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**AN INTEGRATED MANUFACTURING STRATEGY FOR
IMPLEMENTATION OF LEAN MANUFACTURING, SIX SIGMA AND
CAD/CAM METHODOLOGIES IN A SMALL MEDIUM MANUFACTURING
ENVIRONMENT (SMME)**

Adedeji Olasunkanmi Esan

MPhil

2010

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Adedeji Olanukanmi Esan

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Keywords: Manufacturing Strategy, Lean Manufacture, Just-In-Time, CAD/CAM, Six Sigma, Continuous Improvement, Manufacturing Resource Planning, Change Management, Small Medium Manufacturing Environment, and Tooling Reclamation

ABSTRACT

The world is changing rapidly for the engineering community. Sustainability in every sense has become the watchword—in terms of product manufacture and performance, and responding to global market and environmental pressures. A well thought-out manufacturing strategy can help organisations make choices that support its overall business objectives, respond to new opportunities and challenges as they arise. However, manufacturing strategy configuration and deployment in SMME's is a neglected field in manufacturing strategy literatures. More importantly, the application of lean manufacturing, Six Sigma and CIM strategies are said to be more applicable to batch production environments and large manufacturing organisations but not to SMMEs that operates a job shop type operating characteristics and with limited resource availability. With recognition that most of these methodologies were originally conceptualised and implemented in large manufacturing environments with batch and flow type manufacturing architecture, the need to develop solutions specific to SMME's with job shop type operating characteristics (tooling reclamation industry in particular) is imperative.

The fundamental essence of this research is the development of an integrated manufacturing strategy which is based on Lean-Six Sigma-MRP-CADCAM methodologies at the case company. The framework for deploying this strategy is based on inputs from a business environment analysis, a lean strategic planning module (based on production planning and manufacturing/product cost structure analysis) and a lean resource planning interface that is predicated on value stream analysis and simulation models. The material and information flows of the case company manufacturing systems were studied. The approach taken emphasises the well known value engineering concepts of multiple-stage manufacturing system accumulating costs/time between individual stages as well as by transfer/material handling and work-in-process. The study shows that maximisation of capacity and resource utilisation, queue less work flow and flexible labour policies that support the case company's manufacturing system offer potential for reform which can substantially enhance customer service, product quality and overall improvement in investment returns.

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GLOSSARY

CAD: Computer Aided Design
CAM: Computer Aided Manufacture
C&E: Cause and Effects
CIM: Computer Integrated Manufacturing
CNC: Computer Numeric Control
CPK: Capability Index
DMAIC: Define Measure Analysis Improve Control
FMEA: Failure Mode Effect Analysis
FTQ: First Time Quality
HT: Heat Treatment
IDR: Internal Defect Rates
JIT: Just-In-Time
KPI: Key Performance Indicators
MRP: Manufacturing Resource Planning
MPS: Master Production Schedule
OE: Operational Effectiveness
PESTLE: Political Economic Social Technology Legal Environment
PPM: Parts Per Million
R&R: Repeatability and Reproducibility
SIPOC: Supplier Input Process Output Customer
SMME: Small Medium Manufacturing Environment
SWOT: Strength Weakness Opportunity Treats
VSM: Value Stream Mapping
GEMBA: Lean audit
MAS: Manufacturing Advisory Services
WIP: work-in-process
TT: Takt Time or demand rates by customers
ATT: Actual Takt Time
PCE: Process Cycle Efficiency
ROT: the rotary product line
STD: the standard product line
KPIV: Key Process Inputs Variables
KPOV: Key Process Output Variables
LCL: Lower Control Limit
UCL: Upper Control Limit
RPN: Risk Priority Number

LIST OF PUBLICATIONS

Refereed Conference Publications

1. Esan A., Khan M.K, and Naylor C, “The Impact of Manufacturing Systems Optimisation on Sustainable Economic Development: Case study of a SMME”, *International Conference on Industry Growth, Investment and Competitiveness in Africa (IGICA)*, International Conference Centre, Abuja, Nigeria, 2009
2. Esan A, Khan M.K, Naylor C, QI H, “An Integrated approach to Lean Systems and CAD/CAM methodology deployment in a SMME”, *24th ISPE International Conference on CAD/CAM, ROBOTICS & Factories of the Future*, Koriyama, Japan, 2008
3. Esan A, Khan M.K, Naylor C, QI H, “Implementation of Lean manufacturing in a SMME: Case Study—Machine Tools”, *23rd ISPE International Conference on CAD/CAM, ROBOTICS & Factories of the Future*, Bogotá, D.C., Colombia, 2007

Journal Publications

1. Esan A, Khan M.K, “Application of a Lean Check matrix to a SMME’s Manufacturing System”, *International Journal of Lean Six Sigma*, (Under Review)
2. Esan A, Khan M.K, “Integrated manufacturing strategy for deployment of a CAD/CAM methodology in a SMME” *Journal of Manufacturing Technology* (Under Review)

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The world is changing rapidly for the engineering community. Sustainability in every sense has become the watchword—in terms of product manufacture and performance, and responding to global market and environmental pressures. The ability to adapt and be sustainable in a rapidly changing and complex environment has thus become an increasingly important aspect of competitiveness. A well thought-out manufacturing strategy can help an organisation make choices that support its overall business objectives. It can also determine whether an organisation is able to respond to new opportunities and challenges as they arise (Viki Sonntag, 2003).

Attaining such level of performance requires an integrated manufacturing strategy. The integrationist perspective of manufacturing strategy is such that it enables a high level of manufacturing capability transformation into useable capabilities to gain competitive advantage within an organisation's business environment whilst constantly striving to improve those capabilities. With the realisation that manufacturing strategy is such an important role in organisations (and Small Medium Manufacturing Environment (SMME) in particular), key effects for deploying an integrated framework for realisation need to be understood. To solve this fundamental problem Ungan, (2006) argues that manufacturing capabilities, such as decisions on cost, quality, delivery and flexibility in the manufacturing system, need to be identified as well as the creation of an innovative organisational culture.

Innovativeness refers to a climate that supports new ideas concerning work methods. Some studies claimed that organisations with innovative cultures are successful in implementing change programmes and achieving organisational learning (Zeitz et al., 1997). Additionally, for effective strategic deployment of the chosen strategy, a deployment champion (e.g. project manager, six sigma black belts) is a pre-requisite. Meyer, (2000) describes an idea champion as a management-level person who recognises the usefulness of an idea to the organisation and lends authority and resources to innovation throughout its development and implementation. Studies in Advanced Manufacturing Technology implementation found that appointment of a champion ensures success (Hottenstein et al., 1997; Sohal, 1996).

This chapter describes the proposal for realising an integrated manufacturing strategy that employ a holistic set of methodologies such as strategic planning, Lean Manufacturing, Six Sigma process improvement and Computer Integrated manufacturing (CIM) in a SMME. The CIM deployment strategy uses an end-to-end Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) system, to develop a system with extensive and completely integrated suite of tools for concurrent engineering, product life cycle engineering, Product Data Management (PDM), collaboration, and manufacturing planning with the objective of creating a more responsive and interactive manufacturing environment. The research problem and its scope are defined. The objectives of the research are highlighted and a systematic approach is proposed for achieving the objectives. The different sections of the proposal are elaborated in the following sections.

1.2 Research Problem

Manufacturing strategy configuration and deployment in SMME's is a neglected field in manufacturing strategy literature. More importantly, the application of Lean Manufacturing, Six Sigma and CIM strategies are said to be more applicable to batch production environments and large manufacturing organisations but not to SMMEs whose manufacturing system operates a job shop type operating characteristics.

With the recognition that most of these methodologies were originally conceptualised and established within flow type manufacturing architectures, the need to develop solutions specific to SMME's with job shop type operating characteristics is imperative. Hence, the research question is to determine if the integrated manufacturing strategy perspective of Lean—Six Sigma—CIM is applicable to SMME's with job shop type manufacturing systems.

1.3 Research Objective

There are four main objectives for this research. Each of the four objectives then contains sub-objectives/tasks. The research objectives were derived through condensation of a Knowledge Transfer Partnership programme outline into elements of manufacturing strategy, lean manufacturing, Six Sigma and CIM protocols which are in line with the research question. The following highlight gives a concise prologue to these objectives.

- a. The first objective is to identify the current and future market potential of the case company so that the current manufacturing strategy and operations can be devised for expected growth: this will necessitate identifying the current and future trends in the business operations of the case company, through the study

of home and overseas markets. The study will also involve identifying key competitors and key markets and modes of competition, identifying the key manufacturing projects (methodologies, systems, technologies) that will need to be implemented, including all the resources and training needed to achieve the business objectives.

- b. Secondly to design and create an integrated manufacturing knowledge base (scheduling/ capacity planning) system for the case company manufacturing system. This system is necessary because the very nature of the company's services requires them to be a people intensive business, cost of sales are 56% and the need therefore to improve operational efficiency is critical. Any improvement in reducing the cost of production through better production analysis will significantly improve NTR's profitability. By a better understanding and thereby improvements of the true production costs, it is anticipated that a 10% saving can be made in machining costs in addition to an overall in the pricing structure resulting in a further increase in the Earning Before Interest and Taxes (EBIT) or the operating income.

The creation of the knowledge base system that will contain process routes and costing for each of the product range and will involve initially developing the key conceptual model for NTR's requirements, identifying crucial modules such as: capacity planning, scheduling, costing, process routings, and forecasting which will be followed by the implementation of the knowledge database in offices and the shop floor, including training for relevant staff and recording feedback on the knowledge base system's performance and making necessary improvements.

3. To implement a culture of Just In Time through the use of a team based approach with emphasis on key elements of Lean Manufacturing and Six Sigma process improvement methodologies. By better utilising people through the education on JIT principles, operators will be able to directly contribute to production efficiency and performance. This should translate to improved output against targeted performance, positively contributing to the business profitability. A realistic expectation in this project outcome would be an increase in Gross Profit (GP) of between 5-10%.

Additionally, the JIT implementation should enable better utilisation of existing staff to undertake a wider range of tasks through creation of multi-functional team environment whilst striving for lower staff turnover. In return staff can be better rewarded, as well as being buffered from the ups and downs during an economic cycle. This will save on company recruitment, training and development costs whilst improving staff retention. It will also enable the business to better plan and utilise resource according to production need through the month and year with an estimated net profit contribution of about 5-10% within the first 18 months of staff becoming multi-skilled.

4. The fourth objective is to design, develop and implement a CIM environment at the case company that enable it to migrate from manual machining to an automated system. The research will strive to first identify whether the present manufacturing system requires a more advanced and computer integrated one through a techno-economic study. Then a study of the Computer Numeric Controlled (CNC) machines (types of machining controller languages) presently

existing and their suitability for CAD/CAM integration will be conducted and a review of the CAD software being used in the office system carried. Finally an analysis of whether the present CAD and CAM systems can be integrated or whether new CAD/CAM system software needs to be implemented will be carried with the aim of implementing a CNC/CAD/CAM or CIM environment in the case company.

1.4 Conceptual Approach for the Proposed Research

The case study approach has gained considerable recognition over the years and has been used by many researchers. Some examples include a study of the process of using quality function deployment in manufacturing strategic planning (Crowe, 1996); a study of Automated JIT based materials management for lot manufacture (Jina, 1996); a study of manufacturing strategy formation process in small and medium-sized enterprise (Barnes, 2002). The case study method has also been adopted with this study, to gain more in-depth understanding of the strategic intent of the company and the way in which the implementation process of the integrated manufacturing strategic framework is managed.

According to Meredith (1998), gathering data on all the decisions and actions which make up a company's manufacturing strategy in sufficient detail to understand the process by which strategy forms, seems likely to require access to the company. As manufacturing strategy is an integral part of business strategy, an appropriate methodology must lead to an understanding of the strategic processes at work throughout the company as well as within its manufacturing operations. Bryman (1998) argues that investigating manufacturing strategy deployment also requires that the

researcher achieves an understanding of organisational actions in the context in which they occur. **Figure 1.1** shows the conceptual approach to the proposed research.

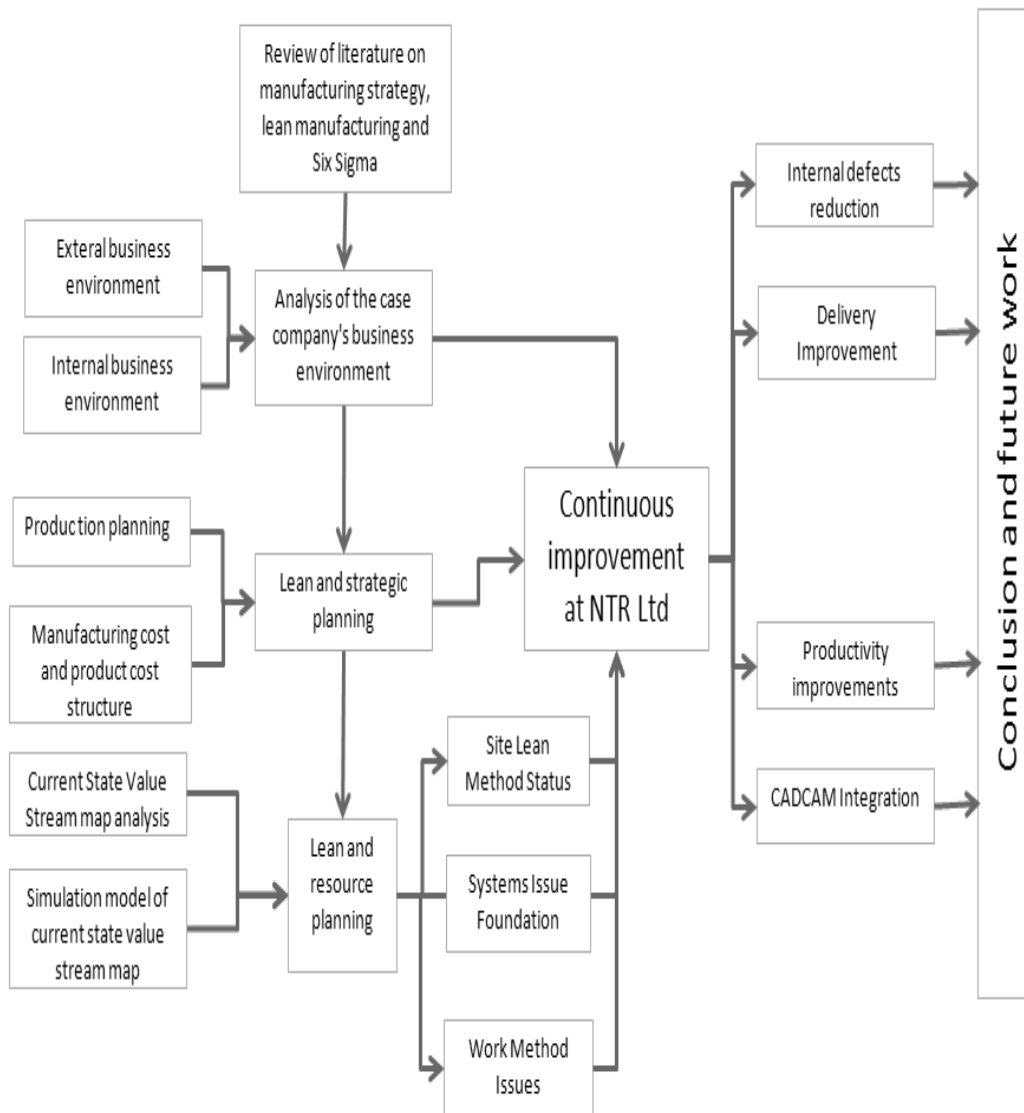


Figure 1.1: Conceptual approach to the proposed research

From **Figure 1.1** it can be seen that the central part of the approach is the development of a continuous improvement framework at the case company based on inputs from a business environment analysis, a lean strategic planning module (based on production planning and manufacturing cost and product cost structural analysis) and a lean resource planning interface that is predicated on value stream analysis and simulation models. Furthermore, the information gathering process, design, development and

implementation of the integrated manufacturing strategic framework for this research project involved active leadership at the design, and deployment phase by a Knowledge Transfer Partnership associate (KTPA).

Knowledge Transfer Partnerships (KTP) is Europe's leading programme helping businesses to improve their competitiveness and productivity through the better use of knowledge, technology and skills that reside within the UK knowledge base. KTP is funded by 17 funding organisations. Each partnership employs one or more high calibre Associates (recently qualified university graduates) to work on a project (often with multiple objectives), which is core to the strategic development of the business. This particular KTP programme (**KTP 1257**) is co-sponsored by the Department of Trades and Industry (DTI), and the Case Company—NTR Ltd with knowledge support provided by the University of Bradford. **Figure 1.2** shows interaction of all elements of the KTP and the strategic role of the KTPA.

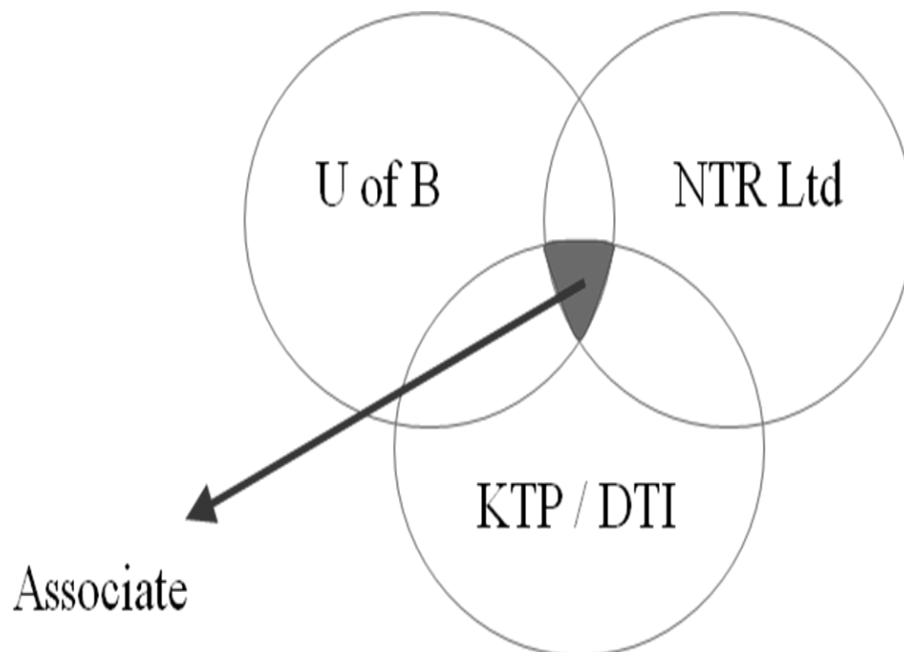


Figure 1.2: Interaction between stakeholders

1.5 Contribution

The research provides an opportunity to have in depth understanding of manufacturing strategy deployment within a Lean Manufacturing, Six Sigma and CAD/CAM implementation framework in SMME and in particular the tooling reclamation industry. From the research problem it is argued that this research provides solutions specific to SMME's with job shop type manufacturing operating characteristics. A point of reckoning in the research is the development and deployment of an integrated golden lean check matrix that allows detailed investigation and optimisation of key components of a manufacturing system. Additionally, a framework for incorporating an integrated manufacturing strategy to SMME's is also proposed.

1.6 Structure of Thesis

The thesis consists of eight chapters and seventeen appendices distributed over four chapters. Chapter 1 covers the introduction to the research, description of the research problem, research objectives, and conceptual approach for the research problem and contribution to knowledge base. The research mainly focuses on the application of lean manufacturing, Six Sigma, and CAD/CAM within a continuous improvement framework to deliver an integrated manufacturing strategy in a SMME. In Chapter 2 the emphasis is to understand the scope of manufacturing strategy in Lean Manufacturing and Six Sigma applications in Small Medium Manufacturing Environment (SMME). The Chapter describes the scope of SMME, manufacturing strategy, Lean Manufacturing, change management and Six Sigma.

Chapter 3 covers an in-depth understanding of the case company and its business environment. The business case investigates the company's external and internal

business environment. This chapter discusses the need for lean manufacturing as a manufacturing strategy in a Small Medium Manufacturing Environment. The business environment is critically evaluated through an industry specific and process specific approach. Using a PESTLE analysis framework and Porter's five forces the chapter significantly examines the industry the case company currently operates. A Strength, Weakness, Threats and Opportunity (SWOT) is utilised in understanding the case company's manufacturing system (process specific). Conclusively, the need for key performance indicators (KPIs) as a progress indicator for Lean Manufacturing strategy deployment is articulated, with relevance indicators developed.

In Chapter 4, Lean Manufacturing as a strategic planning that aids in the development of competitive advantage through streamlining product streams to reflect market needs, having adequate manufacturing plans to cope with market dynamics and competences to develop varying offering/pricing strategies that takes 'care' of the competition is discussed. The chapter also considers the application of the Product Family Matrix (PFM) and its functionality in breaking down products offered by the case company into manageable product families (or Value Streams). Chapter 5 discusses lean manufacture application in resource planning at the case company. The chapter examines the use of mapping, audit and analysis in establishing priorities for lean resource planning implementation. Furthermore, the chapter uses a value stream mapping technique and simulation to qualify the value added, non-value added elements, machine and operator utilisation, and input and output of the case company's manufacturing system after a lean assessment that studied the flow, organisation, logistics, metrics, and process control of NTR Ltd manufacturing system.

Chapter 6 describes the application of a combination of DMAIC & Kaizen events in the effort to deploy Lean Manufacturing as a manufacturing strategy at the case company. The cases presented are illustrated using a project management framework that supports six sigma process improvement methodology—DMAIC and application of components of the golden lean check matrix (Esan et al 2007) in particular work method issues. The chapter focus on creating a future state by exploiting continuous improvement philosophy of lean implementation from the base line strategic goals—Chapter 4) and current state value stream analysis in Chapter 5.

Chapter 7 is a continuation of application of the DMAIC and Kaizen process improvement methodologies from Chapter 6. The chapter investigates and presents solutions to systems issue foundation and work methods issues at detailed in the golden lean check matrix. Furthermore, the chapter uses a case by case (in continuation of the case study approach used in Chapter 6) approach to present some of the solutions to systems and work method issues at NTR Ltd. Chapter 8, the final chapter of the thesis, covers the conclusions and recommendations for the future work of the four primary objectives.

1.7 Conclusion

This chapter has briefly given the background to the research problem of implementation of manufacturing strategy in SMMEs. The primary objectives of this research have been described. A conceptual approach for solving the research problem has also been introduced. The approach mainly converges on the development of a continuous improvement framework from input such as the business environment of the case company, lean strategic planning and lean resource planning analysis. Finally, the chapter discusses the structure and organisation of the thesis.

CHAPTER TWO

LITERATURE REVIEW: LEAN SIX SIGMA MANUFACTURING STRATEGY

2.1 Introduction

In recent years, there has been an increasing application of an integrated manufacturing strategy for Lean Manufacturing and Six Sigma methodology policy deployment in manufacturing environments. This emphasis is to understand the scope of manufacturing strategy in Lean Manufacturing and Six Sigma applications in Small Medium Manufacturing Environment (SMME). This chapter describes the scope of SMME, manufacturing strategy, lean manufacturing, change management and Six Sigma.

2.2 Trend in Small Medium Manufacturing Environment (SMME)

The role of small companies is crucial. According to the Department of Trades and Industry (DTI), 95% of businesses in all industries in the UK are SMEs. There were an estimated 4.3 million businesses in the UK at the start of 2005. The vast majority of these (99%) were small businesses (with fewer than 50 employees) and they provided 47% of the UK private sector employment and 36% of turnover. 65% of Europe's and 45% of US Gross Domestic Product (GDP) come from small to medium-sized enterprises (Taylor MP, 2007). Earlier study has it that 99% of European Union (ENSI, 1994) industries have fewer than 500 employees but account for 50% of manufacturing sales and 67% of services. Furthermore, Small and Medium Manufacturing Enterprises (SMMEs) make a vital contribution to the overall health of most developed economies and will definitely form the basis for improving the productivity of business within developing economies.

The success of manufacturing is crucial to any economic prosperity, now and in the future. Manufacturing is a sixth of the UK economy. It's responsible for around two-thirds of all UK exports, generates around 3.5 million jobs directly - and millions more through their supply chain and related services and also responsible for around 75% of business research & development. In the Small Business Service Annual Survey of Small Businesses: UK 2005 report by the Institute for Employment Studies (IES), Production industries which encapsulate mining and quarrying; manufacturing; and electricity, gas and water supply accounted for 11% of all SMEs making it the third largest contributor. In order to sustain and consolidate this position, an important strategic theme for SMMEs is to encourage a more dynamic business process (founded on an integrated manufacturing strategy) and to build an 'enterprise culture', which will boost productivity and economic growth. It is envisaged that such a vision will encourage economic efficiency and raise productivity levels in any economy. Building the capability for business growth among SMMEs through explicit development of a manufacturing strategy is important, not just because of the direct benefits of SMME potential expansion, but also on account of the stimulus which a more dynamic SMME sector will provide for competition and innovation across any economy as a whole.

2.3 Manufacturing Strategy

Manufacturing strategy has been defined by leading academics as the total pattern of decisions and actions which set the role, objectives and activities of manufacturing so that they contribute to and support the organisation's business strategy (Slack et al., 1998, p. 4).

2.3.1 The role of Manufacturing Strategy

Manufacturing strategy is concerned with developing policies with regard to location, capacity, technology, suppliers and the supply chain and people and organisational aspects. Hill (1987) suggested structural and infrastructural issues as two pillars of manufacturing strategy. Structural issues set the process and technology for operations whereas infrastructure provides it with long-term competitive edge by continuously improving upon human resource policies, quality systems, organisational culture and information technology. Infrastructural issues are long-term goals and supports to the structural issues. Infrastructural issues are developed through persistent day-to-day use and with commitment of top management and teamwork at all levels. These are intangible and developed over a certain period of time with consistent use. Effective use of infrastructural issues with structural issues leads a firm towards manufacturing excellence (Hill, 1987).

