Manager***		
	❑ "In a safe" reflects the external socio-environmental groups perspective in vision statement	❑ Number of accidents or incidents ❑ Weight of scrap from machines ❑ Number of raw material wastes	❑ Lack of recycling ❑ Employee training, understanding and knowledge ❑ Lack of team briefing and communication
	Managing Director (Operations and Sales)		
	❑ External socio-environmental groups perspective taken extremely seriously ❑ Links with Polymer Cluster of University of Wolverhampton and Advantage West Midlands ❑ Cleaner operation and no emissions, solvents or by-products ❑ The company has an environmental policy	❑ Waste ❑ Noise levels	❑ Manufacturing processes and machinery ❑ Flow of production

APPENDIX – 9

PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS AND PRESENTATIONS

JOURNAL PUBLICATIONS

1 Sandanayake, Y. G., Oduoza, C. F. and Proverbs, D. G. (2008), **"Systematic Modelling and Simulation Approach for JIT Performance Optimization"**, *Robotics and Computer Integrated Manufacturing*, **24**, pp. 735 – 743.

2 Sandanayake, Y. G. and Oduoza, C. F. (2007), **"Design of a Performance Measurement System for Just-in-Time Production: A Methodological Framework"**, *International Journal of Manufacturing Technology and Management*, **10** (2/3), pp. 276 – 293.

3 Sandanayake, Y. G. and Oduoza, C. F., **"Dynamic Simulation for Performance Optimization in Just-in-Time Enabled Manufacturing Process"**, *International Journal of Advanced Manufacturing Technology* (In print, Electronic publication is available in http://dx.doi.org/10.1007/s00170-008-1604-4).

4 Sandanayake, Y. G. and Oduoza, C. F., **"JIT Performance Measurement in a Small and Medium Non-Automotive Industry Environment"**, *CONRADI Research Review*, (In print).

CONFERENCE PUBLICATIONS

1 Sandanayake, Y. G. and Oduoza, C. F. (2008), **"Performance Measurement Model for Just-in-Time Manufacturing Plant"**, *The 18th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)*, 30th June – 02nd July 2008 at Skovde, Sweeden, pp. 870 – 867.

2 Sandanayake Y.G., Oduoza C.F. and Proverbs D.G. (2007), **"Simulation, Modelling and Analysis of Key JIT Drivers in an Automotive Component Manufacturing Environment"**, *The 17th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)*, 18-20th June 2007 at Philadelphia, USA, pp. 91 - 98.

3 Sandanayake Y.G. and Oduoza C.F. (2005**), "Development of a Performance Measurement System in JIT Enabled Manufacturing Environments: A Preliminary Study"**, *The 15th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)*, 18-20th July 2005 at Bilbao, Spain, pp. 778 – 785.

CONFERENCE AND SEMINAR PRESENTATIONS

1 Sandanayake Y. G., **"Development of a Model for Performance Measurement in Just-in-Time Enabled Manufacturing Environments",** Presented in *the Building Economics and Management Research Unit (BEMRU) Monthly Research Colloquium*, on 04th October 2008 at the University of Moratuwa, Sri Lanka.

2 Sandanayake Y. G., **"Simulation, Modelling and Analysis of Key JIT Drivers in an Automotive Component Manufacturing Environment"**, Presented in *the 17th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)* on 18-20th June 2007 at Philadelphia, USA.

3 Sandanayake Y.G. (2007), **"Development of a Performance Measurement System for JIT Enabled Manufacturing Environments"**, Presented in *Built Environment & Engineering Research Seminar series (BEERS-6)* on 18th April 2007 at University of Wolverhampton, UK.

4 Sandanayake Y. G.**, "Development of a Performance Measurement System in JIT Enabled Manufacturing Environments: A Preliminary Study"**, Presented in *the 15th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)* on 18-20th July 2005 at Bilbao, Spain.

5 Sandanayake Y.G. (2005), poster presentation entitled **"multidimensional performance measurement system for just-in-time enabled manufacturing environments"**, organised by the RIATec, University of Wolverhampton.

6 Sandanayake Y. G. and Oduoza C. F., **"Performance Measurement Model for Small and Medium Non Automotive Manufacturing Environment"**, Full paper submitted to *the 19th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)*, (Accepted for publication).