In developing appropriate manufacturing strategy for a manufacturing system, it is imperative to integrate the manufacturing strategy with the business objectives. Corporate objectives lead to marketing strategy. Marketing identifies appropriate markets, product mix, services and the degree to which an organisation needs to customise and innovate hence enabling the integration of a manufacturing strategy that focuses on critical dimensions typically cost, lead-time, quality, reliability, capacity, production control, product features, design capability, human resources, suppliers and distribution. This concept of “strategic fit” is central to manufacturing strategy theory (Kim and Lee, 1993; Swink and Hegarty, 1998) and has been elaborated by a number of researchers (Skinner, 1969; Hayes and Wheelwright, 1984; Gupta and Lonial, 1998). However, as Hayes and Pisano (1996) have observed, something more than the right match of manufacturing system to management objectives appears to govern success;

otherwise, firms with identical technologies and similar business goals should perform more-or-less equally.

A shortcoming of strategic fit models deserves explanation (Sonntag, 2003). Despite the stress put on the need for consistency between manufacturing strategy and business objectives, in many firms there appears to be a want of it. This lack of alignment is a common problem that has received significant attention in the literature (Porter, 1996; Millen and Sohal, 1998; Swink and Hegarty, 1998; Tracey et al., 1999). Much of this failure has been pinned on the actual practices of firms. Frequently, actual practice differs from strategic intention (Sonntag, 2003). Often there appears to be two manufacturing strategies at work – the one that identifies the plan and the one that has been implemented (Hayes and Wheelwright, 1984; Gupta and Lonial, 1998; Platts et al., 1998). Many firms do not have mechanisms, that is, strategy formulation and implementation processes, to bring about the desired alignment. Operational decisions are carried out by reference to the firm's "way of doing things", rules built on past experience, which may not be suited to world class and competitive performance.

In a refined view of strategic fit, contingency theory maintains that firm performance is the outcome of fit among several factors: environment, organisational structure, people, technology, strategy, and culture (Kim and Lee, 1993). The resource-based view process models highlight the critical role capabilities play in firms' adaptation to changes in their competitive environments (Wernerfelt, 1984). The task of management is to institute a manufacturing system which matches the company's competitive priorities, capabilities and core competences. Implicit in the theory is that there are trade-offs to be made, and further, that these trade-offs are particular to the organisation, reflecting the specifics of the company's competitive situation and its capabilities.

Summarily, firms cannot expect to optimise performance in all directions. They must necessarily choose how to compete. To this end, the many content models of manufacturing strategy offer decision-making rules.

Dynamic capabilities are the subset of capabilities (decision-making opportunities) by which the firm responds to changing market conditions. Montgomery (1995, p. 263) identifies dynamic capabilities as those that renew a firm's distinctive competencies by generating new routines and resources. The key success factor in dynamic capabilities-based strategies is identifying and cultivating firm-specific capabilities that would be difficult to replicate (Teece et al., 1997) and valuable and non-substitutable from the point of view of the customer (St John et al., 2001). In the manufacturing strategy process, as new opportunities develop, a company exploits those that are suited to its specific capabilities. In turn, these initiatives stimulate organisation's investment in building capabilities that require continuous adaptation and improvement of the organisation's skill base (Hayes and Pisano 1996). For example, make-buy decisions should include consideration of the potential for organisational learning.

To assume that all dynamic capabilities are equally relevant in tomorrow's markets is debatable (Hayes and Pisano 1996). As Teece et al. (1997, p. 281) have remarked, deciding, under significant uncertainty about future states of the world, which long-term paths to commit to and when to change paths is the central strategic problem confronting the organisations. Empirical studies have shown that firms which organise production in a way that reinforces fit with their environments are more successful than those that do not. It is reasonable to conclude that the function of manufacturing strategy should be to inform daily operational decisions and to establish a process for making good decisions (Platts et al., 1998).

2.3.2 Manufacturing Strategy Formation in SMME

The consideration of strategy formation is a neglected area within both the SMME and the manufacturing strategy literatures. Both are characterised by strong prescriptive traditions within the top-down strategic planning paradigm, and are limited in their quantity and scope. Yet, there appears to have been little empirical work undertaken to test whether this approach is reflected in practice. Research by Barnes (2000) concludes that in SMMEs, realised manufacturing strategy seems more likely to be formed through a bottom-up emergent process than being derived, top-down, from business strategy. It has, however, proved impossible to find reports of other studies of this topic (Barnes 2002).

Most of the literature is predicated on the independent ownership of SMMEs. Where this is not the case, one might expect there to be some impact on manufacturing from the parent company. Voss et al. (1998) lend support to this when they found a greater likelihood of manufacturing best practice being found in small firms when they are subsidiaries of larger companies. However, as Goold and Campbell (1987) show, a parent company's relationship with its subsidiaries can take different forms, with in some cases, the parent not involving itself in the operating detail of its subsidiaries. Overall though, manufacturing strategy formation in the SMME sector is a little researched topic and is, in consequence, poorly understood. The following Strength, Weakness, Opportunity and Threat (SWOT) analysis in **Table 2.1** on manufacturing strategy formation in SMMEs (Dangayach, 2001) needs to be noted.

Strengths	Weaknesses
<p>Flexibility: SMMEs can easily absorb new technology, new design, and new processes. The cost of such change is minimal.</p> <p>Quick decision making: Due to minimal layers in management, decision making could be faster.</p> <p>Favourable capital output ratio: By properly utilizing the local reserves, SMMEs can keep low level of capital investment per unit of output.</p> <p>Cooperation from employees: Managers can keep personal contact with employees to ensure full cooperation from them.</p>	<p>Lack of technical superiority: SMMEs are somewhat less oriented to advance their technological capabilities due to lack of funds.</p> <p>Lack of infrastructural facilities: In a developing economy such as India, SMMEs are generally set up at remote places to take advantage of government subsidies and to satisfy local demands and so face problems of infrastructure such as power and transport.</p> <p>Lack of financial strength: SMMEs depend largely on the banks for finance. They do not have good corporate/brand image. Without this, they cannot get money from the equity market.</p>
Opportunities	Threats
<p>SMMEs can act as an excellent ancillary unit for a large company.</p> <p>Due to globalization, SMMEs can interact and have partnership with global companies.</p>	<p>Acquisition and mergers of large companies may affect their business.</p> <p>Government policies, and open competition may threaten their very existence.</p>

Table 2.1: SWOT Analysis of Manufacturing Strategy formulation in SMME

According to Barnes, (2002) the most important message for practitioners and others concerned with the successful management of SMMEs seems to be that it seems unlikely that manufacturing strategy can be entirely determined through a top-down planning process linked to a business planning regime. Incrementalism, culture, politics, leadership and powerful individuals may all play a role. The important thing is to be able to understand these influences on manufacturing strategy formation. For those wanting manufacturing strategy to be more deliberate, it seems that the greater use of business planning may be beneficial, even if this does not explicitly encompass manufacturing. Similarly the identification and agreement of an explicit set of objectives for manufacturing also seems to increase the likelihood of manufacturing strategy formation being more deliberate. Conversely, a reduction in incrementalism seems likely to be achieved by a reduction in the political behaviour by those concerned with manufacturing operations (Barnes 2002).

2.4 Lean Manufacturing: a Preliminary Review

In the 18th century, industries were dominated by CRAFT manufacturing. Everything was made to order one piece at a time. If one needed a replacement, you had to wait and the new part was always different. In 1794 Eli Whitney patented the cotton gin. The concept of interchangeable parts for manufacturing helped usher in the industrial revolution and planted the seeds for mass production. However, these concepts were largely ignored in the early days of automation. By 1908, Henry Ford perfected the concept of interchangeable parts for auto assembly and, by 1913, developed the idea of a moving assembly line, with workers performing specific tasks. Ford's idea was to make a vehicle that anyone could afford and designed nine different car models off a single Model T chassis. Ford's Rouge plant was a self-contained lean enterprise, but lacked a small lot strategy. The early 1950s found a crisis brewing in Japan. Toyota saw

the benefits of the Ford Rouge plant, but desperately needed a way to build a wide variety of products in low volume. This required more frequent changeovers and smaller lot quantities. The foundation was laid for the Toyota Product System (TPS). Further improvement came when Taiichi Ohno, credited with creating TPS, got the idea for Just-In-Time while visiting a US supermarket and was amazed on how well everything was displayed on the shelf and how quickly items were restocked when purchased.

Furthermore, the interest on Lean Manufacturing is mostly based on empirical evidence that it improves company's competitiveness (Sanchez et. al. 2001), hence making it a strategic goal for manufacturers. These improvements are not just evident by performance indicators but also by physical examination of the work place. Womack et. al (1990) advocates that Lean Manufacturing is "lean" because it uses less of everything compared with mass production—half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products.

In addition, getting products right first time, having proactive strategies for capacity and resource utilisation, economic production, cost reduction, short lead time, built in quality, continuous improvement effort, multi-functional workforce, group technology, and minimising waste are some of the techniques for implementing lean systems. Lean manufacturing, advocates having a flexible balanced manufacturing system that is capable of running a variety of people, products, and machinery. Lean Manufacturing supports organisation's view point of adding value by converting inputs to outputs, but

excessive amounts of stock, complexity and constraints make system's entropic thus minimising these negatives is Lean Manufacturing intent. Without Lean Manufacturing organisation's fail to be competitive in many cases because resources are not directed at core objectives which add value and meet customer needs. **Figure 2.1** shows a typical Lean Manufacturing implementation route that advocates a two way approach to Lean Manufacturing policy deployment: Top-down and bottom-up approach.

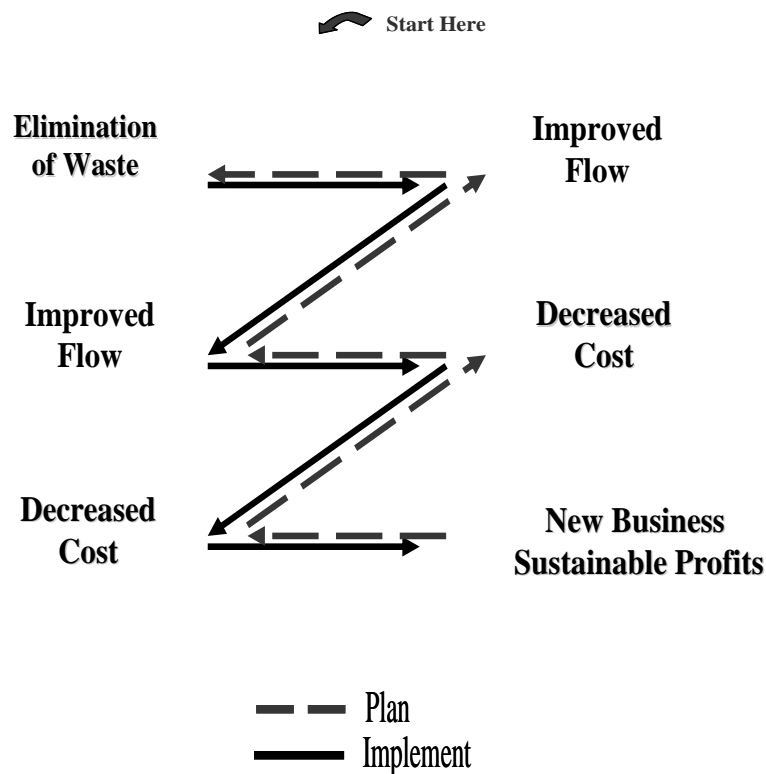


Figure 2.1: Typical Lean Manufacturing implementation guide (Source: A strategic approach to developing a FMA, University of Greenwich, A.Esan, 2005)

2.5 Five Fundamental Concepts of Lean Manufacturing

There are five basic concepts that define lean thinking and enable Lean Manufacturing: specify value, identify the value stream, flow, pull, and perfection (Womack and Jones, 1996).

2.5.1 Specify

In lean manufacturing, the end-use customer solely defines the value of a product. The product must meet the customer's needs at both a specific time and price (Kandebo 1999). The traditional definition of value is the end product that the customer purchases. In the lean model, value is not just the end product, but also the chain of processes that take place in order for an end product/end service to be delivered to the customer. The thousands of mundane and sophisticated things that producers do to deliver a product are generally of little interest to customers. Emiliani (1998) says, to view value through the eyes of the customer requires most companies to undergo difficult and comprehensive reorganisation of people, their mindset and behaviours, and business processes.

2.5.2 Identify

Identifying the value in Lean Manufacturing means to understand all the activities required to produce a specific product, and then to optimise the whole process from the view of the end-use customer (Velocci 2001). Value is identified through value stream mapping. This stream is comprised of each step that has a place in the process and “touches” the end product. Processes can be simple or complex. Processes are driven with customer expectations in mind and designed to be efficient and to eliminate waste. Roles, functions, and responsibilities are designed to make the delivery mechanism more efficient with fewer resources. The viewpoint of the customer is critically important because it helps identify activities that clearly add value, activities that add no value but cannot be avoided, and activities that add no value and can be avoided.

2.5.3 Flow

After value has been specified and value streams have been identified, the next step is to get the activities that add value to flow without interruption (Edwards 1996). Flow in Lean Manufacturing means to process parts continuously, from raw materials to finished goods, one operation, or one piece at a time. Avoid batch and queue, or at least continuously reduce them and the obstacles in their way. Flow is the efficiency of the process that transforms raw material into an end product. This involves analyzing every step in the process that touches and does not touch the end product. The goal is to provide a continuous flow with muda (the Japanese word for “waste”) minimized. Successful change efforts will scrap an existing process and redesign it from scratch.

In creating flow Bicheno (2004) advocates never to delay a value adding step by a non value adding step—try to do such steps in parallel. Batch and queue remains the dominant method of production because the many benefits of flow are counter-intuitive. Flow production methods can be very difficult to implement in mature manufacturing businesses because they challenge all aspects of conventional manufacturing wisdom and practice. It is important to recognise that batch and queue manufacturing is performed solely for the benefit of the producer, whereas flow production responds to the value in products as specified by end-use customers (Emiliani 1998).

2.5.4 Pull

The concept of pull in Lean Manufacturing means to respond to the pull, or demand, of the customer. Lean manufacturers design their operations to respond to the ever-changing requirements of end-use customers, while the operations of batch and queue manufacturers are designed to meet their own local needs (Sohal 1996). Those able to

produce to the pull of end-use customers do not need to manufacture goods according to wasteful and inaccurate forecasts that batch and queue manufacturers must rely upon. The planning for delivery of product to end-use customers is less troublesome, and demand becomes more stable if customers have confidence in knowing that they can get what they want when they want it.

2.5.5 Perfection

If an enterprise can do the first four steps well, then all activities become transparent. This enables people to more easily identify and eliminate waste, and focus on improving activities that create value (Rinehart 1997). The first four steps interact in a "virtuous circle" that enables the pursuit of perfection. The concept of perfection in lean production means that there are endless opportunities for improving the utilisation of all types of assets (Emiliani 1998). The systematic elimination of waste will reduce the costs of operating the extended enterprise and fulfil the end-use customer's desire for maximum value at the lowest price. While perfection will never be achieved, its pursuit is a goal worth striving for because it helps maintain constant vigilance against wasteful practices (Emiliani 1998). The improvements in the identification of value, the analysis and flow of the value stream, and the pulled product/service can be felt and seen at all levels of the organization. It is in this perfect state that the true benefits are recognized and realized. Operational, administrative and strategic improvements are clearly seen and the benefits to the organization are realized with satisfied customers.

2.6 Further Developments in Lean Manufacturing

There exist various but widely same characteristics as stated by various authors on Lean Manufacturing. Warnecke (1995) states that Lean Manufacturing can be best characterised as a system of measures and methods which when taken all together have

the potential to bring about a lean and therefore particularly competitive state, not only in the manufacturing division, but throughout an organisation. Warnecke (1995) also went further to identify four individual aspects of Lean Manufacturing and classified them as:

- product development
- chain of supply
- shop floor management
- after sales service

2.6.1 Product Development

This is a continuous process of product innovation and further development. For productivity to be optimised there is need for the period between product specification and production start-up to be kept as short as possible. This is due to the exponential growth of technology and the extent of competition that is prevalent in the world as at today. Product life cycle is becoming short that a product barely spends up to six months in the market before it becomes obsolete (Warnecke, 1995). Hence, the emphasis on lean product development, that is the ability to eliminate non-value adding process steps in the product development process.

2.6.2 Chain of Supply

In developing a viable lean production system it is imperative for participants in the chain to regularly view the supply chain as part of their own production process. There should be visibility across the supply chain through information sharing, trust and partnership assessment. Suppliers can play an important role in achieving the JIT production concept. By reducing the amount of time required to wait for parts and arrival of materials, manufacturing companies can place an order after they are certain

of the quantity and products desired by their customers. This can greatly reduce “just-in-case” inventories in the system and production lead time. In supporting the existing level of research in the Lean Manufacturing and its appropriateness to supply chain management, McIvor (2001) responded by saying that the concept of lean supply has been used extensively in the auto industries for a long time, especially in Toyota where it is termed TPS (Toyota Production System).

The fundamental principle of lean supply is that the effects of costs associated with less than perfect execution of a sub-process are not limited to the location of execution. In other words, the need for, say, a progress chaser within the customer's organisation, to expedite deliveries traditionally arriving late from the supplier, is to the detriment not only of the customer, but also of the supplier - in fact of all the suppliers, even those whose delivery performance does not warrant expedition (Lamming 1996). Lean supply focuses on two (2) key dimensions—supplier involvement in customer design activities and joint buyer supplier cost reduction.

The issue of design is incorporated into decision sourcing, information exchange, and Research and Development (R&D). The logic behind lean thinking is that companies jointly identify the value stream for each product from concept to consumption and optimise this value stream regardless of traditional functions or corporate boundaries (McIvor 2001). This is thus termed a lean enterprise—lean enterprise is a group of individuals, functions, and legally separated but operationally synchronized companies (Womack et. al 1996). The group's mission is to collectively analyse and focus on a value stream so that it does everything involved in supplying a good or service in a way that provides maximum value to the customer.

However, in order to facilitate this change process, it is necessary to re-define corporate strategy and to identify key processes facing customer such as order fulfilment, new product development and supplier integration (Christopher 2000). The roles of and relationships between suppliers and customers along the value stream are crucial to achieving “leanness” hence the importance of lean supply (McIvor 2001). The partnership must work on the basic premise that only what is consumed is pulled and nothing more. The supplier then replaces what is consumed and nothing more. In this way, inventories are maintained at their minimum for both supplier and customer. Though leadership and initiative are necessary parts of continuous improvement, preconceived, intransigent ideas of who should play such roles are not productive in the long term in a supply relationship.

2.6.3 Shop Floor Management

The characteristics and effects of Lean Manufacturing can best be studied in the factory itself. In a lean manufacturing factory, a conscious effort is made to concentrate all activities on the actual business of creating value. Faults are identified at their points of origin and systematically eradicated. Every body is assumed to be in the inspection department, that is, every body is quality conscious. Furthermore the shop floor layout is arranged in such a way that everyone can see each other, thereby facilitating communication and eliminating laziness.

2.6.4 After Sales Service

The establishment of a relationship of trust with the customer, who expects to be treated courteously and to receive professional advice, is an indispensable pre-requirement for sales success. Warnecke (1995) concludes that Lean Manufacturing is an intellectual process that must be approached with total commitment for everyone concerned (that is

after sales service personnel and end use customer feedback) in its execution. It identifies with issues such as responsibility, teamwork, and most importantly, it is customer driven.

2.7 Lean Manufacturing, Change Management and SMMEs

Although a range of tools and techniques are used in lean deployment, core to effective lean implementation is having a practical manufacturing strategy that supports both the organisation and its work force (the people who actually make lean happen) hence the need for strategic change management. Just as with quality and environmental management systems, change is no longer regarded as a strategic option but a must for companies and in particular SMME—because of their pivotal role in future economic development (Esan et. al 2007). Change can only occur if someone cuts through the morass of rules and regulations and comes to an agreement on what is really important—such as organisational vision, mission, and values (Richard Choueke 2000).

Lasting change can only occur if management fosters excellence and accountability by giving people what they need to do their jobs better, and by instituting new management systems like Lean Manufacturing (that go from top to bottom) and support systems that provide the management of process through liberal exchange of knowledge, building of trust and acknowledgement of the heterogeneity in values preferences and interests (Ayse Saka, 2003). Management behaviour, development of interdisciplinary synthesis and integrated ethics of interdependence (Mulej et.al, 2006) are such an important cultural element. Three key aspects for lean manufacturing integration with soft issues relating to change management are Culture, Commitment and Communication. Communication—a vital tool for developing a knowledgeable and committed work force—provides a structured process for information flow within and between all levels

of the organisation. However, for communication to work effectively a committed atmosphere need to be fostered by acknowledging and appreciating workers behaviours, and also through frequent and sincere recognition, that creates a work environment which promotes loyalty, belonging, confidence, self-worth, teamwork, respect and creativity. Workers also need information to understand business strategies, perform a quality job, achieve customer satisfaction and contribute to performance improvement and ultimate success of the organisation (Esan et. al 2007).

Recently the Department of Trade and Industry (DTI) in the UK commissioned a productivity improvement initiative known as the Manufacturing Advisory Service (MAS), to promote the use of Lean Manufacturing within the SMMEs. This is because Lean Manufacturing is hailed as a cost reduction mechanism, hence the need for its applicability within the SMMEs (Achanga et al., 2004, 2005a, b; Bicheno, 2000, 2004; Creese, 2000; Phillips, 2000; Womack et al., 1990; Womack and Jones, 1996). Several authors have reiterated the importance of cost factors and their reduction strategies in the current production process (Kulmala et al., 2001; Roy et al., 2001; Roy, 2003; Shehab and Abdalla, 2002). They assert that, cost factors are crucial, therefore, fundamental to the survivability of most organisations. Unfortunately, the idea of applying Lean Manufacturing has not been adopted by meaningful numbers of SMMEs with any conviction. These companies require that the implementation costs and the subsequent benefits of Lean Manufacturing adoption, be projected upfront before they are able to commit.

All these said, a fundamental challenge, in SMME environment is little spare resource (finance and people), every employee has a key role (Ryans, 1995) consequently SMMEs tend to be weak in workforce skills such as training and education and

employee involvement which add substantial benefits to lean manufacturing deployment as a manufacturing strategy. In SMMEs, employee involvement (the systems, procedure and programmes that involve all employees as active participant in continuous improvement activities) is based on 'short-term strategic fit' thereby causing partial adoption and adaptation of Lean Manufacturing as a manufacturing strategy for delivering world class performance.

The recognition of employee involvement as natural process that needs to be nurtured and developed is predominately deficient in SMMEs, consequentially creating and maintaining an environment that is receptive to lean initiatives is often difficult. With employee involvement being a key driver of other elements of Lean Manufacturing implementation, and especially in SMMEs environment where special cause of variation are dominated by the need for extensive education and training that require periodic assessment for effectiveness, world class practise tend to fail prematurely, however, exploiting an integrated manufacturing strategy that encompass a rational-linear and systematic-multiple-variant change management perspective for Lean Manufacturing implementation offer SMMEs potential for sustainability (Esan et al 2007).

Additionally, Arnheiter (2005) claim that the most common misconception of Lean Manufacturing is lean means layoffs. While this misconception may be due to the term "lean" (especially in the context of "lean and mean"), it is a mis-interpretation of the term. In Lean Manufacturing, if an employee were performing non-value-added activities within their job, management and the employee would work together to find a better way to perform the job to eliminate the non-value-added activities. Laying-off the employee would be counterproductive since a knowledgeable person would no longer

be available and the remaining employees would be reluctant to take part in future waste elimination projects thereby negating the effectiveness of change. Therefore, layoffs cannot take place in the context of lean manufacturing, unless it becomes an absolute necessity and every effort to re-assign or re-train the employee fails (Emiliani, 2001).

Furthermore, there is much debate as to whether formal quality enhancement approaches, which is a requisite of lean system, can be effectively implemented and subsequently utilised by SMMEs. Thomas and Webb (2003) in their work on analysing quality systems implementation in SMMEs highlight the lack of intellectual and financial capacity within small companies as being the primary issues that lead to poor lean systems implementation. They go on to state that the uniqueness and complexity of SMMEs operations often hinder the implantation process. The main issue is one of developing a rigorous model that is both suitable to the wide range of SMMEs but is not so generic that it fails to provide adequate direction and guidance to the company.

Husband and Mandal (1999) identify the uniqueness of SMME operations as being a limiting factor to quality enhancement implementation and provide a series of dimensions that are unique to SMMEs and suggest that if these dimensions are not integrated into the model then a SMMEs ability to achieve significant outputs from the application of the model will be compromised. These dimensions are:

- Core – products and/or services.
- Structural – size, location, age, ownership and legal entity/structure.
- Fundamental – systems, people and measures.
- Sustainability – leadership and planning, risk and change, and technology and innovation.
- Integrative – customers, suppliers and partners.

- External – competition, stakeholders, government and economy.

Furthermore, Deleryd et al. (1999) identify that SMMEs need to make decisions and improve their processes based on accurate and timely information relating to the performance of their manufacturing process. To manufacturing companies this is crucial not least within the design and production areas. This means that a deeper understanding of the concept of variation, identification of causes of variation and handling of these causes are important factors within SMMEs. It, therefore, follows that the development of process control theory, experimental design concepts and issues relating to product reliability cannot solely remain in the domain of the larger industries in which resources are available to train the workforce to apply these concepts. These statistical concepts have a major part to play in SMMEs and the application of such principles must come from continued training and development of the company's workforce.

The resulting problem shows the lack of application of statistical theory to identify and solve problems within a manufacturing context. There are several reasons for the relatively low application of statistical methods in SMMEs. Management in small companies, in general, do not have the sufficient theoretical knowledge to see the potential of using statistical tools. In many cases, they and their employees even become frightened when statistical tools are discussed. Small companies also lack resources in the form of time and personnel. Small organisations tend to have a lean organisation and, therefore, they find it difficult to appoint a facilitator or co-ordinator for the implementation process. In addition, they also have limited resources to provide internal training. Lack of resources in these aspects leads to a need for a careful analysis of

which strategy to use when implementing statistical methods in order to succeed (Husband, 1997).

Having an array of specific tools and techniques available to the SMME can allow the company to develop what can be termed the “quality enhancement” issues relating to systems and product based quality. These issues are essential to the company's continued development and include amongst other things; problem solving, benchmarking, continuous improvement, etc. These techniques prove to be far more effective when backed by statistical data and can achieve greater success when implemented within a systems approach that is designed to suit SMMEs. The primary focus for any SMME, therefore, that intends to adopt the lean manufacturing methodology is to undertake the project in the most cost-effective manner and, to be able to recoup the initial project costs quickly after the completion of the project. At the heart of this cost-effectiveness is the need to undertake the lean project in-house with the minimum of costly consultancy support.

2.8 Lean Manufacturing as a Manufacturing Strategy

The ability to develop directions for lean implementation through an integrated strategic framework that allows for benchmarking of expectations at intermediate stages of lean principles deployment is core to successful implementation of lean manufacturing as a manufacturing strategy (Esan et al 2007). The integrated strategic benchmarking framework is needed because traditional Performance Management System (PMS) and management accounting systems (Sanchez et.al 2001) are criticised for being obsolete, irrelevant to managerial decision making, unrelated to strategic objectives, and detrimental to organisational improvements (Wibisono and Khan, 2001) hence the need for intermediate indicators to assess the changes taking place in the effort to introduce

Lean manufacturing. In developing the integrated strategic benchmarking framework managers should:-

- Develop critical success factors
- Review / Define appropriate business measures
- Target time-based improvements for each business measure
- Define key business processes
- Decide which process needs to deliver against the target areas in 3
- Understand which process needs detailed mapping

2.8.1 Develop Critical Success Factors (CSFs)

Critical success factors (CSFs) have been defined by Guimaraes et al. (1999) as “the critical areas that management must constantly monitor to ensure successful performance by the organisation”. In developing Critical success factors (CSF) a direct link to specific factors impacting on a company or value stream needs to be established for lean manufacturing policy deployment. Serious consideration should be given to the factors developed, that is, the factors should be achievable. Presented in **Table 2.2**, is a typical CSF matrix for lean policy deployment. On defining the key forces impacting the organisation, a categorisation technique should be employed. Its focus should be on areas such as;

- General business environment
- Industry specific
- Customer specific
- Company specific

Key Forces	Example of Key Specific Factors	Possible Critical Success Factor
General Business Environment	Recession	Turnover growth
Industry Specific	New competitors	Maintain or grow market share
Customer Specific	Main customer in decline	Find new customers
	High cost-down pressure	Dramatically reduce cost
	Severe quality improvements	Dramatically improve quality
	New product requirement	Develop new products
Company Specific	A demanding holding company	Keep holding company happy

Table 2.2: Typical Critical Success Factor Matrix (adapted from Rother, 1999)

2.8.2 Review / Define Appropriate Business Measures

Most companies already have a set of top level business measures, but they are not always aligned to critical success factors. Alignment between business measures and critical success factors is very important as it will ultimately drive performance. A compatibility check between business measures and critical success factors must therefore be made.

		Strategic Level Critical Success Factors						
		Turnover Growth	Improve Market Share	Find New Customers	Reduce Costs	Improve Quality	Develop New Products	Keep Holding Company Happy
Key Business Measures	Return on Capital				Maybe			Yes
	Net Cash				Yes			Maybe
	Stock Turn				Yes	Yes		Maybe
	OEE				Yes	Maybe		Yes
	Total Cost Reduction	Yes	Yes	Yes	Yes		Maybe	Maybe
	Total Turnover	Yes	Maybe	Maybe			Maybe	Maybe
	Market Share	Yes	Yes	Maybe			Maybe	Maybe
	Sales to New Customer	Yes	Yes	Yes			Maybe	Maybe
	Product Quality	Yes	Maybe	Maybe	Maybe	Yes	Maybe	Maybe
	New Product Sales	Yes	Yes	Yes	Maybe	Maybe	Yes	Maybe

Table 2.3: Defining appropriate business measures (adapted from Rother, 1999)

Table 2.3 shows a set of businesses measures to achieve the critical success factors. It should be expected that each measure should correlate to at least one critical success factor, it's not expected that every measure will correlate to every critical success factor. The measures may not be the optimum but good enough to pilot and can be reviewed after the 1st year. The compatibility can be numbered, or can define as a stronger yes. The key to implementation this framework is to start by focusing on the major critical factor, 'Yes'.

2.8.3 Target Time-based Improvements

Many companies only set one target for six months however, for an effective lean conversion a more realistic conversion is 3 to 5 years with staged targets for every 6 months or 12 months. Again, the initial iteration of staged targets may not be optimum but they will be a 'start' which can be annually adjusted. The targets set a board direction for the company over the next 3 years. The organisations need to work out how to achieve them by understanding their key business processes. Although other things can cause an impact and change within the trial period the goal of the organisation is to establish a baseline for effective lean manufacturing implementation as a manufacturing strategy.

2.8.4 Define Key Business Processes

By defining the key business processes this should thus encourage and support interdepartmental communication throughout the company. Although, business processes are not everything a company does but they are core activities undertaken that must be right. The key here is to collectively, through a brainstorming session agree on between 4 and 10 key processes and make sure each has a clear definition. Ideally, it is important to keep an active view on all processes.

2.8.5 Decide Which Process Needs to Deliver Against the Target Areas

Achieve by determining if each business process will yield benefit of each target area – if improved. Decide degree of benefit subjectively by recording Yes, Maybe or No – Yes implies that there is a direct link, this exercise will indicate where improvement activity should be focused.

2.8.6 Understand Which Process Needs Detailed Mapping

According to Anjard, (1998) process mapping is a very effective tool, but often overlooked, in determining what the present process is, evaluating other potential improved processes and determining an optimum process. This is an invaluable tool for effective manufacturing strategy implementation in a lean environment. It is best used at the micro-level, and it is essential to consider interfaces and time factors. A process map is used to understand businesses and improve the performance of processes. However, a pre-requisite to detailed process mapping is identifying which processes are likely to yield the greatest gains against target areas after which process classification should take effect. Typical categorisation methods follow the three dimensional route detailed below;

- Processes which focus overall direction – Strategic
- Processes directly impacting on targets – Core
- Processes indirectly impacting on targets – Support

The processes have been classified as, Strategy / Policy employment for setting the direction; core processes deliver the targeted results and support processes aid core processes. It is imperative that things are kept as simple as possible during the classification process. A best practise advance will be to use one time scale right through the target areas. Furthermore, the ability to estimate percentage of targeted gains to be delivered from each core processes is a requirement for effective lean manufacturing deployment as a manufacturing strategy.

A suggested order of mapping would be to start with order fulfilment because this is central to the operation of most companies and value streams. Listed below a typical process mapping approach in lean policy deployment;

- Order fulfilment
- Sales acquisition
- Supplier integration
- Product life cycle management
- Technology plant and equipment management

Finally, processes are critical to seizing and maintaining a competitive advantage. Processes are the vehicles for exceeding customer expectations and achieving organizational goals. The performance of individuals is only as good as the process will allow it to be. Processes, especially cross-functional business practices, are usually not documented, not standardized, not measured, not systematically and continually improved and not managed by the micro-process doer or owner (Anjard, 1998).

2.9 Lean Manufacturing and Quality Management

Quality management has long been established as an important strategy for achieving competitive advantage. Traditional quality initiatives such as statistical quality control, zero defects, and total quality management have been key initiatives for many years. Six Sigma can be considered as a recent quality improvement initiative that has gained popularity and acceptance in many industries across the globe (Nonthaleerak and Hendry, 2005).

2.9.1 The Six Sigma Approach

The roots of sigma as a measurement standard go back to Frederick Gauss (Raisinghani, 2005), who introduced the concept of a normal curve or a normal distribution. In 1922, Walter Shewhart introduced three sigma as a measurement of output variation; he stated that process intervention is needed when output went beyond this limit. The three sigma

concept is related to a process yield of 99.973 percent or a defect rate of 2,600 per million opportunities. This was adequate for most manufacturing units, at least until the early 1980s (Raisinghani, 2005) when Motorola introduced six sigma. Six Sigma could also be described as an improvement programme for reducing variation, which focuses on continuous and breakthrough improvements. Improvement projects are driven in a wide range of areas and at different levels of complexity, in order to reduce variation. The main purpose of reducing variation on a product or a service is to satisfy customers. The goal of Six Sigma is that only 3.4 of a million customers should be unsatisfied (Magnusson et al. 2003).

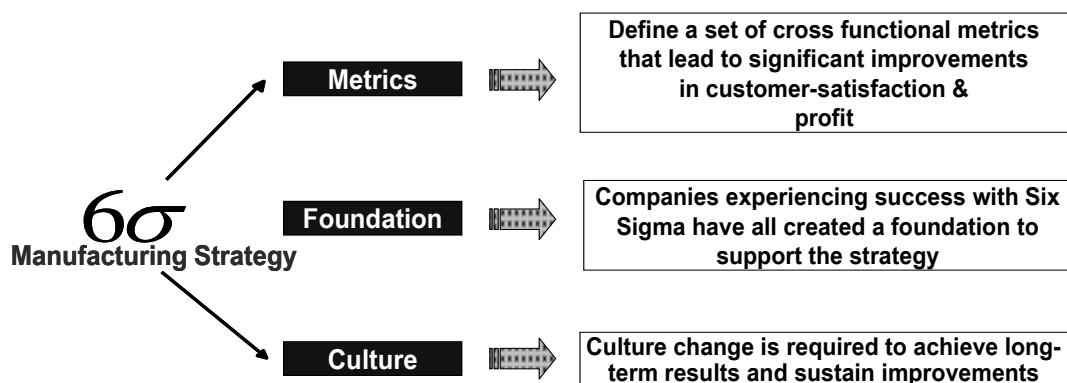


Figure 2.2: Six Sigma as a manufacturing strategy

As shown in **Figure 2.2**, Six Sigma can be considered both a business strategy and a science that has the aim of reducing manufacturing and service costs, and creating significant improvements in customer satisfaction and bottom-line savings through combining statistical and business process methodologies into an integrated model of process, product and service improvement. In Six Sigma, customer focus becomes the top priority. Six sigma improvements are defined by their impact on customer satisfaction and value (Pande and Holpp, 2002). From an internal perspective, Six Sigma provides a way of improving processes so that the company can more efficiently and predictably produce world-class products and services. According to Waxer (2004)

there are four major requirements for successfully implementing Six Sigma within any organisation, regardless of the size of the organisation:

- management team buy-in and support;
- education and training;
- resource commitment; and
- link to compensation.

In relation to small companies Jiju (2005) argued that as small companies are more agile, it is much easier to buy-in management support and commitment, as opposed to large organisations. Henderson and Evans, (2000) further add that top management involvement helps to influence and restructure business organisations and the cultural change in attitudes of individual employees toward quality in a short implementation period. Six Sigma is considered a breakthrough management strategy and it involves the adjustment of a firm's values and culture. In some cases, substantial change to an organisation's structure and infrastructure needs to take place (Coronado and Antony, 2002). People facing cultural change and challenges due to the implementation of Six Sigma need to understand this requirement. Also needed are a clear communication plan and channels to motivate individuals to overcome resistance and to educate senior managers, employees, and customers on the benefits of Six Sigma (Kwak and Anbari, 2006).

Education and training (Johnson and Swisher, 2003; Coronado and Antony, 2002; Goh, 2002) is another important feature of Six Sigma. It involves the elaborate training and certification processes that result in Black Belts, Green Belts, etc. (Goh, 2002). Education and training help people understand the fundamentals, tools, and techniques of Six Sigma. Training is part of the communication process to make sure that manager

and employees apply and implement the six sigma techniques effectively (Kwak and Anbari, 2006). The education and training component is much harder for smaller companies. Moreover, small companies do not have the slack to free up top talented people to engage in training followed by execution of six sigma projects as they are crucial to the day-to-day operations and problem solving within the company.

Being able to link compensation to six sigma implementation is much easier in small companies compared to a large company. Attaching the success to financial benefits (Goh, 2002) and representing the success of six sigma projects in terms of financial benefits and measurement performance has made their selection and completion an important aspect for organisations (Henderson and Evans, 2000). Financial benefits as a measure of achievement makes it easily understandable for employees and help them to relate to six sigma project outcome (Goh, 2002). Furthermore, there is traditionally a five-phased DMAIC methodology applied by Six Sigma teams that tackle specific problems to reach Six Sigma levels of performance (Breyfogle, 1999). These phases are detailed in **Table 2.4** below:

<i>Steps to follow within each phase of the DMAIC implementation</i>	
<i>Define</i>	<ul style="list-style-type: none"> • Define the problem (as a project) both succinctly and specifically. • Identify stakeholders. • Understand the link between the problem at hand and the criticality of the problem from the perspective of the customers. • Carry out a simple mapping of the processes both up- and down-stream to determine where the problem lies. • Establish the process inputs, outputs and various controls of the processes. • Form a six sigma project charter which clearly illustrates the roles of people and their responsibilities for the project. Define the resources required for the project and allowed time-frame for the project at hand. The charter should also reveal the scope of the project, the project boundaries and the key benefits to internal or external customers. • Identify the project sponsor and stakeholders and determine whether this project is worth an effort using cost-benefit analysis. • Identify all customers (both internal and external) and justify how this problem is linked to customer satisfaction.
<i>Measure</i>	<ul style="list-style-type: none"> • Determine the current performance of the service process (process yield, DPMO, short-term and long-term capability); • Decide what to measure (critical-to-quality characteristic – CTQ) and how to measure; • Establish a simple measurement system study (if applicable); • Determine how well our process is performing compared to others through benchmarking exercise; and • Identify the strengths and weaknesses and determine the gaps for improvement.
<i>Analysis</i>	<ul style="list-style-type: none"> • Uncover the root causes of defects in processes; • Understand the root causes of variability which lead to defects and prioritise them for further investigation; • Understand the nature of data and the distribution or patterns of data; • Determine the key service process variables that may be linked to defects; and • Financially quantify the improvement opportunity (i.e. estimate of potential financial benefits).
<i>Improve</i>	<ul style="list-style-type: none"> • Develop potential solutions to fix the problems and prevent them from recurring. • Evaluate the impact of each potential solution using a criteria-decision matrix. Solutions that have a high impact on customer satisfaction and bottom-line savings to the organisation need to be examined to determine how much time, effort and capital will need to be expended for implementation. • Assess risks associated with potential solutions. • Validate improvement (i.e. reduce defect rate or improve sigma quality level of the process) by pilot studies. • Re-evaluate the impact of chosen potential solution.
<i>Control</i>	<ul style="list-style-type: none"> • Develop corrective actions to sustain the improved level of service process performance; • Develop new standards and procedures to ensure long-term gains; • Implement process control plans and determine the capability of the process; • Identify a process owner and establish his/her role; • Verify benefits, cost savings/avoidance; • Document the new methods; • Close project, finalise documentation and share key lessons learned from the project; and • Publish the results internally (monthly bulletins) or externally (conferences or journals) and recognise the contribution made by the team members.

Table 2.4: Six Sigma DMAIC methodology Summary (Anthony, 2006)

Typical tools and techniques used in implementing Six Sigma are Measurements Systems Analysis (MSA), process control, Design of experiments, Failure Mode Effect Analysis (FMEA), quality control and capability study. These methodologies are explained in greater depth below.

2.9.1.1 Measurement system analysis

Manufacturing process produces goods that have physical characteristics that can be measured. The quality of the goods produced is based on their usefulness to the end user or customer of the products (Raisinghani et al., 2005). The definition of quality has evolved to include the utility of that which is produced to the end customer. The measure of these characteristics become the first concern of a manufacturing organization that employs a Six Sigma quality system. The area responsible for determining the fitness of the measuring equipment is called measurement system analysis (MSA). The first act in utilising a Six Sigma approach to a problem is to analyze the ability to measure the characteristics that need to be optimised (Henderson and Evans, 2000).

The approach to MSA is to perform a gage study – this separates the repeatability (due to the measuring instrument) and reproducibility (due to operator bias) into separate factors. It can also determine relative accuracy between different measuring systems where there are multiple gages to measure the same output. This activity always precedes any attempts to optimize a manufacturing process to understand the accuracy of the measurements relative to the desired range of control (Raisinghani et al., 2005). Once this study has been completed, the process can be experimented and the accuracy of the results can be understood.

2.9.1.2 Process control

Process control is a function in a production process that seeks to find deviations from the optimum process outputs and also uses proactive means to look for any process shifts before the product quality is compromised (Goh, 2002). Many well-documented techniques are used in this endeavor – the most obvious is the use of statistical process

control (SPC). In a simple manufacturing process, the use of SPC will entail the use of control charts where the output of a given process is measured and charted. Dr Walter A. Shewart (1891-1967) is credited for the development of the control chart, where the upper and lower limits are set at ± 3 times the standard deviation, based on normal variation. When the process produces results outside these limits, it is said to be out of control (Goh, 2002).

Although Dr Shewart never received the recognition he deserved in his lifetime, he was responsible not only for the concepts we use in modern process control, but also the concepts that were developed by his student, W. Edward Deming based on Shewart's original "Plan, Do, Check and Act" cycle. His publications in 1931 and 1939 were the basis of the quality movement that was taken to post war reconstruction in Japan by Deming, Ishikawa, Juran, and others. The concept of SPC and the use of control charts are not complicated, but in real world application, there are very few organizations that use and understand the concept correctly (Goh, 2002). Simply put, a product or process has specific requirements and, as explained earlier, are related to the functionality and usefulness to the end customer (Henderson and Evans, 2000).

These requirements are manifest in the product specifications, outside of which the product is usually rendered worthless, creating scrap. This is referred to as product control – not process control. Process control is unrelated to the product requirements, but related to the production capability (Henderson and Evans, 2000). An example of this would entail running a process many times under normal conditions and measuring the output. After sufficient data are collected – at least 30 runs, but not limited to 30 – the distribution parameters are calculated. Limits are placed on the process output at the mean ± 3 standard deviations (sigma). Subsequent runs are evaluated against these limits

and not the specification limits. A measurement outside these limits indicates that something has changed or drifted in the process and the output is unusual. Actions must be taken at this point to bring the process or tool back into control. In some large manufacturing operations, the number of control charts can be as high as 100,000 and periodic checks of the control limits integrity must be preformed.

2.9.1.3 Design of experiments

When a process is being developed or has been identified as needing optimization, a technique called design of experiments (DOE) is utilized. If the process is simple and involves only one or two inputs, simple experimentation is usually sufficient (Raisinghani et al. 2005). When the process is more complex, involving several inputs that may have interactions, a DOE is required to explore the relationship of the output to the inputs. An example of this is a complex manufacturing process that has inputs such as temperature, pressure, several gas flows, process speed, etc. where each can be changed independently. The outputs of a process may be dimensions, thickness of a film, resistance of a material, or any other measurable property that results from the process.

The traditional experimental procedure of taking one factor at a time most times will not be successful in optimization due to the factor-to-factor interaction that is ignored (Raisinghani et al. 2005). The DOE technique explores the operational space for all the inputs, producing results that could show non-linearity and interaction. The output of a well-defined DOE is a mathematical process model that predicts the response of all the output variables for any combination of inputs. The rigorous treatment of a manufacturing process, including process modelling, is integral to Six Sigma methodology. Each factors' significance is quantified using analysis of variance and the

resulting model is used not only to optimize the process, but to trouble shoot the process when deviations occur (Raisinghani et al. 2005).

2.9.1.4 Failure mode and effects analysis

Another quality tool used by a Six Sigma organisation (Raisinghani et al. 2005) is the failure mode and effects analysis (FMEA) methodology. This process involves gathering a representative from all the stakeholder groups, such as manufacturing, process engineering, equipment engineering, test or product engineering and a facilitator to collectively complete the FMEA (Henderson and Evans, 2000). . The process starts with a tool or device schematic and a process map (Raisinghani et al. 2005).

The process is carefully examined systematically to proactively determine what could possibly happen detrimental to the product at each step of the process. Depending on the severity, the possibility of occurrence and the ability to detect the failure, a relative priority number (RPN) is assigned to each activity. If the magnitude of the RPN is high, usually defined as greater than 120 (60 for a Six Sigma organization), corrective actions must be undertaken to reduce it. A good FMEA can predict and eliminate many sources of problems before they occur. The FMEA process may identify areas that require a designed experiment for optimisation or even require the purchase of new metrology equipment if the exposure to potential problems is too great. A detailed FMEA for a complex process may require a weekly meeting with five or six experts for a period of six months (Raisinghani et al. 2005).

2.9.1.5 Quality control and capability analysis

After all the preventative measures are taken and corrective actions have been completed, a measure of the final quality of any process or product must be taken to

ensure a level of Six Sigma has been obtained. The standard measure of conformance to requirements is the process capability (Cpk). This is a quantitative measure of how much variation there is in the product or process with respect to the requirements/specifications (Raisinghani et al. 2005).

The process capability is reported as an internal measure of goodness of any process or products and it is also required from key suppliers. The manufacturing organization then reports the key characteristic Cpk to their end customers. As with high RPNs from the FMEA, any parameter with a capability index less than a certain threshold requires corrective actions; for Six Sigma organizations this threshold is two.

2.9.2 Integrating Lean and Six Sigma

The term Lean Six Sigma is described as a management system that combines lean methods and Six Sigma approaches (Sheridan, 2000). Lean Six Sigma builds on the knowledge; methods and tools derived from decades of operational improvement research and implementation. Lean approaches focus on reducing cost through process optimization. Six Sigma is about meeting customer requirements and stakeholder expectations, and improving quality by measuring and eliminating defects. The lean Six Sigma approach draws on the philosophies, principles and tools of both. However, lean Six Sigma's goal is growth, not just cost-cutting. Its aim is effectiveness, not just efficiency. Lean Six Sigma incorporates key methods from its predecessors (George Byrne et al., 2007). **Table 2.5** suggests a most effective framework for bringing lean and six sigma methodologies together.

	Men/People	Machine	Method	Material / Product	Measure	Mother Nature
Variation	Lean (teams involvement, policy deployment kaizen)	Six Sigma (CpK) Lean (SMED)	Lean (5S, SOPS) Six Sigma (SPC, DOE)	Lean Supply Six Sigma (SPC, DOE)	Lean (policy deployment) Six Sigma (DPMO, Gauge R&R)	Six Sigma (DOE)
Mistakes	Lean pokayoke	Lean pokayoke	Lean pokayoke	Lean pokayoke	Six Sigma Lean	Six Sigma (DOE)
Complexity	Lean (cross training, waste removal)	Lean (TPM, 5S)	Lean (Waste Removal)	DFSS Lean (GT, Design)	Lean (policy deployment)	Six Sigma (DOE)

Table 2.5: Combining Lean and Six Sigma (Adapted from Bicheno 2004)

For effective application of the framework presented in **Table 2.5**, Arnheiter (2005) advocates that the performance of a business is determined by the complex interactions of people, materials, equipment, and resources in the context of the program that manages these interactions. It is fair to say that management theory regarding operating systems is still evolving. While both Six Sigma and lean manufacturing represent the state-of-the art, each system gives priority to certain facets of organizational performance. Therefore, in a highly competitive environment, diminishing returns may result when either program is implemented in isolation (Arnheiter, 2005). A thorough analysis of the two programs provides some likely reasons why the programs alone may fail to achieve absolute perfection (Arnheiter, 2005)

2.10 Summary

For organisations to survive the turbulent business and competitive environment, lean manufacturing policy deployment is a must. This chapter has reviewed the current business environment of small medium manufacturing organisations. The effect of SMME on national Gross Domestic Products (GDP) was highlighted from a socio-economic perspective. The chapter further reviewed manufacturing strategy, and the process of manufacturing strategy formulation in SMME with focus on critical dimensions typically cost, financial capability, lead-time, quality, reliability, capacity, production control, product features, design capability, human resources, suppliers and distribution.

Additionally, the chapter reassessed how to successfully implement lean manufacturing as a manufacturing strategy by developing directions for lean implementation through an integrated strategic framework that allows for benchmarking of expectations at intermediate stages of lean principles deployment. There are five basic concepts that define lean thinking and enable lean manufacturing: specify value, identify the value stream, flow, pull, and perfection. The chapter suggested that lean manufacturing can be best characterised as a system of measures and methods which when taken all together have the potential to bring about a lean and therefore particularly competitive state, not only in the manufacturing division, but throughout an organisation. Further four individual aspects of lean manufacturing were classified as product development, chain of supply, shop floor management and after sales service

The chapter also examined the Six Sigma framework with the framework suggesting a goal of only 3.4 of a million customers should be unsatisfied. Six Sigma can be considered both a business strategy and a science that has the aim of reducing

manufacturing and service costs, and creating significant improvements in customer satisfaction and bottom-line savings through combining statistical and business process methodologies into an integrated model of process, product and service improvement. In Six Sigma, customer focus becomes the top priority. Furthermore, there is traditionally a five-phased DMAIC methodology applied by Six Sigma teams that tackle specific problems to reach Six Sigma levels of performance. Typical tools and techniques for implementing Six Sigma include, Measurements Systems Analysis (MSA), process control, Design of experiments, Failure Mode Effect Analysis (FMEA), quality control and capability study

The chapter concluded by examining the interaction between lean manufacture and Six Sigma. Lean approaches focus on reducing cost through process optimization. Six Sigma is about meeting customer requirements and stakeholder expectations, and improving quality by measuring and eliminating defects. ‘Lean Six Sigma’ is relevant for effective lean manufacturing policy deployment because the performance of a business is determined by the complex interactions of people, materials, equipment, and resources. Hence having an integrated manufacturing strategy that manages the interaction is imperative for lean—Six Sigma manufacturing policy deployment sustainability.

CHAPTER 3

THE CASE STUDY COMPANY: NTR LTD

3.1 Introduction

This chapter discusses the need for lean manufacturing as a manufacturing strategy in a small medium manufacturing environment (SMME). The business environment is critically evaluated through an industry specific and process specific approach. Using a PESTLE analysis framework and Porter's five forces the chapter significantly examines the industry the case company currently operates. A Strength, Weakness, Opportunity and Threats (SWOT) is utilised in understanding the case company's manufacturing system (process specific). Conclusively, the need for key performance indicators (KPIs) as a progress indicator for lean manufacturing strategy deployment is articulated, with relevance indicators developed. These KPIs will form outputs (performance against plan) in Chapter 5.

3.2 The Need for Lean Manufacturing in NTR LTD

The case study company—NTR Ltd, Precision Tooling Engineers (a SMME)—provides many of Europe's leading automotive, aeronautical and high precision sub-contract manufacturers with tooling reclamation. The business has been built up over 28 years, during which time the service has significantly developed, however the company continues to provide manufacturers with substantial cost savings against the price of new tooling –up to 75%. Working through a network of Agents and Partners, NTR occupies 11,000 square feet of manufacturing facility and currently employs about 45

people, turning over about £1.5m. The company continues to grow as the need to renew and recycle becomes increasingly important. **Figures 3.1** and **3.2** shows NTR Ltd's trading countries and customer base respectively: a brief description of NTR Ltd's aerospace customer is given below.



Figure 3.1: NTR Ltd trading countries

BAE Systems

Machining components for both civil and military aircraft, projects include Typhoon, JSF, Airbus, Nimrod & Hawk; components vary from large airframe fuselage sections, leading edge aerofoil, flap track beams and engine pylons. Typical tooling types used and reclaimed at NTR Ltd include: milling/porcupine cutters, end-mills, routers & u-drills.

Rolls Royce Aerospace

Machining various aero engine components depending on site, components include fan disks, fan blades, compressor blades and disks, shafts etc. Typical tooling types used and reclaimed at NTR Ltd include: milling/porcupine cutters, end-mills & special form cutters.

Airbus Industries (Filton)

Manufacture and assemble airframes and components for Airbus A318-A380. Typical tooling types used and reclaimed at NTR Ltd include: milling/porcupine cutters, end-mills.

Messier Dowty

Manufacture aircraft landing gear predominantly for Airbus and Boeing. typical tooling types used and reclaimed at NTR Ltd include: milling/porcupine cutters, end-mills, ball-nose cutters & u-drills.

Hyde Group

Sub contract machining of aircraft components, customers include BAe Systems, Airbus, Lockheed Martin, Boeing, Raytheon, and Shorts, components include Engine pylons for airbus single isle, A400m and A380 aircraft, Gear ribs for A380, and machined parts for JSF and Typhoon project. Typical tooling types used and reclaimed at NTR Ltd include: milling/porcupine cutters, end-mills, ball-nose cutters, routers & u-drills.

CAV Aerospace

Manufacturing wing stringers and leading edge components for Airbus Industries and Boeing, typical tooling types used and reclaimed at NTR Ltd include: milling/porcupine cutters, end-mills.



Figure 3.2: Cross-section of NTR Ltd customer base

Figure 3.3 and **Table 3.1** shows a cross section of products reclaimed at NTR Ltd and a high level process map of the case company's business system whilst **Figure 3.4** and **Table 3.2** shows a flow chart of NTR Ltd's manufacturing system and a typical reclamation process. With a 70% share of the UK tooling reclamation market, the company strategic objective is to consolidate its position through improved process, and tooling performance, which will pilot further reclaim vs. new tooling cost reduction for

its customers. Further more, the need to develop a strategic focus that requires a process of creating and sharing strategic goals of the business throughout the organisation in such a way as to enable each individual or problem-solving group to focus efforts on improvements, which will have impact on strategic targets created the need for NTR LTD to implement lean manufacture. The company's business plan includes developing strategic targets such as accessing appropriate markets, product mix, improved customer's services level-requirements, and product development which would lead to reduction in manufacturing costs, response time to customer, non-value added activities, WIP, and structural costs.



Figure 3.3: Cross-section of products reclaimed at NTR Ltd

The company displays a make-to-order manufacturing characteristics as it does not have the luxury of an easily manageable, forward, visible workload as schedule repair times vary considerably depending on the severity of tooling damage and complexity. Customer demand pattern is very irregular as parts are not sent in for repair until they are damaged. So in a scenario where major customers improve their production efficiency (that is less damaged parts), there is great possibility of low company

turnover! A key order-winning factor is turnaround time or just-in-time supply. The recent introduction of a Knowledge Transfer Partnership (KTP) programme co-sponsored by the Department of Trades and Industry (DTI) and case company with knowledge support provided by the University of Bradford with a change agent (KTP Associate)—catalyst for continual challenge and debate of underlying assumptions and action plans—demonstrates the company’s desire to become a world class manufacturer which in turn will allow it to grow by effectively using lean manufacturing strategic deployment developed as part of the KTP programme.

SALE	PRODUCTION	ADMIN	MARKETING	QUALITY	IT	ENGINEERING
Collection & Return	Planning & Control	Sales Admin	Business Planning	Policy	Production (Equinox)	Research
Accounts Management	Material Purchasing	Customer Liaison	Marketing Communications	Document Control	MS Excel	Design
Sale Development	Pre-inspection	Booking Off	Web marketing	Inspection	Accounts management (Opera)	Supply Chain Management
Competitor Analysis	Good In/Booking In	Production Control		Calibration		Product launch
Product Pricing	Spares Admin	Purchase record		Analysis		Customer feedback
	Different processes Steps	Credit Control		Delivery Rate		

Table 3.1: High level process map of NTR Ltd

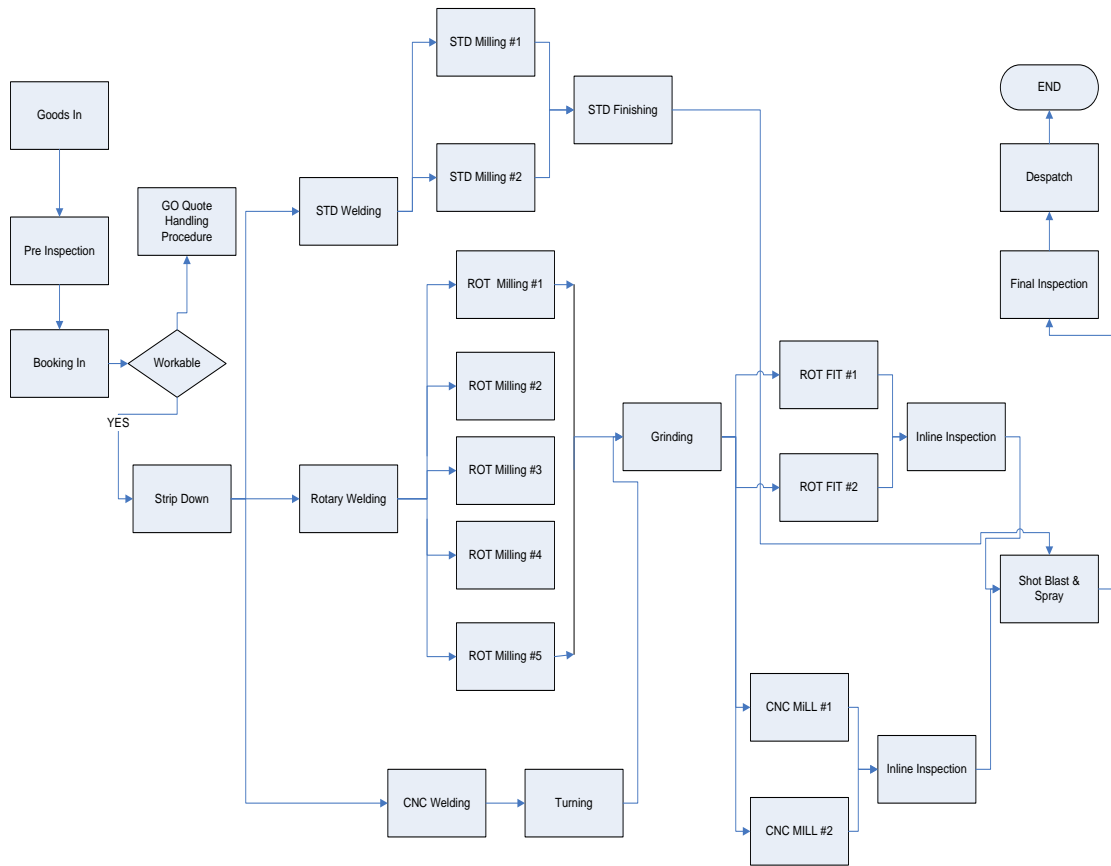


Figure 3.4: NTR Ltd manufacturing system





			
<p>Stage 1: Picture show a cross-section of Tool (Long Edge Cutter-"Porky" and Face mill) with top pocket smashed in and outer diameter badly damaged.</p>	<p>Stage 2: Tool stripped-down with "pick-ups" ground off. Picture also show tool damaged pocket welded with filler rod that closely matches the parent metal. This guarantees tool reliability during service.</p>	<p>Stage 3: Tool pocket precision milled and ground to tight tolerance using our flexible machining capabilities and calibrated measuring equipment.</p>	<p>Stage 4: Tool finished to high quality standard with screw holes precision drilled, tapped, and countersunk. The tool is also deburred and any other machining marks are abrasive rolled/finished/ power filed.</p> <p>Stage 5: Tool is bead blasted and inspected - screw holes, tolerances and finished quality are verified. The tool is then labelled (seal of quality), packed and delivered.</p>

Table 3.2: Typical tooling reclamation process

3.3 Business Environment

This section discusses the business environment (external and internal) of the case company using Porter's 5 forces, competitor's analysis, PESTLE analysis and a process SWOT analysis framework.

3.3.1 Industry Analysis using Porter's 5 Forces

Globalisation and emerging technologies are having enormous impacts on the manufacturing industry around the world. This scenario has seen the exponential upsurge in new entrants to the market environment, prompting stiff competition in the market place (Umble et al., 2003). Many SMEs are vulnerable as they operate in sectors where Porter's 5 forces are prominent. Specifically, in SMEs there are few barriers to new entrants and they have little power to dictate to suppliers their needs. The Porter's 5 forces analysis is a framework for industry analysis and business strategy development which aid lean manufacturing strategy deployment (premise: business and manufacturing strategy are intertwined).

Developed by Michael E. Porter of Harvard Business School in 1979 (Umble et al., 2003), it uses concepts developed in Industrial Organization (IO) economics to derive 5 forces that determine the competitive intensity and therefore attractiveness of a market. Porter referred to these forces as the microenvironment: 'the environment of organisations at the microscopic or cellular level' (as in the case of product families in lean systems design), to contrast it with the more general term macroenvironment (Umble et al., 2003). They consist of those forces close to a company that affect its ability to serve its customers and make a profit. A change in any of the forces normally requires a company to re-assess the marketplace.

The use of Porter's five forces framework in lean manufacturing strategy deployment is for qualitative evaluation of organisation's strategic position for systems planning purposes as this forms a key requirement for lean manufacturing and strategic planning (which is discussed extensively in Chapter 4). The framework is textbook material for modern business studies and therefore widely known. As rendered in the case of the case company in **Figure 3.5**, Porter's five forces include three forces from 'horizontal' competition: threat of substitute products, the threat of established rivals, and the threat of new entrants; and two forces from 'vertical' competition: the bargaining power of suppliers, bargaining power of customers. The information in **Figure 3.5** were collected through an eclectic approach which included discussion with the Managing Director of NTR Ltd, NTR Ltd's Europe agents, UK sales agents, production team leaders, key customers, key suppliers, competitors website and market performance, research on current manufacturing trends as reported by the EEF and other various UK governments based manufacturing/engineering association.

Key outputs from **Figure 3.5** are that NTR Ltd is susceptible to high threat of substitute product. A typical scenario is that Original Product Manufacturer (OPM) might achieve lower product cost (e.g. through flexible manufacturing techniques) to the extent that the cost of reclaim to cost of new is not significant enough to warranty product reclamation. This sort of behaviour further buttress the need for lean manufacturing strategy deployment in the case company, as lean can significantly low manufacturing cost, hence achieving competitive advantage and sustainability.

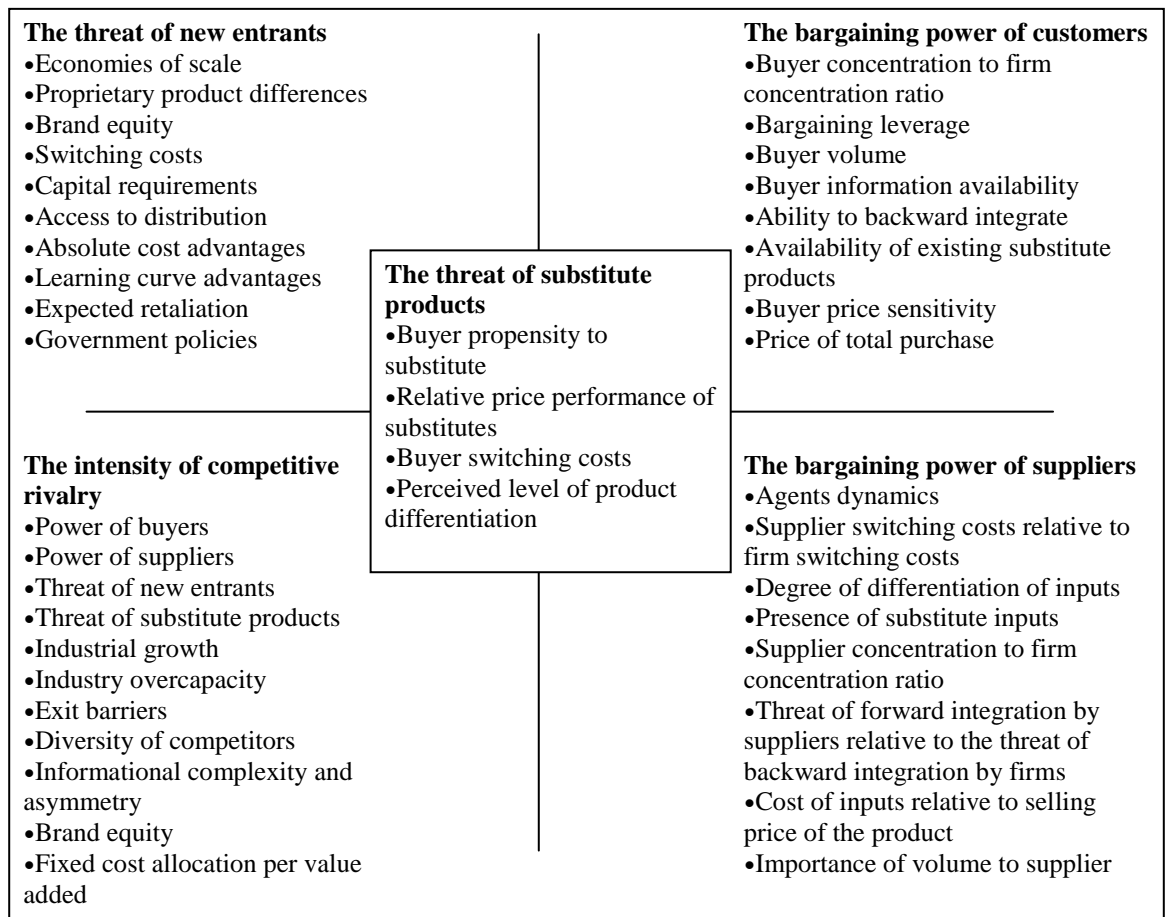


Figure 3.5: A graphical representation of Porter's five (5) forces in NTR Ltd

Another observable from **Figure 3.5** is the bargaining power of suppliers, that is, agent's commission. The commission regime might tend to erode the profit margin of the organisation; thereby making it less competitive in terms of disposable cash for marketing, technology upgrade and other vices. With regards to the intensity of competitors, the analysis detailed below provides an in-depth understanding of the case company's competitors and their activities. The names of the companies have been replaced with arbitrary alphabets.

- **The case company's UK competitors**

With the exception of competitor A and competitor B all other competitors in the UK have emerged out of NTR Ltd over the last 28 years. Competitor B was established at

the same time as NTR but has never been able to compete against NTR's quality and service. However, what successive competitors have done is to drive down the value of reclamation by providing an inferior product and service to that offered by NTR.

Competitor A

With an estimated turnover of £300,000, Competitor A quote for all tooling repair and appear to be the only competitor who have not been drawn into a discount battle. The Chairman and owner runs two other companies and uses his skilled Millers to support both businesses. They have recently appointed a sales representative for the North West, a centre of excellence for aeronautical manufacturing and subcontract, although no real inroads have been made to date, possibly due to the poor standard of reclamation being undertaken, (based on recent tooling received). The company made a post tax, post appropriation profit of £9,000 in 2003. Liquidity has improved over the past year from net current assets of £608,000 to net current assets of £622,000. Bank and cash figures total £528,000. Reserves stand at £696,000. For credit insurance purposes the credit limit is nil.

Competitor B

Competitor B is based about 40 miles from NTR and has a turnover of £480,000. The profit and loss account suggests that the company made a post-tax, post-appropriation profit of £57,000 during the 2003 trading period. There are intangible fixed assets of £108,000. Net current liabilities are £132,000. Bank and cash figures total £9,400. Reserves stand at £57,000. The company appears to be of sufficient financial stability to undertake contracts to a value of £75,000. Key accounts include X which NTR are currently tendering based on poor quality reclamation provided by competitor B.

In 2006 the business was bought (management buy-out). Since then the business has struggled and a recent meeting held between NTR and competitor B suggest that NTR is a real and significant threat to their future.

Competitor C

No real information available – other than the fact that the business is run out of a small unit by the son who does everything. Low volume, low value turnover servicing North Eastern customers.

Competitor D

The profit and loss account suggests that the company made a post-tax, post-appropriation profit of £22,100 during the first trading period. There are intangible fixed assets of £284,050. Net current liabilities are £271,000. Bank and cash figures total £70,000. Reserves stand at £22,100. For contracts, it is suggested that a performance/indemnity bonding is obtained; a credit limit on monthly terms of £ 1,000 is recommended.

- **The case company's competitors in Germany**

Germany outside the UK is the only other country to offer tooling reclamation. Germany was once a bastion for NTR, however as a result of falling quality (production management rather than process) and the sale of the Germany Agency representing NTR, the market and business was lost at the end of 1990. Since then NTR have not made any real attempt to return, allowing competition to develop.

Competitor E

Competitor E is NTR's largest competitor in Europe, however Competitor E use Spark Erosion to remove weld. This process combined with higher employment costs means that Competitor E's ability to compete in the export market has been limited. However, they dominate the German reclamation market and this combined with Germany's reluctance to trade with non-German suppliers has strengthened their position. (NTR have recently approach Y in the UK to better understand their position and to date unless we employ or are based in Germany trade is unlikely). Estimated turnover for Competitor E is £1.5 to £2 million.

3.3.2 Industry Analysis using PESTLE Framework

PESTLE analysis allows one important aspect of strategic analysis (the external environment) of an organisation to be investigated systematically by the use of a simple methodology. Illustrated below in **Table 3.3** is the application of PESTLE approach in an effort to understand the wider business environment of the case company and impacts on lean manufacturing strategy deployment. The information in **Table 3.3** were collected through an eclectic approach which included discussion with the Managing Director of NTR Ltd, NTR Ltd's Europe agents, UK sales agents, production team leaders, key customers, key suppliers, competitors website and market performance, research on current manufacturing trends as reported by the EEF and other various UK governments based manufacturing/engineering association

POLITICAL	ECONOMIC
<ul style="list-style-type: none"> • Change in Govt/leadership reduced investment in funding for Manufacturing • Commitment to contracts Airbus/Boeing/MoD etc • EU closed vs. open economy • Change in working practices, hours/min wage/paternity etc 	<ul style="list-style-type: none"> • Shift in manufacturing base • Cost of employment: high cost of UK staff relative to Far East • Margins – UK vs. Overseas • Emerging economies and labour market opportunities/threats • Growth/Recession –likelihood: finance dependent economy • Manufacturing incentives • Employer and Employee tax & National Insurance? • Fuel / Utility costs: \$105/Barrel (at time of writing)
SOCIAL	TECHNOLOGICAL
<ul style="list-style-type: none"> • Lack of skill • Ageing population • Aging work force • Ability to attract young people into business • Immigration and use of talent pool 	<ul style="list-style-type: none"> • Change in cutting tool tech – laser/water • Machine tool technology reducing tooling damage • Machining technology increasing process automation • Cheaper tooling alternatives
LEGAL	ENVIRONMENTAL
<ul style="list-style-type: none"> • Change in working time regulations • Health & Safety – handheld devises and noise. • Increased legislation on industry and individuals to recycling. 	<ul style="list-style-type: none"> • Carbon Trust and Global warming. • Increased pressure on Industry to act ethically. • EU/UK legislation e.g. Euro V emissions criteria for the automotive industry.

Table 3.3: PESTLE Analysis of NTR Ltd

The PESTLE analysis presented in **Table 3.3** suggests that NTR Ltd is susceptible to the current trend of globalisation and global economics. This impact is bore out in the fact that the cost of manufacturing (in particular labour) in the UK is relatively higher than developing economics hence the potential of the market place been flooded with cheaper tooling alternatives. Although the effective use of machining technology that facilitates lower set-up procedures, lower operator intervention (other loading and unloading parts, several machine to one operator), and high throughput offers potential for sustainable competition with developing economics. Furthermore, the aging population (experience) and the ability to attract young and dynamic individuals to the organisation

offers potential for reforms which can substantially improve the organisations competitive position.

3.3.3 Process Specific: SWOT Analysis

Recent empirical work suggests that successful strategies emerge from a comprehensive situation audit (Menon et al., 1999). On the one hand, the audit includes a planning input to a systematic evaluation of both external (opportunities and threats) and internal (firm strengths and weaknesses) environments (Novicevic et al., 2004). The process specific approach taken in analysing the case company's internal dynamics models the SWOT framework. However the context in which the external element of the framework is used is subjectively internal. Key factors in performing SWOT analysis of the case company are:

- Critical offer features (COF),
- Significant operating factors (SOF),
- Strategic resources, and
- Issues needing immediate attention.

3.3.3.1 Critical offer features (COF)

COF is used to determine the value a company can add to its core products or services. From observation, discussion & review of the shop floor & company's business plan, the operators and management appear to have an understanding of what the order-winning features for the industry in which NTR operates are i.e. quality, delivery & cost.

However, the COF are not properly managed, analysed and used to drive process improvement. These findings further suggest the need for lean manufacturing strategy deployment as a common platform for systems integration in NTR.

3.3.3.2 Significant operating factors (SOF)

The SOF is those characteristics of the operating environment where all successful businesses must have strong positions. SOFs within the reclamation industry will ideally involve the following:

- Product knowledge
- Capable manufacturing process
- Customer & Supply relations management (*concentration should be on 80/20 basis*): customer/supply/OEM/NTR development forum
- Disruptive Technology vs. Sustainable Technology (*Radical change vs. CI*)

3.3.3.3 Strategic resources

The resources of a company determine the value it can add to its products as well as the different types of offers it can offer. Strategic resources available within NTR Ltd from observation are:

- People
- Reasonable level of technology.

Although the level of involvement of the people is localised this conversely has enabled them to develop speciality skills in each work area. Furthermore, a worrisome issue is the transferability of these skills sets to new recruits (which often times is said to “take

up to two years for one to be competent on a range of parts”) and the diversification of NTR Ltd’s capability. This recognition of the organisation’s capability diversification is evident in the requirement for extensive manual milling (a core process at NTR). This might be a barrier to its flexibility because manual milling is labour intensive; there are limitation in the manual milling machines capability especially in handling circular interpolation and its repeatability and reproducibility of complex parts geometric configuration. In Chapter 7, opportunities are highlight on how to reduce/remove this barrier by effectively applying lean product development. The lean product development strategy will examine key issue such as CAD/CAM, concurrent engineering through technology requirements of the case company.

3.3.3.4 Issues needing immediate attention

The present issues as used in the context of this analysis are those issues that have to be reacted to fairly immediately to support NTR Ltd’s operations in the short term which will ultimately help deliver a long term lean strategic deployment. **Table 3.4** shows a SWOT table detailing key issues needing immediate attention with NTR Ltd’s manufacturing system.

Strength	Weakness
<ul style="list-style-type: none"> • Skilled Work Force • Functional Production Planning Methodology • Management's commitment to change & CI 	<ul style="list-style-type: none"> • No product development process for new tooling • Insufficient background information on tooling been reclaimed • Too many manual operations • Inadequate analysis of quality issue • No true knowledge of production capacity, ½ customer demand & cost of reclamation • Long waiting time & excessive transportation • Job shop type production process layout • Inadequate maintenance of work area & machinery • Poor glass wall location & inadequate key metrics for measuring production performance
Opportunity	Threat
<ul style="list-style-type: none"> • Develop cross functional teams • Develop a culture of quality at source (Built in Quality) • Develop flow type production process • Develop database of frequently reclaimed tooling • Introduce PMP, 5S culture & TPM (introduce standard mtce sheet) • Develop relevant key metrics for performance measure at cell/line/shop floor level (s) (daily, weekly, monthly, quarterly & yearly) 	<ul style="list-style-type: none"> • Over dependency on a set of highly skilled operator • No customer/OEM/NTR development forum (Customers Relation Management) • Over the wall syndrome (welding/CNC case study)

Table 3.4: Process specific SWOT analysis of NTR Ltd

3.4 The Change Management Approach

The emphasis on organisational change has been on the incremental, cumulative change process, which has been used to explain almost everything (Gersick, 1991). The dominant approach – the configuration school – assumes that organisations evolve mainly through periods of stability, which are interrupted by occasional discontinuities

(Miller and Friesen, 1984). These revolutionary changes are usually driven by external events, such as changes in technology, in the competitive situation or in the political conditions (Tushman and O'Reilly, 1996), but they may also be a result of internal factors (Gersick, 1991). Organisational changes range from slight adaptations to dramatic shifts in organisational structure, strategy and culture (Schuh, 2001).

The theoretical explanation of this development – the punctuated equilibrium paradigm – is based on the assumption that incremental change during the stable periods develops through adjustments to the existing system, with the activity patterns remaining the same, whereas during revolutionary periods the deep underlying structures in the system also change (Gersick, 1991). In **Figure 3.6** the practical application of the punctuated equilibrium paradigm of organisational change management utilised in deploying lean manufacturing as a manufacturing strategy in the case company is presented. **Figure 3.6** shows a three (3) stage lean manufacturing change management deployment strategy in the case company. Stage one (1) advocate the development of various continuous improvement (CI) projects and teams.

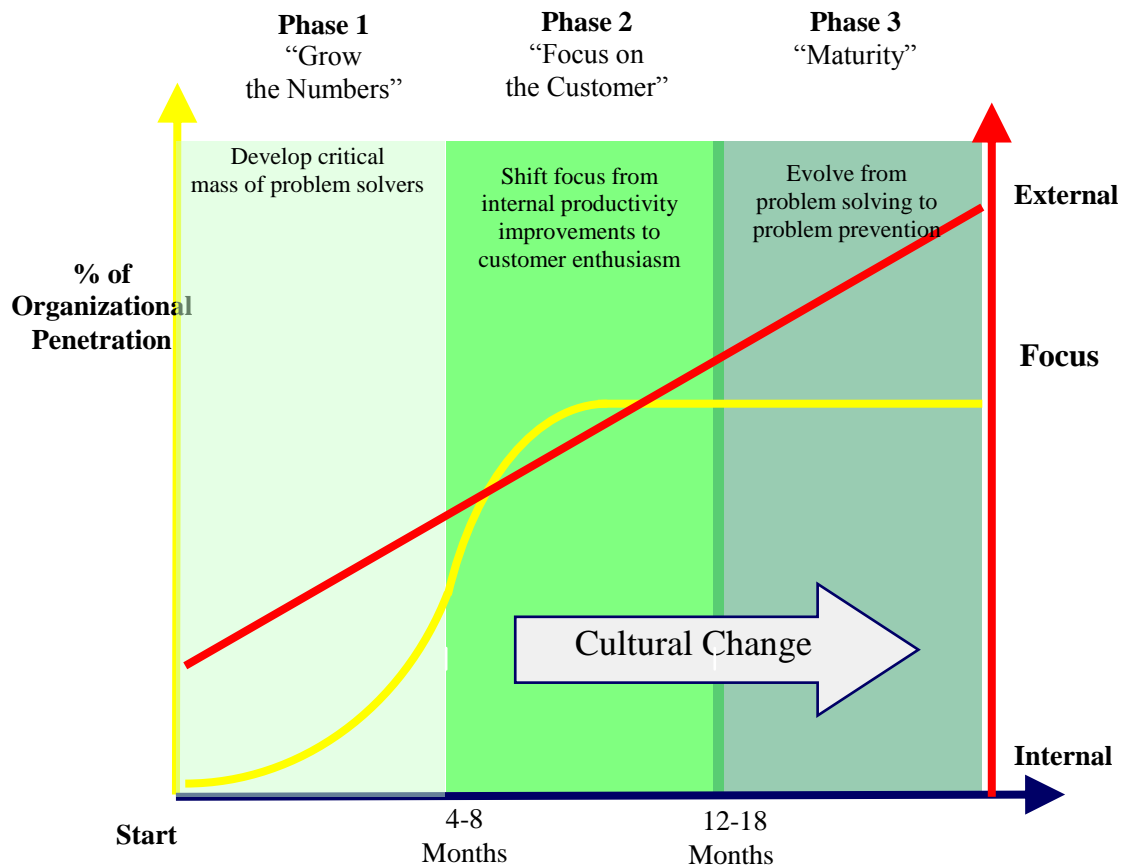


Figure 3.6: Lean manufacturing change management approach (Esan et. al, 2007)

This stage envisage that with good numbers of individuals nurtured on key principles and fundamental application of lean manufacture’s tools and techniques there will be less resistance to change. The manner in which this phase of change took place within the case study company was through a combination of classroom study (education and training) and practical application of the tools on the shop-floor (outputs from this exercise is presented in Chapter 5, 6 & 7). Furthermore, stage two (2) of the lean change management strategy involve shifting focus from internal productivity improvements to customer’s enthusiasm which is in-line with the Kano model. According to Kano these types of focus are regarded as satisfiers—performance requirements. Typical outputs from this stage include improved delivery time, product and offer enhancement through

manufacturing and product cost structure streamline and improved product quality. Finally, stage three (3) advocates developing control plans and being proactive as against reactive to process issues, that is, innovation and the development of innovative initiative that do not appear yet in the marketplace.

Additionally, for the change management strategy to be success there is need for performance indicators that shows the intention of any organisational change to be realised. Ideally, one would expect, to move the organisation from its current state to a more desirable, improved state hence the need for a “before” and an “after” state. Especially in busy, task-oriented organisations it can be tempting to focus on the “after” and to neglect the “before”, and the value of reflecting on questions such as “What sort of organisation are we?” and “What are we doing?” may be overlooked. The following section elaborates more on these key performance indicators, their application and measurement focus at the case company.

3.5 Key Performance Indicators

Manufacturing system key performance indicators (KPIs) provide opportunities for standardisation, communication and tracking continuous improvement. The plant is required to use these KPIs to communicate key manufacturing strategic objectives to all employees and accelerate continuous improvement in their work area. These KPIs will be posted throughout the facility to enhance plant floor communication. For optimisation of the plant manufacturing system, these KPIs will be analysed as a group. Since optimisation of any one indicator can be detrimental to another, for this reason, the indicators will be analysed as a set in order to manage improvement strategies and resources.

3.5.1 Indicator Focus and Review

To ensure performance improvements are occurring, frequent review of relevant KPIs should be done as part of process/production meeting. The focus is on trend analysis, rather than on month-to-month variation. **Table 3.5** shows the indicators requiring measuring and/or reviewing on a consistent basis within NTR Ltd. Measurement points for each indicator are described as Required (R) or Optional (O). The KPI in **Table 3.5** were established following extensive discussion with the Managing Director, and production team leaders at NTR Ltd and examination of current KPIs within the manufacturing system which are directly relevant to achieving an integrated manufacturing strategy based on Lean Manufacturing, six sigma, CIM and general plant performance.

Measurement	Function	Plant	Value Stream/ Department	Cell/Line/ Process
Health and Safety				
Lost Work Day Cases per 5 Employees	Mfg.	R	O	
Recordable Rate per 5 Employees	Mfg.	R	O	
Quality				
Rejected/Returned Parts Per Million (PPM)	Quality	R	O	
First Time Quality (PPM, % at Goal)	Quality	R	O	R
Operational Availability				
Operational Effectiveness (% , % at Goal)	Mfg.	R	O	R
Cost and Lean Manufacturing Performance				
Ship Window Compliance (PPM)	PC&L	R	O	

Table 3.5: Key performance indicators for NTR

3.5.1.1 Health and Safety (H&S): Lost Work Day Cases and Recordable

Lost Work Day Cases per 5 Employees and Recordable Rate per 5 Employees are measures of work environment safety, illness and injury data. The intent of measuring this function is to assess the level of risk employees are subject to in the work environment and to generate action plans to minimize this risk. This measure is for the previous 12-month period, not year-to-date or for the quarter. Both measures are tracked by plotting individual monthly data points and maintaining a rolling 12 month average for each measure. All leaders, shop floor delegates and H&S officer must review H&S data monthly with emphasis on the review of safety programmes and processes that will drive improved results. The health and safety process is generally a joint activity and should assure each employee's well being. NTR Ltd's management is directly responsible for H&S and should see it as the overriding priority of the organisation. The fundamental belief system that should be sponsored in the organisation is that **all incidents are preventable**. Management should see it as appropriate to elevate the communication and awareness of the recordable injuries and near misses. Each location is encouraged to create a communication system that ensures organisation-wide awareness.

Measurement Point
<ul style="list-style-type: none">• Lost Work Day Cases are measured at the plant level.• Recordable Rate is measured at the plant level.• Plant report data is aggregated to create an organisation-wide report,• Lost Work Day Cases are measured daily and reported on a monthly basis.• Recordable are measured daily and reported on a monthly basis.

Table 3.6: KPI- Health Safety & Environment

3.5.1.2 Quality: Rejected/Returned Parts Per Million

The number of customer rejected/returned parts per million is expressed as a ratio to the total parts shipped. This indicator is used to measure the level of product dissatisfaction which should lead to focused problem resolution within NTR Ltd. Rejected/Returned PPM should be sort by plant, product and customer. Internal calculations must use the calculation method requested by the customer. Note only product shipped to a customer is counted.

Measurement Point	Frequency of Measurement
<ul style="list-style-type: none">• Rejected/Returned PPM is measured at the plant level by product and customer.• Plant report data is aggregated to create organisational reports.• It is also appropriate to measure R/RPPM at the value stream level within the plant.	<ul style="list-style-type: none">• Rejected/Returned PPM is measured daily and reported on a monthly basis by product and customer.

Table 3.7: KPI: Rejected/Returned Parts Per Million (PPM)

3.5.1.3 First Time Quality (FTQ)

First Time Quality (FTQ) is the measure of the number of pieces rejected in NTR Ltd manufacturing process versus the total number of pieces attempted. The goal of tracking FTQ is to drive quality improvement. Prioritisation and improvement of the metric should help to drive quality improvement at the source and ultimately improve outgoing quality within NTR Ltd's manufacturing system. FTQ is reported in Parts Per Million (PPM). Calculation of FTQ should be owned and tracked by the manufacturing floor

work teams or their supervisor. FTQ is best tracked and improved by the work group that owns the process.

Measurement Point	Frequency of Measurement
<ul style="list-style-type: none"> • At a minimum, FTQ is measured at each work station, line, and major stand-alone process (e.g. the Heat Treatment facility) using the FTQ Tracker. • Further FTQ measurement points may be identified through the Failure Modes and Effects Analysis • FTQ Performance to Goal is measured at the plant level using a comparison of the number of processes that should track FTQ versus those who track FTQ and meet their goal and those that track FTQ but do not meet their goal. 	<ul style="list-style-type: none"> • First Time Quality is measured daily at each work station, line, and major stand-alone process and summarised monthly to drive quality improvement. • FTQ Performance to Goal is measured monthly at the plant level.

Table 3.8: KPI—FTQ PPM

3.5.1.4 Operational Effectiveness (OE) (%)

Operational Effectiveness (OE) is the actual production of good parts from a machine or process stated as a percentage of its designed capacity. The intent of OE as a KPI is to measure the level of operational availability of an area. Calculation of OE should be owned and tracked by the manufacturing floor work teams or their supervisors (Team leaders). OE is best tracked and improved by the work group that owns the process.

Measurement Point	Frequency of Measurement
<ul style="list-style-type: none"> At a minimum, OE is measured at each work station, line, and major stand-alone process using the OE Tracker. Further OE measurement points, at individual machines, constraint machines, etc. may be identified at the plant's discretion. OE Performance to Goal is measured at the plant level using a comparison of the number of processes that should track OE versus those who track OE and meet their goal and those that track OE but do not meet their goal. 	<ul style="list-style-type: none"> Operational Effectiveness is measured daily at each work station, line, and major stand-alone process and summarised monthly to drive performance improvement. OE Performance to Goal is measured monthly at the plant level.

Table 3.9: KPI—Operational Effectiveness (OE %)

3.5.1.5 Ship Window Compliance

The number of non-compliant (correct quantity and time) shipments divided by the total number of shipments sent in a given time frame. A customer shipment that does not have all the correct items in the exact quantity, shipped at the time specified, is considered non-compliant. Use as a measure of customer dissatisfaction. This indicator is captured for a given time period. There is generally a positive correlation between Ship Window Compliance and Premium Freight.

Measurement Point	Frequency of Measurement
<ul style="list-style-type: none"> Ship Window Compliance is measured at the plant level. 	<ul style="list-style-type: none"> Ship Window Compliance is measured daily and reported monthly to monitor any customer dissatisfaction.

Table 3.10: KPI—Ship Window Compliance PPM

3.5.2 The Golden Lean Check Matrix

Presented in **Table 3.10** is an integrated golden lean check matrix that contributes towards the incorporation of lean manufacturing principles and world class practise into

NTR Ltd's business system. There are numerous check-list and/or key performance related models with almost the entire genre having been developed in large organisations (Wilkes and Dale, 1998), for example the business excellence model, the balance scorecard, ISO 9000, Investors in People, business process improvement, etc. However, there are more or less no pragmatic studies which have investigated the employment of intermediate indicators to assess manufacturing changes towards lean system in SMME (Esan et al., 2007). The golden (the term "golden" is used to emphasis the degree of importance of the matrix) lean check matrix (Esan et al., 2007) enables intermediate measure of continuous improvement at the case company. Additionally, the golden lean check matrix provides a set of guidelines to follow in implementing three key areas for successful Lean Systems Design (LSD) as an operational strategy for delivering world-class performance: site lean method status, system issues foundation, and work method issues. These are identified with phases, check points, focus, results, tools, measures and who clearly specified. Furthermore the golden lean check matrix integrates the KPI defined in Section 3.5 into easily manageable and useable measure for purpose of continuous improvement SMMEs.

Area	Phase	Checkpoint	Focus	Result	Tool	Measure	Who
Site lean method status	Product & process knowledge	Shop floor	Short lead time, push & pull information	Identify system weakness, increase Throughput	VSM, order production, forecast	Leadtime, WIP	Production manager
System issues foundation	Scheduling Process	What is demand? Do we have clear shipping order from customer? Do we make an accurate schedule? Do we have clear production instruction?	Demand = shipping Order = production, Schedule = production instruction	Volume achievement, WIP reduction	Advanced Production Scheduling (APS), Critical Path Analysis (CPA), TOC-Constraints Management	Ship Window Compliance, Production Schedule attainment	Production Control and Logistics
		Does actual production = demand?	Schedule = actual output	WIP & Lead Time Reduction	Operations /problem registration sheet, hourly output tracking, uptime%		
	Capacity Utilisation	Does installed capacity meet the demand? Is capacity been used fully?	Installed Capacity	Line balancing, Investment efficiency	Standard Work, ABC analysis, Work Combination Table (WCT)	Longest Cycle Time Vs Takt Time, Installed Capacity Vs Output Vs Demand	Production
Work method issue	Cost Reduction	Do we make efficiently? Do we make the cheapest way?	Resource Utilisation	Manpower Reduction, Equipment Reduction	WCT, Multifunctional teams, Operations sheet	FTQ, % multifunctional team, Work Element and Takt Time	Production
			Investment Efficiency and material/consumable costs	Low cost/high quality Machinery Low material/consumable cost	Group Technology, Cell Systems Design, Cost Reduction engine	Productivity and machinery availability, Purchase part per cost per unit	Production & Purchasing
		Do we have support logistics for lean systems Design?	Logistics Cost Reduction	Low logistics cost—premium freight	Truck Flow Analysis	Delivery frequency, container quantity Vs Daily demand	Production Control & Logistics

Table 3.10: The golden Lean Check Matrix (Esan et al., 2007)

3.6 Summary

In this chapter, the need for Lean manufacturing and the details of the knowledge transfer partnership programme between the case study company and the University of Bradford has been defined. Additionally, the current business environment of the case company has been established using an industry specific and process specific analysis framework. The industry analysis used porter's five force analysis and the PESTLE external factor analysis frameworks. Key outputs from the porter's five force analysis were: barriers to new entrants and that the case company have little power to dictate to customer their needs in terms of price flexibility. A typical scenario is that Original Product Manufacturer (OPM) might achieve lower product cost (e.g. through flexible manufacturing techniques) to the extent that the cost of reclaim to cost of new is not significant enough to warranty product reclamation. This sort of behaviour further buttressed the need for lean manufacturing strategy deployment in the case company, as lean can significantly low manufacturing cost, hence achieving competitive advantage and sustainability.

In relation to the competitors interface in the porter's five force analysis it is found out in this chapter that with the exception of competitor A and competitor B all other competitors in the UK have emerged out of NTR Ltd over the last 28 years. Competitor B was established at the same time as NTR but has never been able to compete against NTR's quality and service. However, what successive competitors have done is to drive down the value of reclamation by providing an inferior product and service to that offered by NTR.

The chapter further investigated the external business environment of the case company through a PESTLE analysis. The PESTLE analysis shows the impact of globalisation on the UK manufacturing and the case company in particular and also demographically implication of changes on the age distribution on the case company. The PESTLE analysis further suggests that NTR Ltd is susceptible to the current trend of globalisation and global economics. This impact is bore out in the fact that the cost of manufacturing (in particular labour) in the UK is relatively higher than developing economics hence the potential of the market place been flooded with cheaper tooling alternatives. Although the effective use of machining technology that facilitates lower set-up procedures, lower operator intervention (other loading and un-loading parts, several machine to one operator), and high throughput offers potential for sustainable competition with developing economics. Furthermore, the aging population (experience) and the ability to attract young and dynamic individuals to the organisation offers potential for reforms which can substantially improve the organisations competitive position.

In addition, the chapter examined process specific issues relating to the case study company using a SWOT analysis, change management model and performance measure framework. The SWOT analysis identified typical opportunities for improvement at the case company as need for increased workers cross functionality, improved quality systems, improved work place organisation, production planning and control and so on. Whilst the change management model advocated the practical application of a punctuated equilibrium paradigm of organisational change management utilised in deploying lean manufacturing as a manufacturing strategy, a three (3) stage lean manufacturing change management deployment strategy in the case company was also

enunciated with stage one (1) advocating the development of various continuous improvement (CI) projects and teams, stage two (2) of the lean change management strategy involved shifting focus from internal productivity improvements to customer's enthusiasm and stage three (3) advocated developing control plans and been proactive as against been reactive to process issues, that is, innovation and the development of innovative initiative that do not appear yet in the marketplace

The chapter concludes by advocating that performance indicators are key criteria for integrating lean manufacturing policy deployment into the case study company as it explicitly shows the effect of changes taken place. The plant is required to use these KPIs to communicate key manufacturing strategic objectives to all employees and accelerate continuous improvement in their work area. Typical KPI developed in the chapter include: FTQ, HSE, OE%, and ship window compliance. To ensure performance improvements are occurring, the chapter suggested that frequent review of relevant KPIs should be done as part of process/production meeting. The focus is on trend analysis, rather than on month-to-month variation.

CHAPTER 4

LEAN MANUFACTURING AND STRATEGIC PLANNING

4.1 Introduction

Lean Manufacturing serves as a strategic planning prospect for SMMEs because it aids in the development of competitive advantage through streamlining product streams to reflect market needs, having adequate manufacturing plans to cope with market dynamics and competences to develop varying offering/pricing strategies that takes 'care' of the competition. The following sections of this chapter consider the application of the Product Family Matrix (PFM) and its functionality in breaking down products offered by the case company into manageable product families (or Value Streams).

PFM is a key criterion in any lean deployment, as it sets the tone for recognising where constraints exist within a manufacturing systems product family. The chapter further examine the relevance of forecasting in production planning and in particular its significance in generating Master Production Schedules (MPS) and expected customer demand volumes for the case company's manufacturing system. Based on key input from the PFM and the MPS, the chapter concludes by critically evaluating the case company's manufacturing cost and product cost structure and its role in strategic planning as this is core to effective lean policy deployment. In studying the actual manufacturing cost of products offered by NTR Ltd, the material, information and cost flows were studied (further examination of the material and information flow is detailed in Chapter 5).

4.2 Production Planning & Forecasting

Traditionally, production planning involves a gamut of techniques ranging from mathematical programming to ‘eye balling’, however for the purpose of this analysis and relevance of production planning techniques to the case company, the discussion presented in this section is limited to creation of product families and a master production schedule (MPS). The case company’s product exhibits a high variety, low volume structure but with no requirements for finished goods inventory, no explosive Bill of Materials: ‘spares’ and raw materials ordering are very limited (consumable monthly cost £500 to monthly T/O: £100,000) and there is very minimum form of assembly or sub-assembly. Although cases of capacity requirements planning (CRP) through machine and resource utilisation and production smoothing is applicable to the case company, this however, will be analysed in Chapter 5.

4.2.1 Product Family Matrix (PFM)

Product Family Matrix (PFM) is about breaking down the full product range of NTR Ltd, into groups that can be managed together, or share a significant part of a value stream. It is usually the first step in developing both a strategic advance and technical approach to manufacturing system’s optimisation. It helps to determine where to focus limited resources on data collection and observation, hence enabling the creation of Value Stream Maps (further discussion in Chapter 5) in the least possible way and with less effort.

Presented in **Appendix 4.1**, is the PFM of NTR Ltd’s manufacturing system. The analysis presents three (3) distinctive product families which are classified as: Standards (STD), Rotary (ROT) and CNC tooling product lines. The method utilised in arriving at the categories includes:

- Listing the process across the manufacturing system across the top of the matrix
- Listing each product down the side
- Marking which product use which process, and
- Sorting out products into families based on the similarity of process flow

Table 4.1 shows the customers demand pattern across each of these product lines. The values presented in **Table 4.1** are based on 2005 and 2006 invoice lines of the case study company. The 2007 and 2008 figures are forecast generated from the preceding years. The forecasting technique utilised is exponential smoothing with a smoothing constant of 0.8 allocated to the most recent value.

	2005	2006	2007 (F)	2008 (F)
Standards (STD)	11146	9535	9857	9793
Rotary (ROT)	6549	4211	4679	4585
CNC	4599	7092	5098	4998

Table 4.1: Customer demand pattern and two (2) years forecast

F: Forecast with α (Smoothing Constant) value of 0.8

The main objective of conducting this high level forecast is that output from this breakdown will form a key requirement in estimating the Takt Time (TT) (rate of production needed to meet customer demand) for each product line in Chapter 5. More so, the ability to predict the demand volume for the case company will enable it to plan its production capacity accordingly. Furthermore, the model in **Figure 4.1** shows the comparison between 2005/2006 quarterly product volumes across NTR Ltd's manufacturing systems. It illustrates that irrespective of the quarter of the year, the

manufacturing systems, volume distribution exhibits same fluctuation patterns with product clusters 1, 9, 13, and 16 having a consistently high volume ratio as compare to other products.

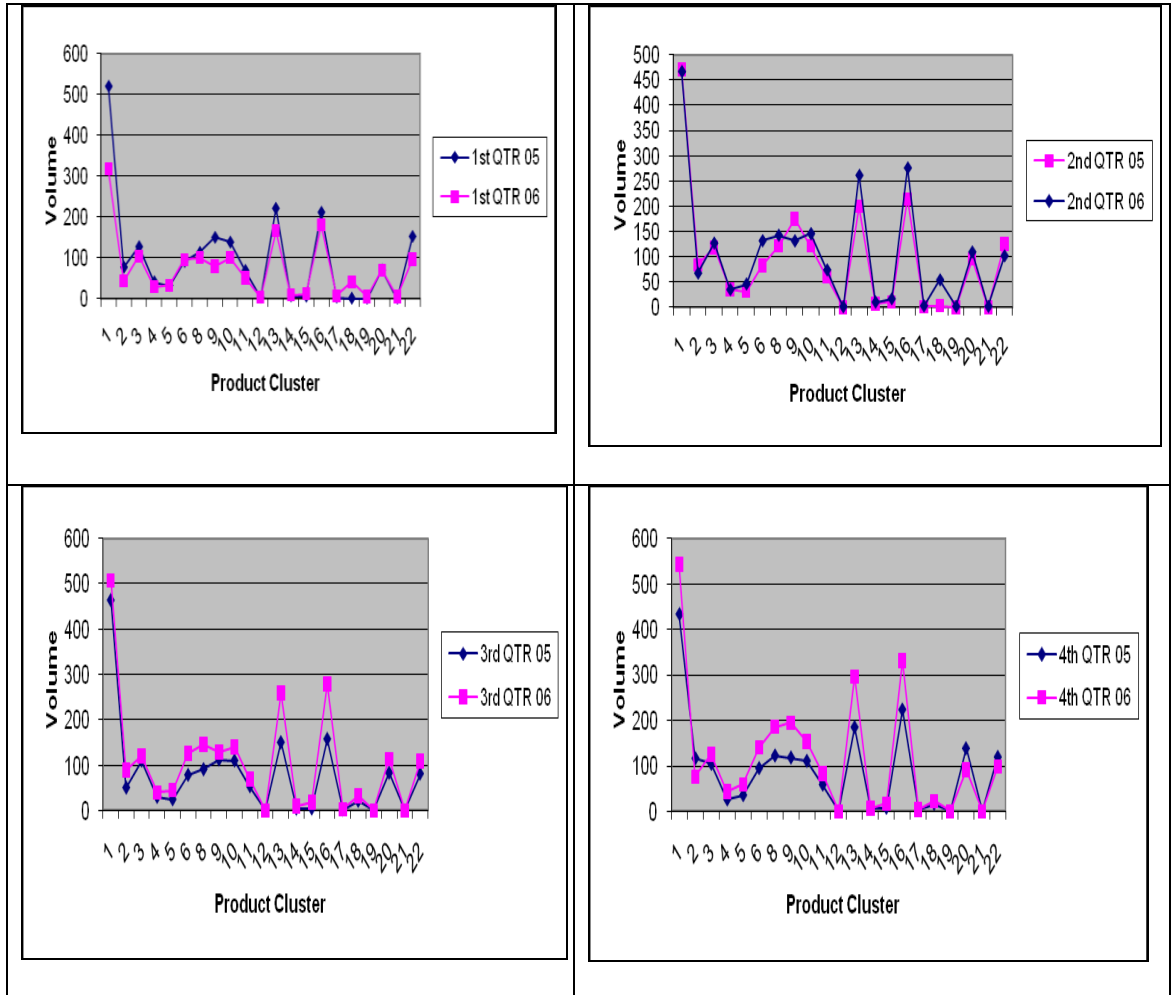


Figure 4.1: 2005/2006 product cluster quarterly fluctuation

In **Figure 4.2**, effort is made in deciphering the customer demand history of the case company using double exponential smoothing. Double exponential smoothing uses the level and trend components to generate forecasts. The forecast for m periods ahead from a point at time t is:

$$L_t + mT_t, \text{ where } L_t \text{ is the level and } T_t \text{ is the trend at time } t \dots\dots\dots \text{Equation 4.1}$$

Data up to the forecast origin time is used for the smoothing. The fitted trend in **Figure 4.2** shows a two (2) stage ‘sharp’ downward trend between years 2001 and 2006. This sort of downward trend re-emphasises the need for lean manufacturing in the case company because significant drop in inputs are evidence of poor management and management systems, poor quality, lack of continuous improvement, poor sales and/or marketing strategy, poor manufacturing and/or business strategy, low staff moral, and a host of ‘wasteful practice’ that exist within the manufacturing systems and the organisation as a whole.

According to Slack and Lewis (2002), volumes changes should lead to change in manufacturing strategy or the development of an integrated manufacturing strategy if the organisation does not have any form of strategic framework in place. Slack and Lewis (2002) further argue that dynamic sustainability is key to organisations competitiveness. This sort of sustainability should encourage both single loop and double loop learning or evolution.

Although there might exist some environmental constraints on the organisation as alluded to in Chapter 3 (that is, Porter’s 5 forces, and PESTLE analysis), core to effectively mitigating the negatives is the proactive application of lean manufacturing as an integrated manufacturing strategy. The deployment of the strategy should be sure that supports incremental and radical changes, which will have lasting effective on the manufacturing system. The initiative should not just cover the internal dynamics of the organisation but rather right through its supply chain and reflect the organisation’s trends.

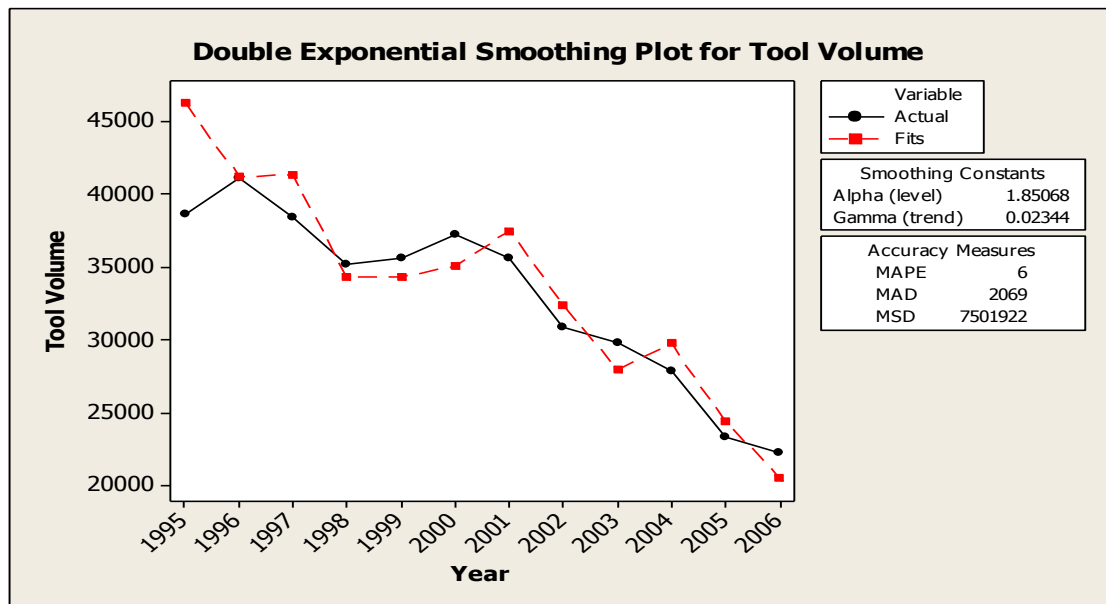


Figure 4.2: Customer demand history

4.2.2 Master Production Schedule

To further understand the individual break-down of each product produced across the product lines, a Master Production Schedule (MPS) (an aggregate plan showing required amounts vs. planning periods for multiple end items to be produced) was generated using exponential smoothing as a forecast mechanism. The special feature of using this (exponential smoothing) type of time series analysis is that successive observations are usually not independent and so the analysis takes into account the order of the observations, that is, exponential smoothing provides a forecast based on a weighted average of current and past values. In forming this average, most weight is given to the most recent observation, rather less to the immediately preceding value, less to the one before and so on. In the case of the MPS, most weight (a smoothing constant of 0.8) was given to the 2006 order figures whilst a weight of 0.2 was given to the current year.

In addition, the MPS structure for NTR Ltd follows a Make-To-Order (MTO) aggregate production planning structure. In this type of MPS, no order is scheduled until sales has occurred, thus future demand is usually an order backlog, no finished goods inventories exist and demand forecast always show a close match with actual demand. Presented in **Figure 4.2**, is comparison of the MPS and actual production for four (4) months – January to March 2007.

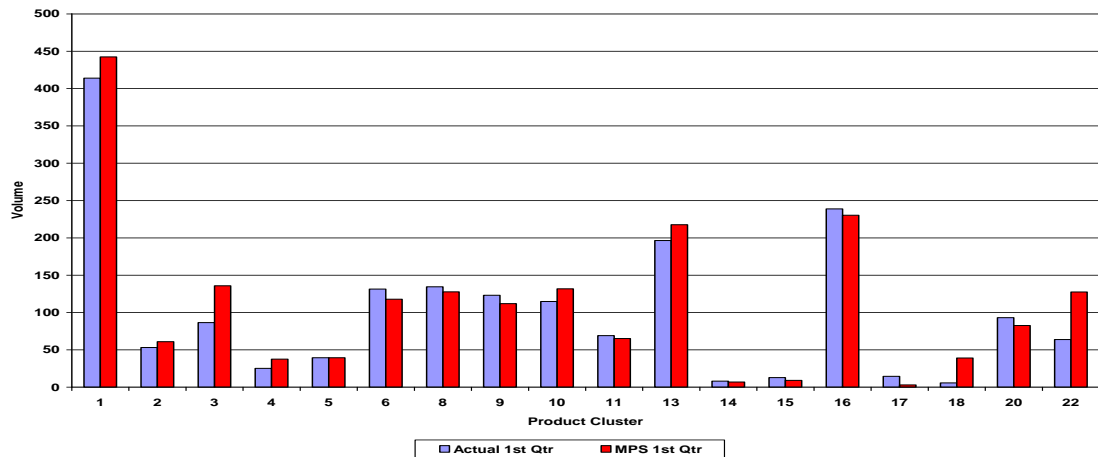


Figure 4.3: MPS and Actual Production for four months in 2007

The analysis of variance (ANOVA) presented below further illustrate the correlation between the forecasted MPS and actual production for quarter one at the case company. The finding from the ANOVA is that since the P-value is greater than the alpha value (single factor ANOVA at 0.05 significance OR 95% confidence level) the null hypothesis cannot be rejected, that is, the means can be assumed equal.

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Actual 1st Qtr	18	1822.333	101.2407	10373.03
MPS 1st Qtr	18	1984.933	110.2741	11241.63

ANOVA

<i>Source of</i>						
<i>Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	734.41	1	734.41	0.067955	0.795911	4.13001
Within Groups	367449.3	34	10807.33			
Total	368183.7	35				

Table 4.2: ANOVA MPS V Actual

4.3 Manufacturing Cost and Product Cost Structure

The approach taken in developing the manufacturing cost and product cost structure of the case study company is the well known value engineering concepts of multiple-stage manufacturing system accumulating costs between individual stages as well as by transfer/material handling and work-in-process. The details collected also include principal industrial statistics (such as salaries and wages, cost of materials and supplies used, cost of energy and water utility etc.), as well as information about the products produced and consumed. The analysis also shows that due to the ‘labour intensive’ nature of NTR Ltd’s manufacturing system; costs are dominated by the costs of labour. Considering the stated cost is a major factor in its manufacturing activities, the organisation is susceptible (staff T/O to Volume ratio) to any fluctuation in salaries and wages.

The results presented in **Table 4.2** shows the database layout for a 12-20mm short-hole drill. Presented in **Appendix 4.2** is a comprehensive MCT (Manufacturing Cost/Time) database of processing times and allocated cost for tool ranges offer by NTR Ltd. The extent of damage across a particularly product is specified. This was done in order to

damp systems repair time variability, to have a strong base for analysis and also to model various systems conditions with respect to capacity/resource utilisation and production planning.

		Shank Size 12-20mm		
Process Centres	Operation Time (Minutes)	Slightly Damage	Medium Damage	Excessively Damage
Booking In	Processing Time	2	2	2
Strip-Down	Processing Time	3	6	8
Welding	Setup	0.2	0.2	0.2
	Processing Time	6	8	12
Turning	Processing Time	1.5	2	2.2
Grinding	Processing Time	1	1	1
CNC Milling	Setup	10	10	10
	Manual Fitting	8	8	8
	Processing Time	23	23	23
	Walk Time	0.3	0.3	0.3
	Line Inspection	0.4	0.4	0.4
Finishing	Processing Time	7	7.5	7.5
	Line Inspection	0.3	0.3	0.3
Heat Treatment	Processing Time	3	3	3
Sand Blast & Spray	Processing Time	3	3	3
Final Inspection	Processing Time	3	3	3
Booking off/Packaging	Processing Time	4	4	4
Total Time		1.26 hrs	1.36 hrs	1.47 hrs
Cost		£69.39	£74.89	£80.58
Average Cost		£74.95		

Table 4.3: The MCT database layout

Table 4.3 shows the calculation and cumulative figure for the direct and in-direct cost within NTR Ltd's business system. The Overhead Recovery Rate was used in-conjunction with the total processing time in **Table 4.3** to estimate the cost to repair a product within NTR Ltd's manufacturing systems. **Equation 4.2** shows how this cost was deduced:

$$MCP_y = Cfn * (OpT_1 + OpT_2 + OpT_3 + \dots + OpT_n) \dots \text{Equation 4.2}$$

Where, MCP_y is Manufacturing Cost for Product Y across a particular damage category; Cfn is the Cost Function (the overhead recovery rate in **Table 4.3**) and OPT_{1-n} is the processing times of each operations the product goes through.

Factors considered when calculating the overheads include the cost of energy, water utility, administrative staff's salaries and expenses, motor expenses, rent and other administrative function. The sales to break-even cell in **Table 4.3**, was deduced by estimating the production staff wages, materials (consumables inclusive) cost, depression of machineries and other vices.

Available hours per Week	39
Working Weeks 52-7	45
Producers	22
Total Available Hours	38,610
Overheads (Full Year)	£550,000
Sales To Break Even	£1,341,463
Break-Even per hour	£35
Plus 30%	£10
Market Fluctuations**	£10
NTR Ltd's Overall Recovery Rate: Cost Function (Cfn)	£55

Table 4.4: Overhead Recovery Rate

Source: NTR Ltd's accounts department

**Safety factor

Furthermore, in order to guarantee the accuracy of the cost function (overhead Recovery Rate) allocated has the hourly rate, a market fluctuation section is added to compensate for any error in forecast, business overheads due to the enterprise dynamics, rate of

change in volume, inter-relation of cost volume factors, inflation and inherent systems variability.

4.3.1 Comparison of NTR Ltd 2007 Price to the MCT Database

This section compares NTR Ltd 2007 price with the MCT database, the purpose of this is to determine price variation with respect to processing time and examine if the company is actually making money across each product group, hence creating a strategic product planning view point of profit/value matrix. The analysis is streamlined to a set of product groups based on their historic demand volume and value.

Figure 4.4, shows the contrast between NTR Ltd 2007 and the MCT database for product cluster one (1) that is, External Tool holders. For shank sizes 3225, 3232 and 4040 mm, the company loses on average about £13 per tool repaired while for the 5050mm external tool holder gains about £4 per tool repaired.

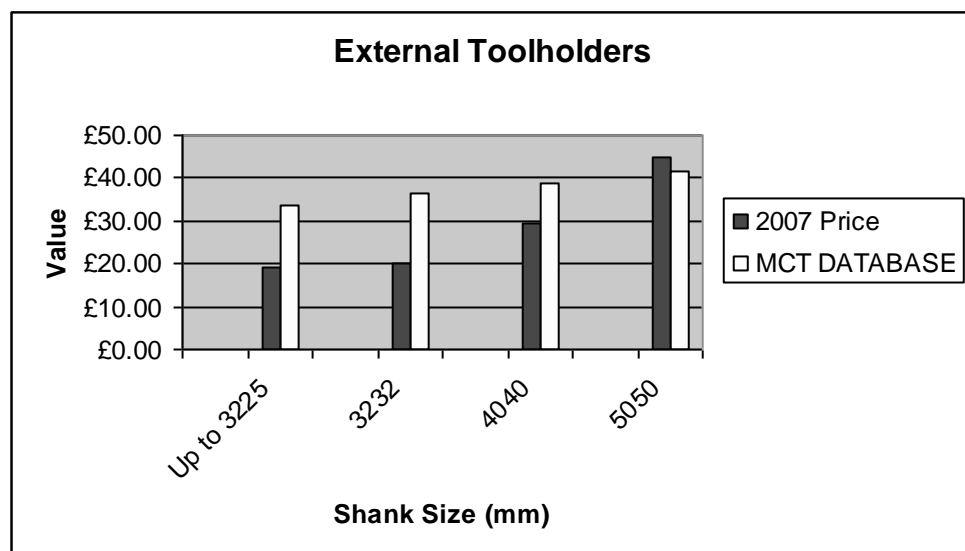


Figure 4.4: External Tool holders (Product cluster 1)

Figure 4.5 illustrates the product cluster two (2) value against the tool holder's shank size. Based on this comparison it's evident that the company loses on average about £31 per tool repaired. An assumption in calculating the total processing time is based on the fact that each tool will require different set-ups when being processed at the CNC milling workstation. However, for a run (Batch) of tool holders with same pocket geometry across this product range there is potential savings of about 10minutes per tool (set-up time).

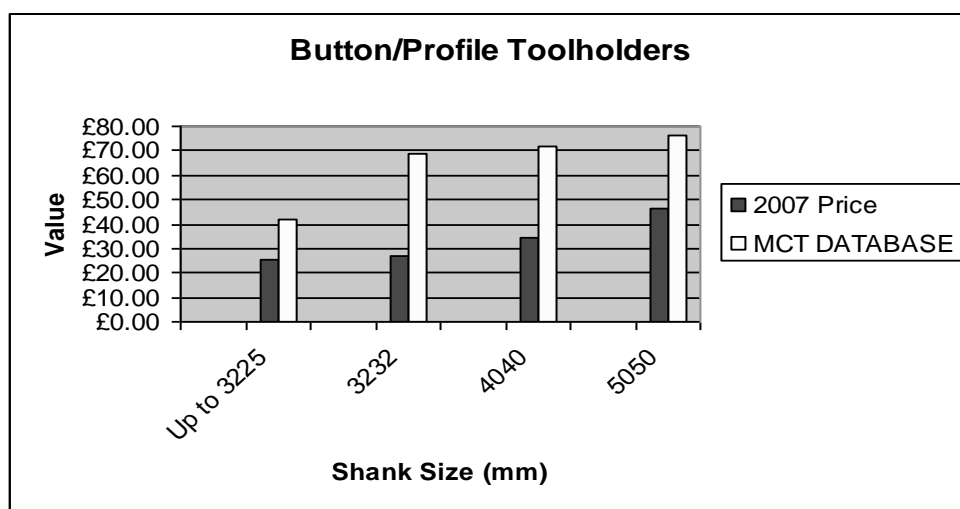


Figure 4.5: Button /Profile Tool holders (Product cluster 2)

For product cluster 3 (Parting, Grooving and Threading Tool holders), **Figure 4.6**, shows a graphical representation of the deviation between NTR Ltd's 2007 price list and the MCT database. With an average value of about £15 lose per tool repaired; the company is not making profit on this tool holder range!

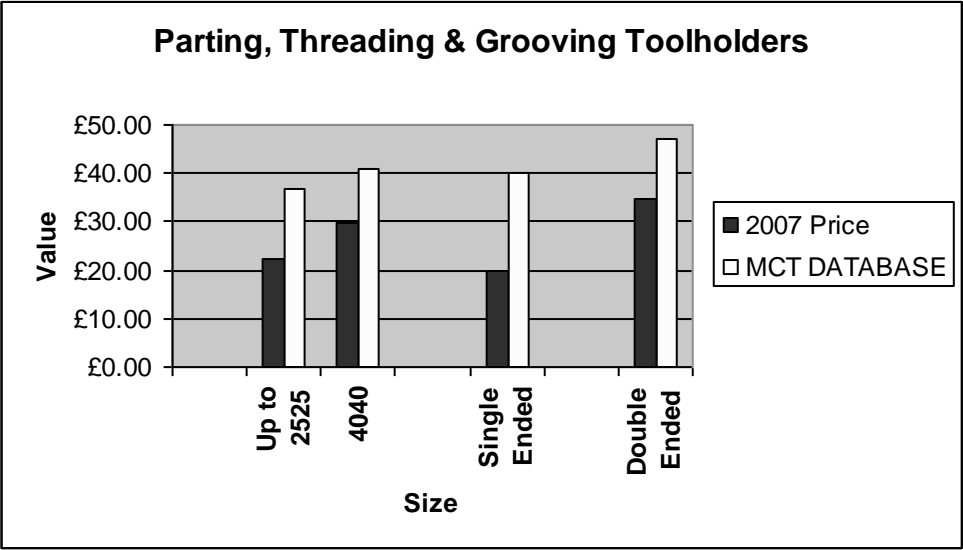


Figure 4.6: Parting, Threading & Grooving Tool holders (Product cluster 3)

Figure 4.7, demonstrates the deviation in value between the NTR Ltd’s 2007 price list and the MCT database. Loses of up to £7:00 is witnessed for the small sized tool holders while gains up to £17:00 is evident for the larger size tool holders.

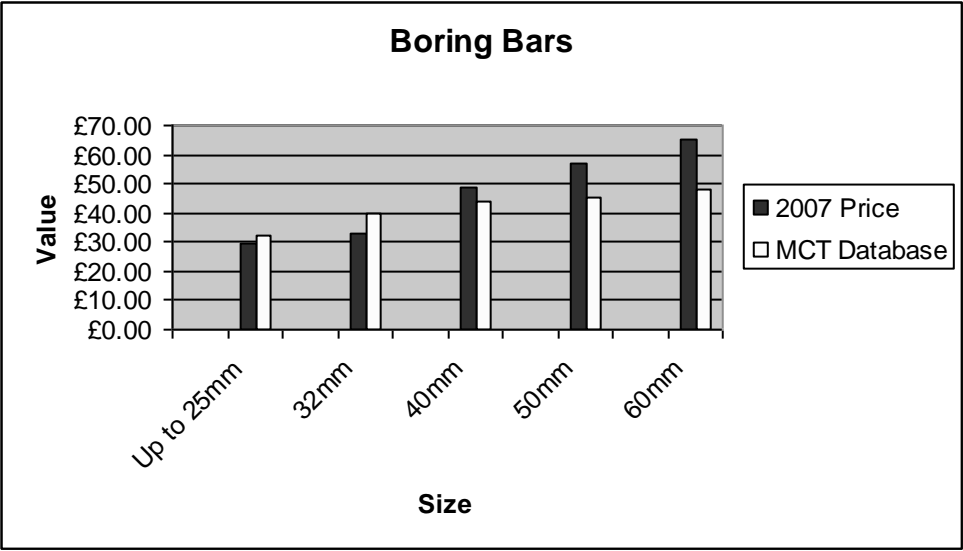


Figure 4.7: Boring Bars (Product cluster 1)

From **Figure 4.8**, it's apparent that NTR Ltd makes substantial profit from this product group. Profit as defined, is comparison of the 2007 price list to the MCT database. Gains of up to £10 - £40 are obvious across the products size range. The irony however, is that these tool holders are of same shape and size (pocket area wise) as the boring bars (product group 6) but the pricing is quite different. A school of thought has it that the price was set based on the actual market value (OEM' price) of these products as against NTR Ltd's processing times.

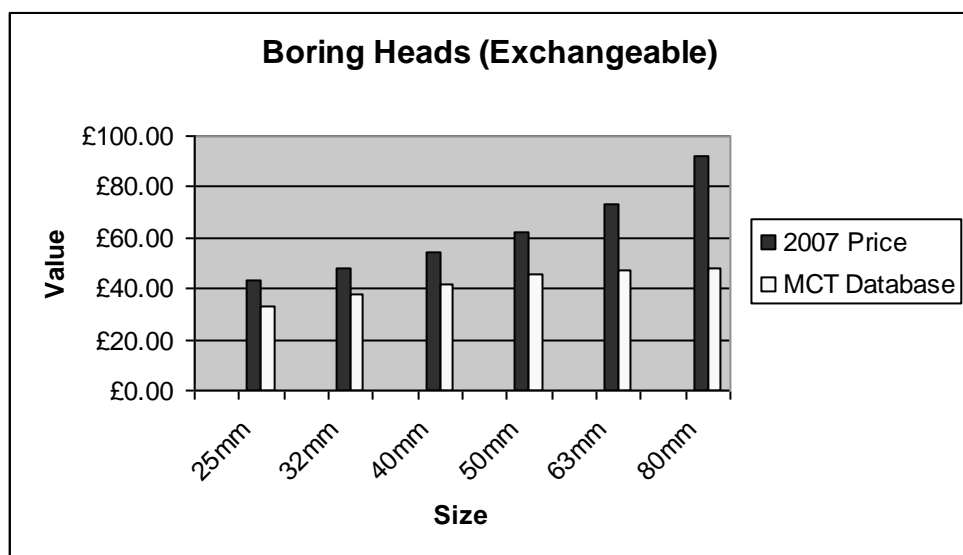


Figure 4.8: Boring Heads (Exchangeable) (Product cluster 5)

For product group 14, **Figure 4.9**, shows value against the tool holder's shank size. Based on this comparison it's evident that the company loses on average about £10 per tool repaired for shank sizes 12mm — 41mm, while for shank sizes 42mm — 59mm gains of about £10 per tool is plausible—break even point. As with product group two (2), the product is a family of the CNC milling product line and the assumption in calculating the total processing time is based on the fact that each tool will require different set-ups when being processed at the CNC milling workstation. However, for a

run (Batch) of tool holders of same geometry across this product range there is a potential savings of about 10minutes per tool (set-up time).

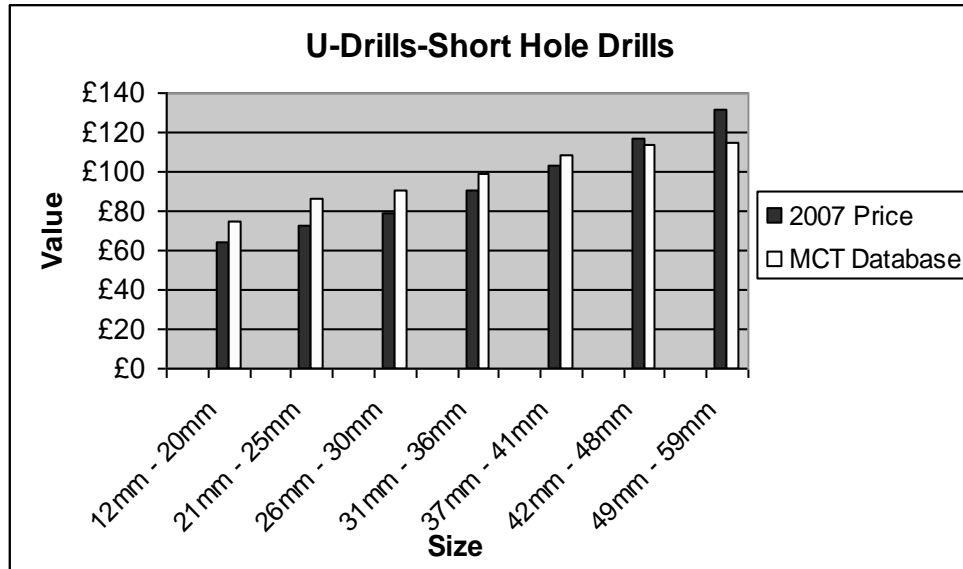


Figure 4.9: U-Drills—Short Hole Drills (Product cluster 10)

For product group 17, that is, Index-able End Mills loses of between £8:00 and £20:00 per tool repaired is observed across the product range. As seen from **Figure 4.10**, the deviation is more pronounced in the 16mm and 20mm tool ranges, a better pricing structure that takes into account actual processing times is recommended. For this particular product group it's essential that the company's pricing structure model the MCT database because it's high value and high volume. Product group 17 contributes about 7-9% of total tooling volume for year end 2005 and 2006 and month end January and February 2007.

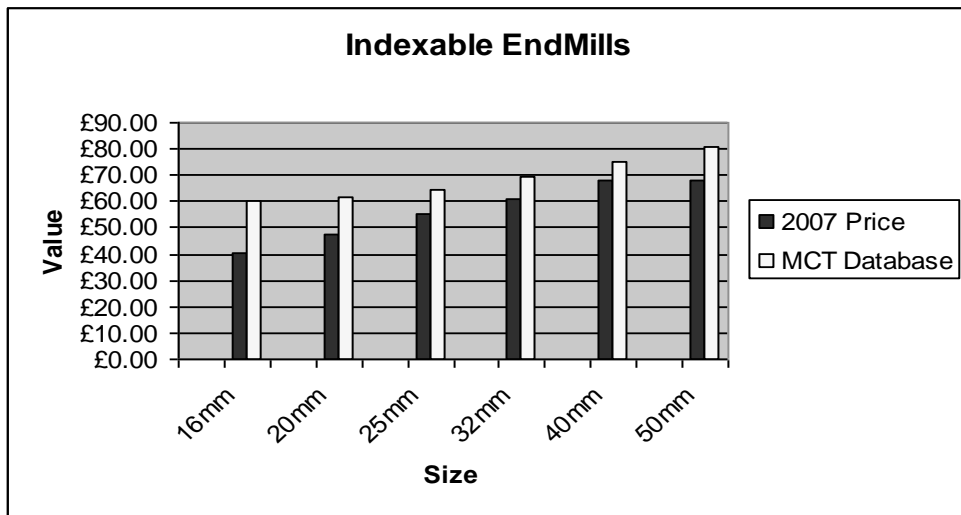


Figure 4.10: Index-able End Mills (Product cluster 13)

Figure 4.11, demonstrates the deviation in value between the NTR Ltd’s 2007 price list and the MCT database for the Long Edged Milling Cutters (Product cluster 6). Loses of up to £15:00 is witnessed for the small sized cutters (20mm & 25mm) while gains between £18 —£132:00 is evident for the larger size cutters (32mm – 125mm).

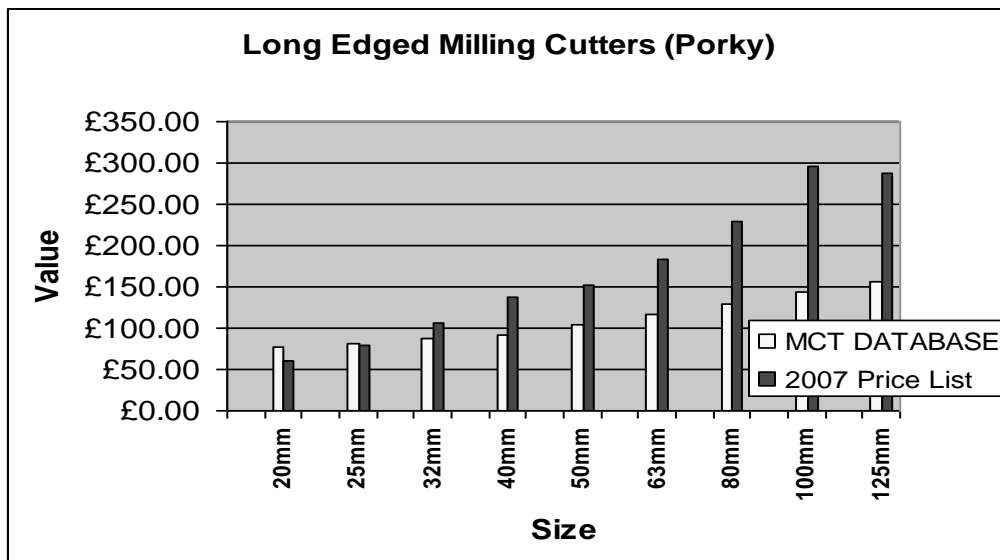


Figure 4.11: Long Edged Milling Cutters (Product cluster 6)

Product cluster 16 (Milling Cutter), shown in **Figure 4.12**, exhibits a similar pattern to Figure 4.10. This connotes that the smaller sized cutters (50mm — 100mm) exhibits loses of up to £20:00 while gain between £48 — £230 is evident for the larger size cutters (125mm — 315mm). An important variable considered when assigning the processing time to these tool holders is the number of pockets on the cutter.

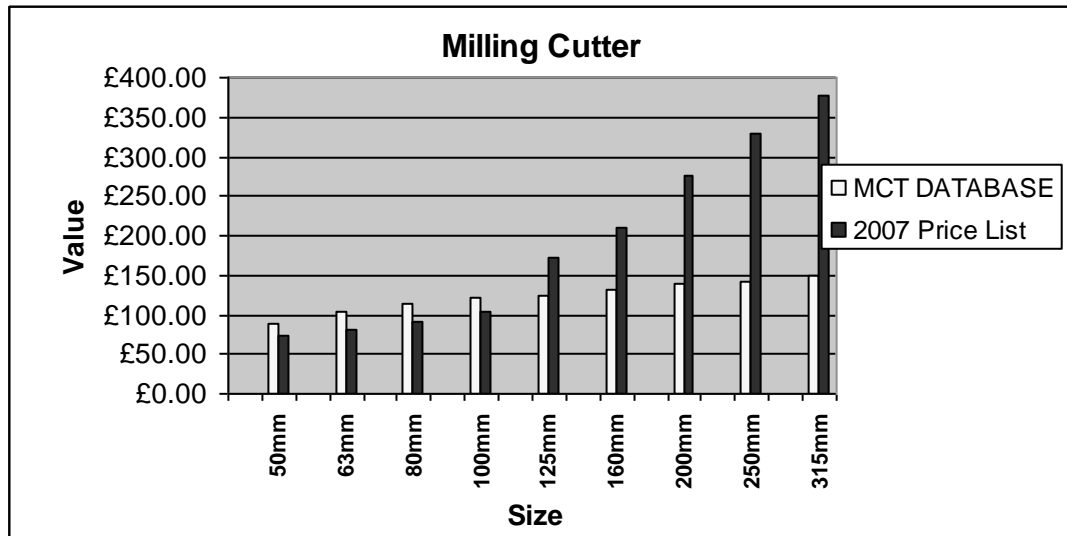


Figure 4.12: Milling Cutter (Product cluster 16)

4.3.2 Profit/Value Matrix

Following the analysis in section 4.3.1, **Table 4:4**— Profit/Value Matrix of NTR Ltd’s products — shows an implicit relationship between profit and value across the case company’s product families. Value in the case of this analysis is the selling price of a product. The analysis reveals that the rotary product family (ROT) is highly profitable and high value, whilst the CNC product family (CNC) is low profit and high value. Although, the standards product family (STD) is practically not profitable and of relative low value, however, the analysis further establishes that a product: Boring Heads Exchangeable of the standards product family is high profit but low value.

Profit	High	Boring Heads (Exchangeable) (STD)	Milling Cutter and Porcupine Cutter (ROT)
	Low	External, Parting, Threading Tool holders (STD) and Button Tools (CNC)	Short Hole Drills (CNC) and Index- able end mills (ROT)
		Low	High
		Value	

Table 4.5: Profit/Value Matrix of NTR Ltd’s product

Furthermore, the very nature of the company’s services requires it to be a people intensive business, cost of sales are 56% and the need therefore to reduce or improve operational efficiency is critical. Any improvement in reducing the cost of production through better production analysis will significantly improve NTR’s profitability. By a better understanding and thereby improvements of the true production costs, it is anticipated that a 10% saving can be made in machining costs in addition to an overall in the pricing structure resulting in a further 15-20% increase in the Earning Before Interest and Taxes (EBIT) or the operating income. Quantifiable improvements made towards achieving this strategy are detailed in the remaining chapters of this research. A significant advantage of conducting the analysis presented in **Table 4.4** is that, it could aid the case company in introducing discounting strategies based on the matrix whilst developing a pricing strategy that implicitly examines the relationship between profit and value. Additionally, the matrix would assist in product line discontinuation and/or augmentation decision making process.

This type of manufacturing strategy is required in the current competitive environment of the case company as discussed in Chapter 3 because it serves as a proponent to lean manufacturing policy deployment (in terms of waste elimination). If a product or a product family is not profitable, Lean Manufacturing advocates that it's non-value adding! By streamline the case company's manufacturing system to value adding product or product families the company will substantially gain from lower overheads (direct labour cost and utilities), increased focus on high and low value, but high profit products or product families and a leaner (high quality, low volume, low manufacturing cost, high profit to input ratio and high delivery rate) nonetheless more dynamic manufacturing system.

4.4 Summary

In this chapter, Lean Manufacturing and strategic planning has been defined, with a production planning and manufacturing cost and product cost structure approach established. The production planning framework established the Product Family Matrix (PFM) as a baseline in Lean Manufacturing policy deployment. PFM aggregated the product cluster of the case company into three (3) distinctive product lines: Standards, Rotary and CNC Tooling product lines. The chapter further create a master production schedule (MPS) for the case company using exponential smoothing forecasting technique and a smoothing constant of 0.8 for determining the MPS. The analysis suggested that the MPS structure for NTR Ltd follows a Make-To-Order (MTO) aggregate production planning structure, hence no order is scheduled until sales has occurred, thus future demand is usually an order backlog, no finished goods inventories exist and demand forecast always show a close match with actual demand.

The chapter also examined the manufacturing cost and product cost structure of the case company. The approach taken in developing the manufacturing cost and product cost structure of the case study company is the well known value engineering concepts of multiple-stage manufacturing system accumulating costs between individual stages as well as by transfer/material handling and work-in-process. The details collected also include principal industrial statistics (such as salaries and wages, cost of materials and supplies used, cost of energy and water utility etc.), as well as information about the products produced and consumed. The analysis showed that due to the 'labour intensive' nature of NTR Ltd's manufacturing system; costs are dominated by the costs of labour. Considering the stated cost is a major factor in its manufacturing activities, the organisation is susceptible (staff T/O to Volume ratio) to any fluctuation in salaries and wages.

The chapter concluded by critically investigating the output of the manufacturing cost by constructing a profit/value matrix. The products comparison showed an implicit relationship between price and value across the case company's product families. The analysis revealed that the Rotary product family is highly profitable and high value, whilst the CNC product family is low profit and high value. Although, the Standards product family is practically not profitable and of relative low value, however, the analysis further established that a product: Boring Heads Exchangeable of the standards product family is high profit but low value. Furthermore, the profit/value matrix was used to determine the relationship between Lean Manufacturing and strategic planning using a competitive discounting and pricing strategy approach and a product family discontinuation and/or augmentation for effective Lean Manufacturing strategic deployment.

CHAPTER 5

LEAN MANUFACTURING AND RESOURCE PLANNING

5.1 Introduction

This chapter discusses lean manufacture application in resource planning at the case company. The chapter examines the use of mapping, audit and analysis in establishing priorities for lean resource planning implementation. Furthermore, the chapter uses a value stream mapping technique and simulation to qualify the value added, non-value added elements, machine and operator utilisation, and input and output of the case company's manufacturing system after a lean assessment that studied the flow, organisation, logistics, metrics, and process control of NTR Ltd manufacturing system.

5.2 Mapping, Audits and Analysis

Mapping and audits are major analysis tools in lean (Bicheno, 2004). The aim is to establish priorities for lean implementation, both short and medium term. Mapping provides a visual aid for picturing work processes which shows how inputs, outputs and tasks are linked. It highlights major steps taken to produce an output, the steps, and where problems consistently occur. They allow one to view the big picture, to prompt new thinking about how work is done, to select priorities and to avoid rushing into inappropriate sub-optimisation activities (Bicheno, 2004). A prominent mapping technique used in this chapter is a Value Stream Map (VSM). VSM is created by following a product's production path from customer to supplier and carefully drawing a visual representation of every process in the material and information flow. Then by asking a set of key questions a "future state" map of how value should flow is generated.

Additionally, Mapping and Auditing (VSM in particular) helps visualise more than just a single process level and gives the potential to see more than waste due to its capability of identifying the sources of waste in the value stream (Bicheno, 2004). It also provides a common language for talking about the manufacturing process. There are three main elements in lean system's Value Stream Mapping:

- Current State,
- Continuous Improvement, and
- Action/Implementation Plan

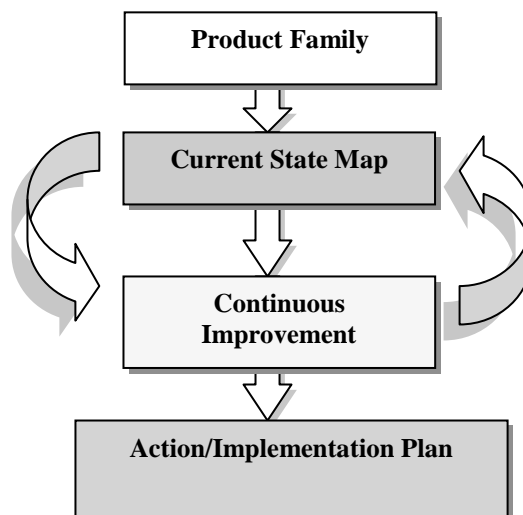


Figure 5.1: A typical value stream mapping approach

5.3 Lean Assessment

A lean assessment of NTR Ltd manufacturing system was carried out using the checklist detailed in **Appendix 5.1—Lean Assessment**. As seen from the appendix the flow, organisation, logistics, metrics, and process control of NTR Ltd manufacturing system are considered and rated accordingly during a GEMBA event. Key output from the lean assessment suggests that the case company's workstations are not designed to

meet daily customer demand, the manufacturing system lack one piece flow between operators, team leaders are not held accountable for end product performance results, there are no accurate production schedule, shopfloor performance are not continually targeted for improvement, shopfloor operators doesn't own and report their performance data, there is no formal continuous improvement programme, and there is no philosophy of "everything has a place and everything in its place".

Furthermore, the score rating of 46% from the lean assessment shows that a fair understanding of lean is demonstrated by NTR Ltd but guidance is required to reach the next level. This initial understanding of lean manufacture by the company had been enabled through two stages of process improvement under the auspices of the Manufacturing Advisory Services (MAS) with initiatives such as quote handling procedure review and production due date visibility (production batch weekly colour coding system) but with the lean assessment rating of less than average its apparent that the company is a long way from adopting lean manufacturing. Hence, the need to set-up current state maps to generate a clearer picture of the process route and procedure. Further to developing the lean assessment, a layout of NTR Ltd manufacturing system was mapped (**Appendix 5.2: NTR Process Layout**). This shows a detail view of how the process is laid out and how materials flow through the value stream.

5.4 Current State Value Stream Map

The need to understand how NTR Ltd's manufacturing system currently operates was possible by mapping, based on facts observed by walking the flow and conducting an activity sampling exercise. The steps involved in creating the current state map are as following:

- Understand customer demand (discussed in Section 4.2)

- Map the process flow
- Map the material flow
- Map the information flow

During the process of mapping the current state of NTR Ltd manufacturing system, the following attributes were documented:

- Shipping/Receiving schedules
- Cycle times (C/T) of each process or product cell
- Changeover time (C/O) of each process or product cell
- Number of operators required
- Machinery used and the uptime of machinery and operators
- Average batch sizes at each process
- Demand rates by customers (Takt Time) and working hours and breaks
- Defect rate, and work-in-process (WIP) inventory

It is worth noting that in estimating the cycle time of individual work stations of NTR Ltd manufacturing systems, random samples (intervals between observations are selected at random due to the variety of product processed at each process centre) of individual product's processing times was observed over a long period (total time taken for sampling was 3 months) with focus on various activities and various operators within a particular process route. Each observation records what is happening at that instant and the percentage of observations recorded for a particular activity is a measure of the percentage of time during which that activity occurs. Thereafter, the average processing times for the most occurring products at each product line was used as the cycle time for that operation.

Furthermore, the data set provided in this section is based on the product family matrix in Section 4.2 that is product grouping against their processing centres. The evaluation presents three distinctive product lines: CNC, Rotary and Standards. **Table 5.1** shows the available work time through NTR Ltd’s manufacturing system. The available work time for the production line is five (5) days per week and one (1) shift per day.

Potential Shift Patterns	Shift (Time in Minutes)
Available Time/Day	510
Contractual Time/Day	45
Planned Down Time	0
Scheduled Run Time	465
(Minutes / Week)	2325

Table 5.1: NTR Ltd available work time

5.4.1 Analysis of the CNC Product Line

Tables 5.2a & b, an extract of the VSM (see **Appendix 5.3**) for the CNC product line shows the current state attribute of the product line. The Takt Time (TT) was determined using the 2006 customer demand in Chapter 4, Section 4.1. From **Table 5.2b**, it is evident that the effective value added time within the CNC product line per tooling repair is 1.7 hours whilst the non value added time is 7 days @ 7.75hrs/day. The bulk of the non value added time within this process line is a direct result of the queue before the parts are processed at the CNC milling and welding workstation/centre and also due to poor First Time Quality (FTQ) at the CNC milling workstation. The FTQ data and issues needing resolution are further highlighted in Section 5.5.

Machine Type	C / T	C / O	Uptime	No. of Op.	No. of M/C	FTQ (%)	WIP	
	Mins	Mins	(%)				Before (No of Batches)	After (No of Batches)
Good-In	10	0	95	1	1	90	30	30
Pre-Inspection	1	0	90	1	1	80	30	20
Booking In	5	0	100	1	1	90	20	5
Strip Down	10	0	90	1	1	60	2	2
Welding	25	3	90	1	1	90	8	5
Turning	2.25	3	90	1	1	90	5	4
Grinding	5	1	90	1	1	90	4	12
CNC Milling & Line Inspection	20	35	50	2	2	50	12	5
Finishing	8	0	90	1	1	90	5	3
Heat Treatment	4	0	80	1	1	70	1	8
SS & Final Inspection	8	0	90	1	1	90	5	3
Despatch	4	0	90	1	1	90	8	4

Table 5.2a: Current state attribute of the CNC product line

In addition, **Figure 5.2** focuses on the queue by showing the location of work in progress (WIP) inventory within the CNC product line. The purpose of this is to further establish where the bottle necks exist so that they can be targeted for reduction / elimination. From **Figure 5.2**, it can be seen that the majority of WIP inventory (time dependent variable) in the CNC product line is found at points before production at the CNC milling workstation. The reason for this been that the welding workstation stores welded parts for a full day before ‘PUSHING’ it to the turning workstation.

	Minutes	Hours	**Days
Takt Time	14	0.23	0.03
Value Added Time	102	1.7	0.22
Non Value Added Time	3240	54	7
**Available Hrs/day = 7.75			

Table 5.2b: Current state data CNC product line (see VSM: **Appendix 5.3**)

The case against this kind of behaviour is that lean manufacturing identifies WIP inventory as the mirror of the imperfection system contain. Every imperfection creates a requirement for WIP in manufacturing. Apart from being a great reflector to the system imperfections, WIP inventory becomes a waste by itself. Therefore work in progress inventory in general is classified as a waste in lean waste classification. With higher WIP inventory, capital will be tied up. Problems are hidden in higher work in progress and will be not possible to remove from the system. For example if we have one day of work in progress with us, a part manufactured today will be used in the next work station only tomorrow. If we start making a quality defect today, only by tomorrow we will get to know about that. So we will loose full one day of effort. Worst part is we have to redo it. This is almost three times of the effort and cost.

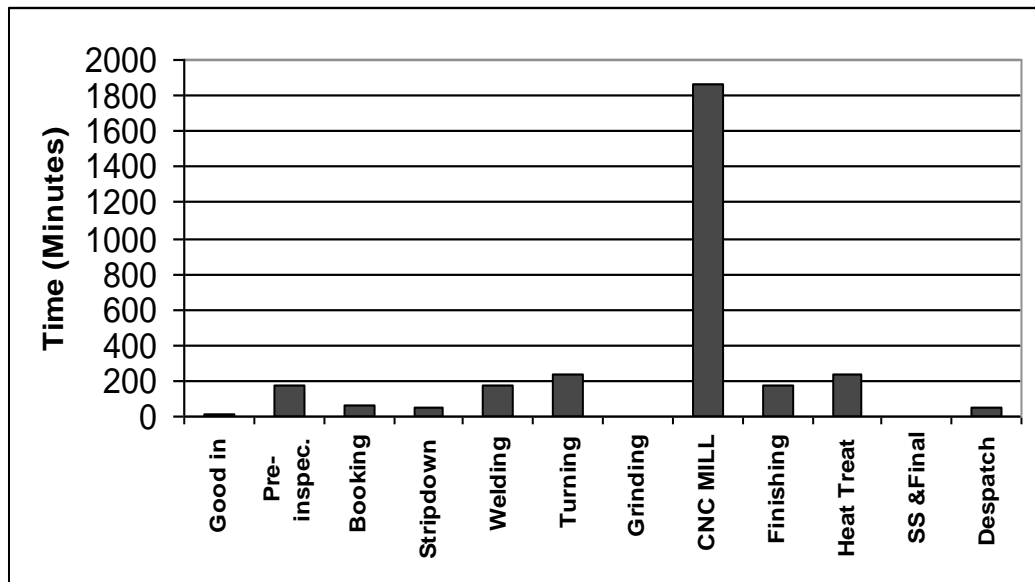


Figure 5.2: Major WIP inventory location in the CNC product line

5.4.1.1 Machine and operator utilisation CNC product line

Figure 5.3a & 5.3b shows the cycle time analysis of the CNC product line. Figure 5.3a examines the effective machine utilisation. From the graph it is obvious that the over-cycled workstation within this product line is CNC milling. Although the turning and grinding workstations appear to be over cycling, it should be noted that the number of parts produced per period is 20 as against 1 part produced at the CNC milling workstation. The Process Cycle Efficiency (PCE) (indicates how efficiently the process is converting work-in-process into exits/completions: $\sum CT / ATT$) for the CNC product line is **37%** (**Appendix 5.4** for summation of the Longest Cycle Time or Actual Takt Time (ATT) against the Takt Time (TT)).

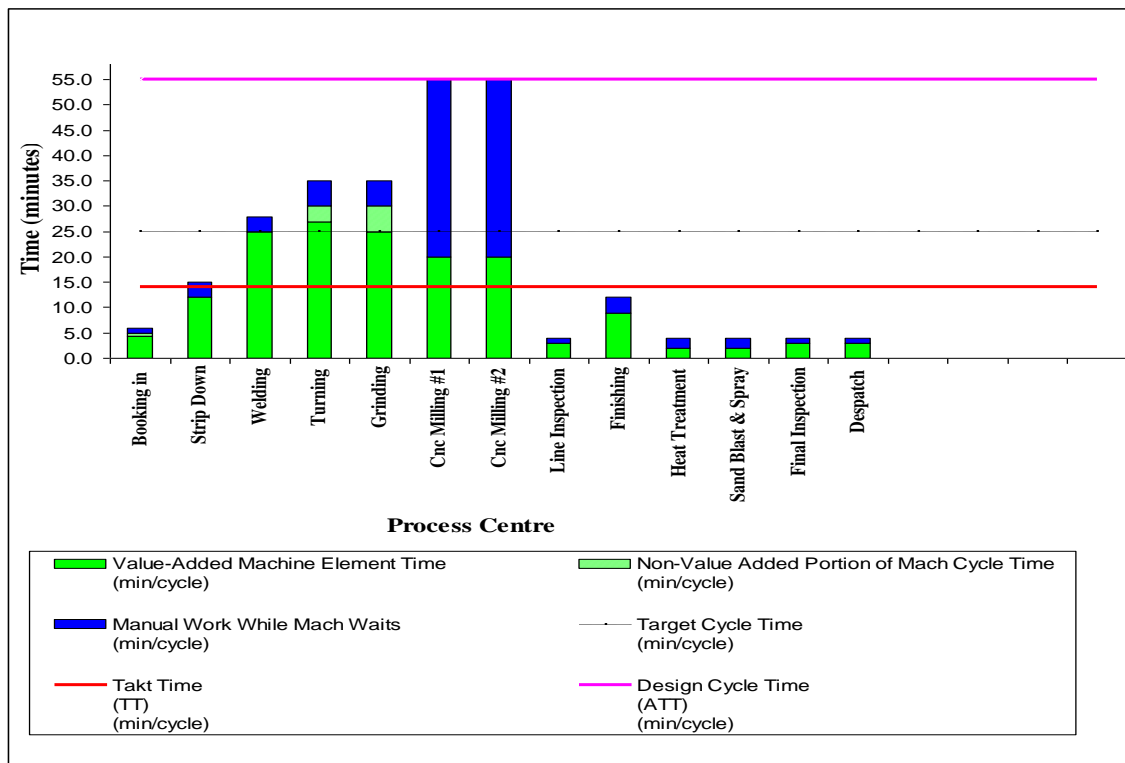


Figure 5.3a: CNC product line machine utilisation chart

Furthermore, **Figure 5.3b** shows the manual work and the forced waits at the CNC product line. This operator utilisation chart goal is to further breakdown the non-valued added elements from the machine utilisation chart in the **Figure 5.4a**. From the graph below it is obvious that a chunk of the non-value added activity within the product line is found at the two (2) CNC milling workstations with manual work of about 33 minutes and forced wait for machine cycle of 2 minutes. The PCE for the CNC product line operator's utilisation is **21%**.

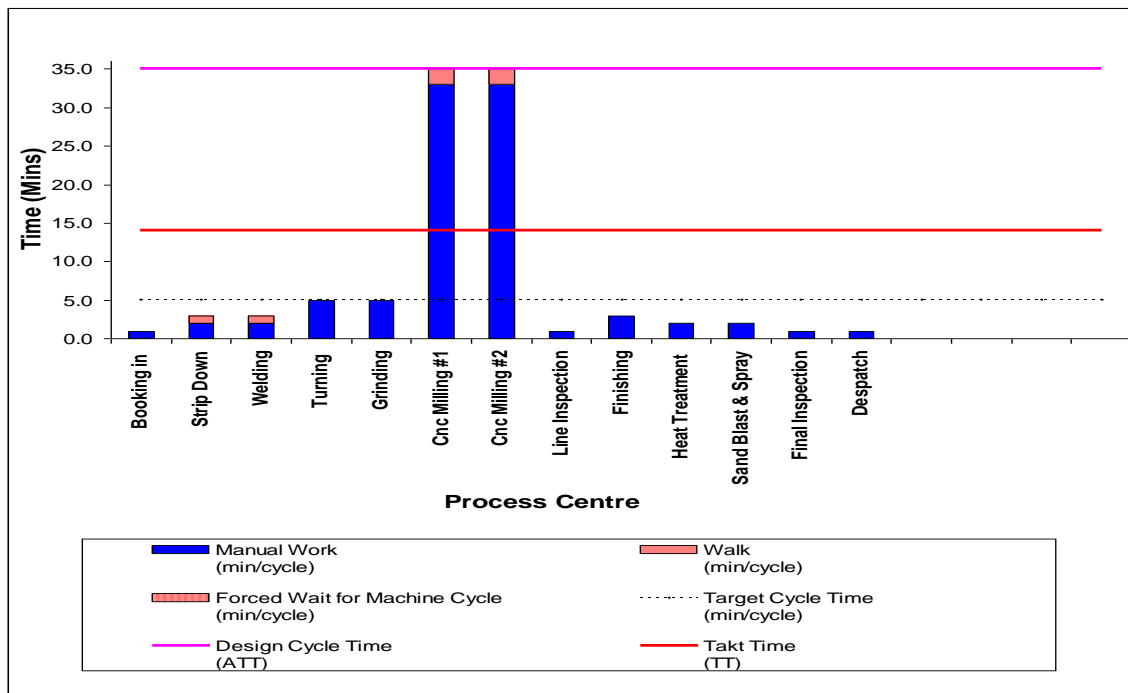


Figure 5.3b: CNC product line operator utilisation chart

5.4.1.2 Work combination table CNC product line

Figure 5.4: work combination table (commonly used as a standard work combination table at process standardisation stage but used in this instance as a detailed activity map) of the CNC milling workstation, shows an initial detailed activity map which explains the sequence of operations within the process centre. The aim of this activity map is to further understand exactly where in the machine and operation utilisations (**Figures 5.3a & b**) does value added, necessary non-value added and non-value added activities accumulate. From **Figure 5.4**, it is evident that the operator's cycle time is above the process takt time. This number is determined by comparing the operator's cycle time to the cycle times of the individual machines they run. This number is the larger of the manual work or the machine cycle times. This number represents the cycle time that limits the operator's output.

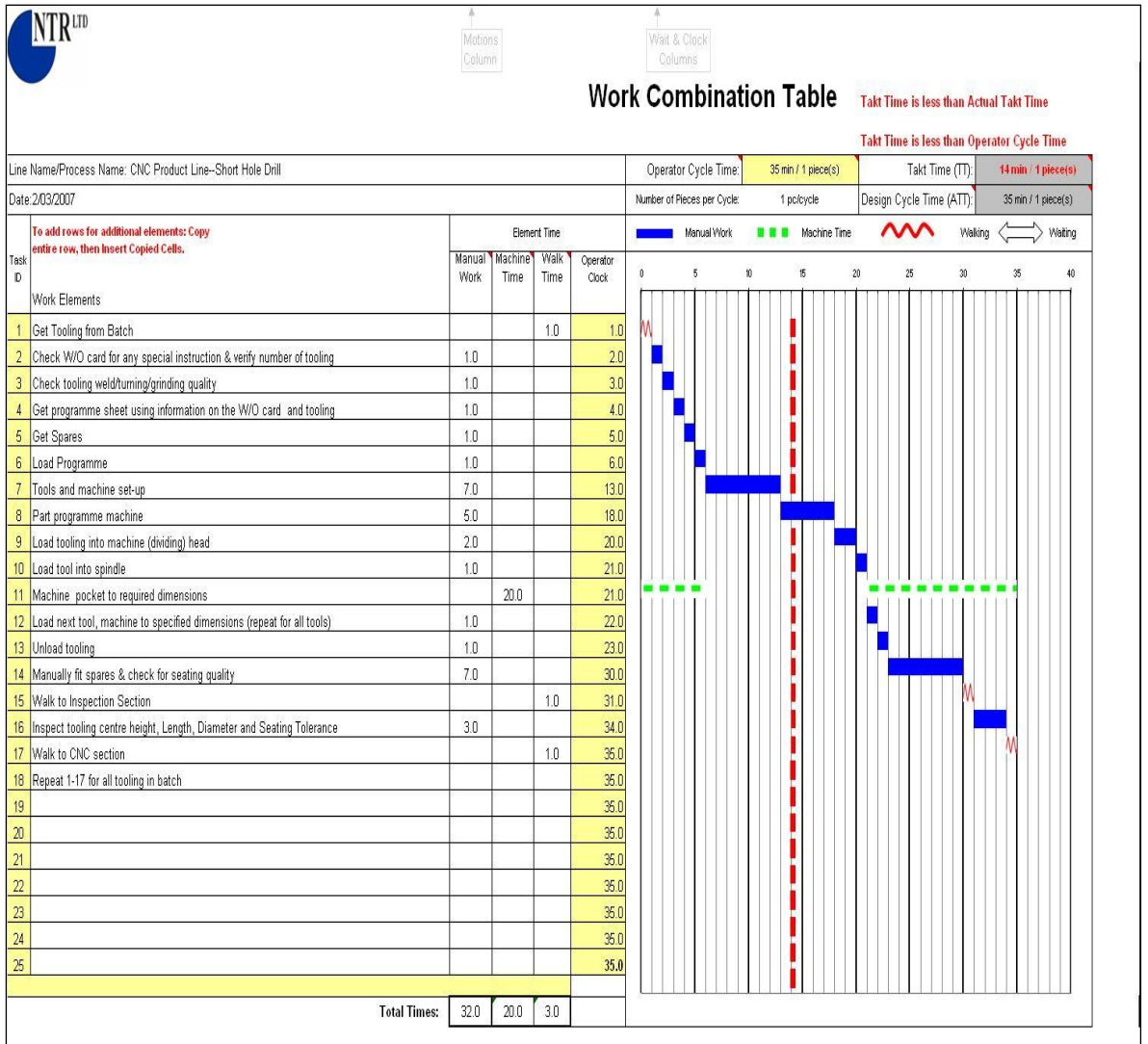


Figure 5.4: work combination table of the CNC milling workstation

Additionally, **Figure 5.4** also shows that work elements 7, 8, 14 and 16 accumulate a staggering 22 minutes of both necessary non-value added and non-value added times. In particular work elements 7 & 14: tools & machine setup and manual fitting of spares & checking for seating quality, amass 14 minutes of the total necessary non-value added activity.

5.4.2 Analysis of the Rotary Product Line

Tables 5.3a & b, an extract of the VSM (see **Appendix 5.5**) for the rotary product line (ROT) shows the current state attribute of the product line. From **Table 5.3b**, it's evident that the effective value added time within the Rotary product line per tooling repair is 1.95 hours whilst the non value added time is 8.3 days @ 7.75hrs/day. The bulk of the non value added time within this process line is a direct result of the queue before parts are processed at the Rotary milling workstation/centre and also due to poor First Time Quality (FTQ) at the Rotary milling workstation. The FTQ data and issues needing resolution are further highlighted in Section 5.5.

Machine Type	C / T	C / O	Uptime	No. of Op.	No. of M/C	FTQ (%)	WIP	
	Mins	Mins	(%)				Before (No of Batches)	After (No of Batches)
Good-In	10	0	95	1	1	90	30	30
Pre-Inspection	1	0	90	1	1	80	30	20
Booking In	5	0	100	1	1	90	20	34
Strip Down	10	0	90	1	1	60	34	10
Welding	15	2	90	1	1	40	10	37
Rotary Mill	25	10	90	5	5	40	37	6
Grinding	8	2	90	1	1	90	6	5
Finishing	20	5	90	1	1	40	5	3
Line Inspection	10	2	80	2	2	80	3	8
SS & Final Inspection	5	2	90	1	1	90	8	11
Despatch	3	1	90	1	1	90	11	8

Table 5.3a: Current state attribute of the rotary product line

Table 5.3b further shows the current state data for the rotary milling product line with a takt time of 19minutes. In estimating the cycle time across this product line, average process time value for 50mm, 63mm and 80mm milling cutter were used as the base for analysis. A base part was required because of the wide variety of product type been processed within the product line. The milling cutter range chosen exhibits the three (3) highest volumes across the product line (**Appendix 5.6: Invoice line 2006**). **Table 5.3b** also suggests that 95% of the operation within the rotary product line is non-value adding and a mere 5% value added time.

In addition, **Figure 5.5** focuses on the queue by showing the location of work in progress (WIP) inventory within the Rotary product line. The purpose of this is to further establish where the bottle necks exist so that they can be targeted for reduction / elimination. From **Figure 5.5**, it can be seen that the majority of WIP inventory (time dependent variable) in the Rotary product line is found at points before production at the rotary milling workstation. The reason for this been that the welding workstation stores welded parts for a full day before ‘PUSHING’ it to the rotary milling workstation.

	Minutes	Hours	**Days
Takt Time	19	0.3	0.04
Value Added Time	117	1.95	0.25
Non Value Added Time	3830	64	8.3
**Available Hrs/day = 7.75			

Table 5.3b: Current state data of the rotary product line (see VSM: **appendix 5.5**)

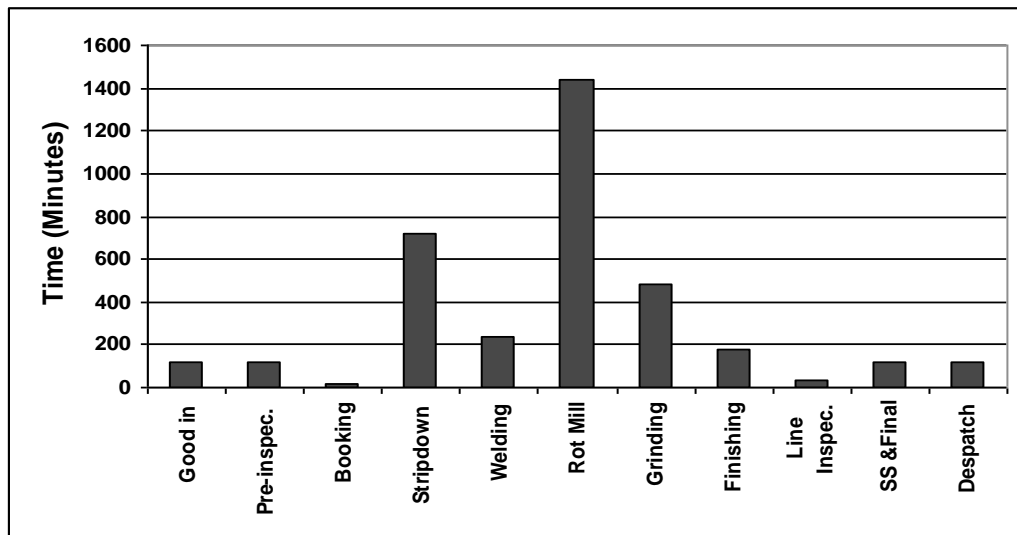


Figure 5.5: Major WIP inventory location in the rotary product line

5.4.2.1 Machine and operator utilisation rotary product line

Figures 5.6a & b shows the cycle time analysis of the Rotary product line. **Figure 5.6a** examines the effective machine utilisation. From the graph it is obvious that the over-cycled workstations within the product line are rotary milling and finishing workstations. The main time trap/capacity constraint within the rotary milling process centre is largely due to excessive manual work. The Process Cycle Efficiency (PCE) for the Rotary product line's machine utilisation is **54%** (see **Appendix 5.7** for summation of ATT against TT).

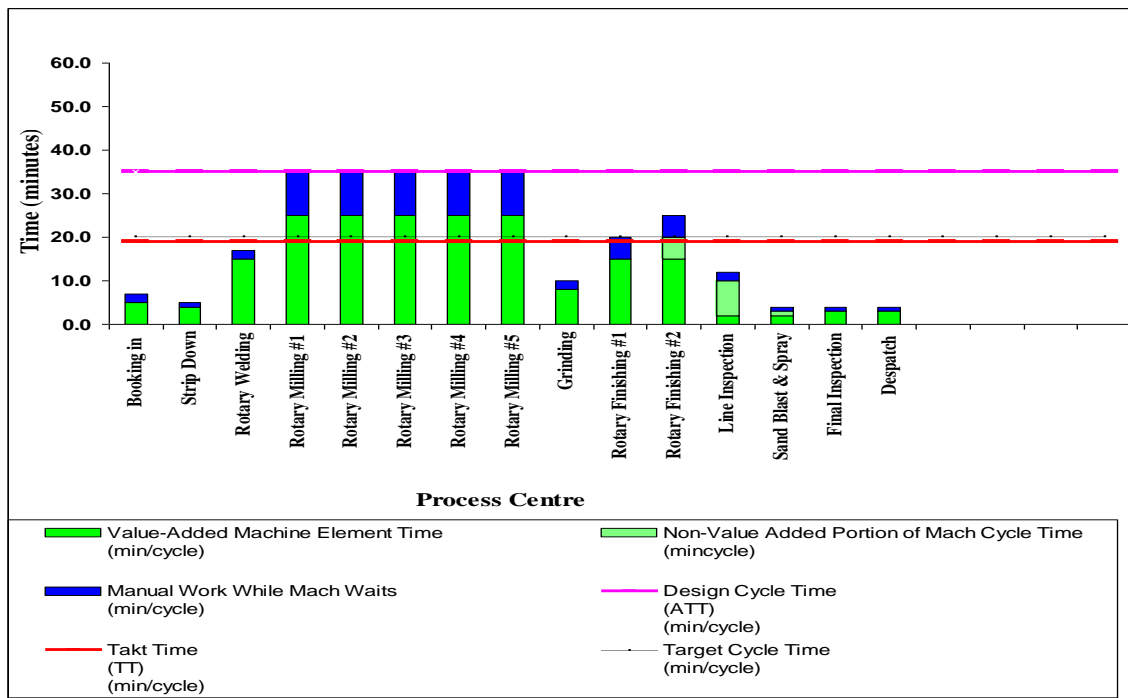


Figure 5.6a Rotary product line Machine Utilisation Chart

Furthermore, **Figure 5.6b** shows the manual work while machine waits and the forced waits at the Rotary product line. This operator utilisation chart goal is to further breakdown the non-valued added elements from the machine utilisation chart in the **Figure 5.6a**. The PCE for the Rotary product line of operator utilisation is **53%**.

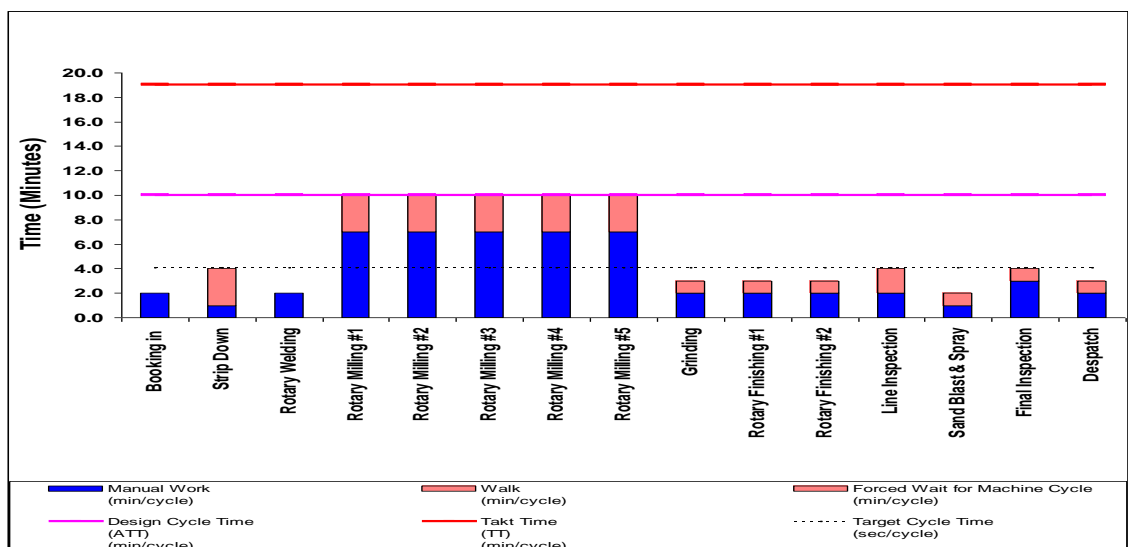


Figure 5.6b: Rotary product line operator utilisation chart

5.4.2.2 Work combination table rotary product line

Figure 5.7: work combination table of the rotary milling workstation, shows an initial detailed activity map which explains the sequence of operations within the process centre. From **Figure 5.7**, it's evident that the operator's cycle time is below the process takt time. This number (operator cycle time) is determined by comparing the operator's cycle time to the cycle times of the individual machines they run. This number is the larger of the manual work or the machine cycle times. This number represents the cycle time that limits the operator's output.

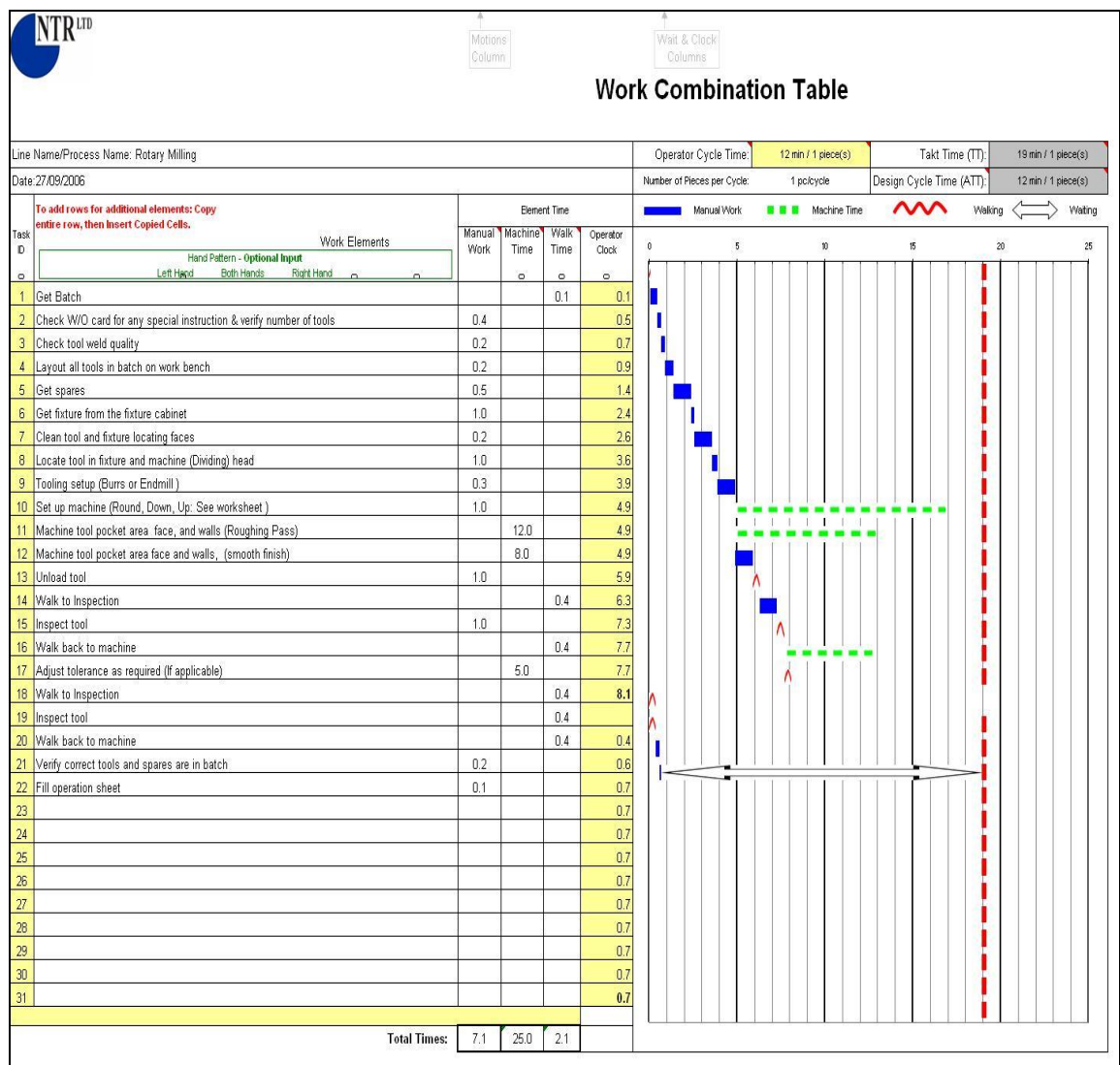


Figure 5.7: Work combination table of the rotary milling workstation

5.4.3 Analysis of the Standard Product Line

Tables 5.4a & b, an extract of the VSM (see **Appendix 5.8**) for the Standard product line (STD) shows the current state attribute of the product line. From **Table 5.4b**, it's evident that the effective value added time within the Standard product line per tooling repair is 1.05 hours whilst the non value added time is 7.4 days @ 7.75hrs/day. The bulk of the non value added time within this process line is a direct result of the queue before parts are processed at the standard milling workstation/centre. **Table 5.4b** further shows the current state data for the standard milling product line with a takt time of 11minutes. **Table 5.4b** also suggests that 95% of the operation within the standard product line is non-value adding and a mere 5% value added time.

Machine Type	C / T	C / O	Uptime	No. of Op.	No. of M/C	FTQ (%)	WIP	
	Mins	Mins	(%)				Before (No of Batches)	After (No of Batches)
Good-In	5	0	95	1	1	90	30	30
Pre-Inspection	1	0	90	1	1	80	30	20
Booking In	5	0	100	1	1	90	20	10
Strip Down	5	0	90	1	1	90	10	5
Welding	5	1	90	1	1	50	5	31
Standard Mill	15	1	90	2	2	70	31	19
Finishing	10	1	90	2	2	60	19	3
SS & Final Inspection	4	0.2	90	1	1	98	3	9
Despatch	4	1	90	1	1	98	7	8

Table 5.4a: Current state attribute of the standard product line

In addition, **Figure 5.8** focuses on the queue by showing the location of work in progress (WIP) inventory within the Standard product line. The purpose of this is to further establish where the bottle necks exist so that they can be targeted for reduction / elimination. From **Figure 5.8**, it can be seen that the majority of WIP inventory (time dependent variable) in the Standard product line is found at points before production at the standard milling and fitting workstations.

	Minutes	Hours	**Days
Takt Time	11	0.18	0.02
Value Added Time	63	1.05	0.14
Non Value Added Time	3420	57	7.4
**Available Hrs/day = 7.75			

Table 5.4b: Current state data of standard product line

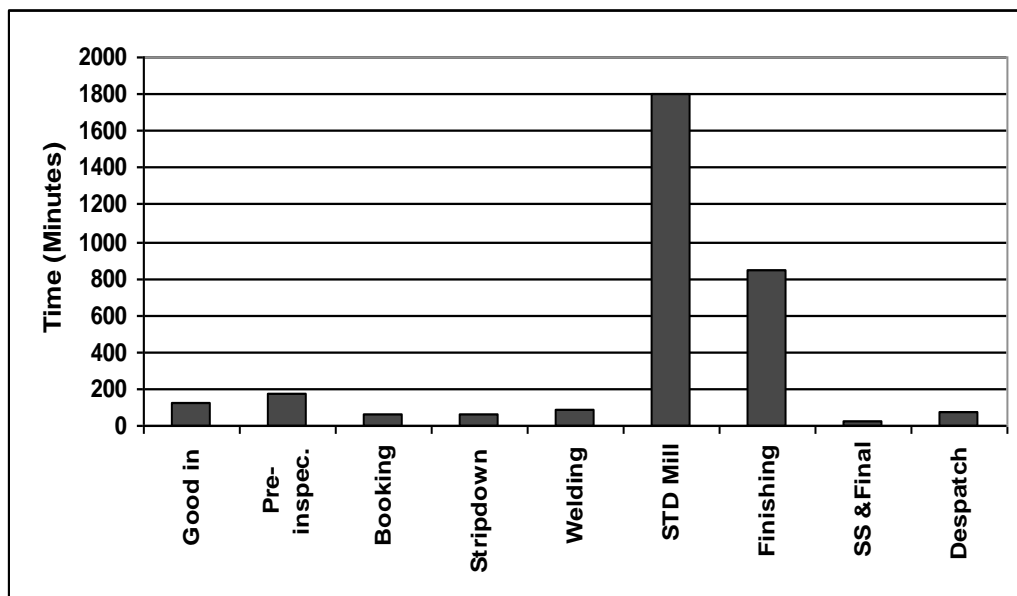


Figure 5.8: Major WIP inventory location in the standard product line

5.4.3.1 Machine and operator utilisation standards product line

Figures 5.9a & b shows the cycle time analysis of the Standard product line. Figure 5.9a examines the effective machine utilisation. From the graph it is noticeable that the over-cycled workstations within the product line are standard milling process centre and operator two (2) at the finishing workstation. The main time trap/capacity constraint within the standard milling process centre is largely due to excessive manual work. The Process Cycle Efficiency (PCE) for the Standard product line is **55%** (see Appendix 5.9 for summation of the ATT against the TT).

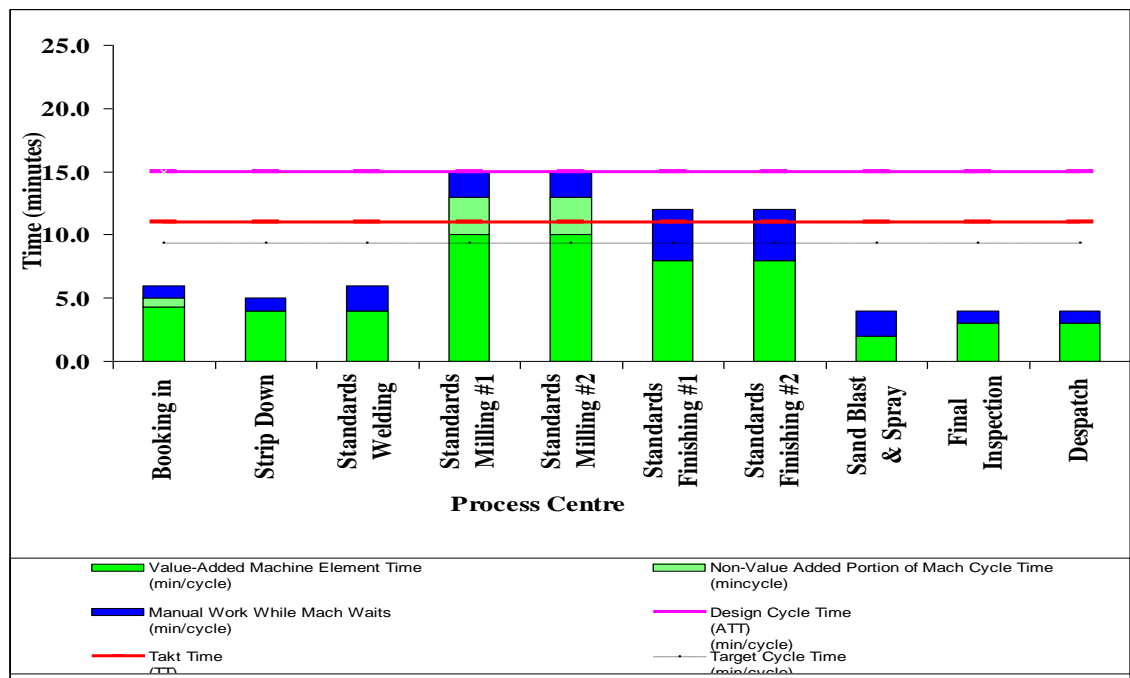


Figure 5.9a Standard product line machine utilisation chart

Furthermore, Figure 5.9b shows the manual work while machine waits and the forced waits at the standard product line. This operator utilisation chart goal is to further breakdown the non-valued added elements from the machine utilisation chart in the Figure 5.9a. The PCE for the standard product line's operator utilisation is **56%**.

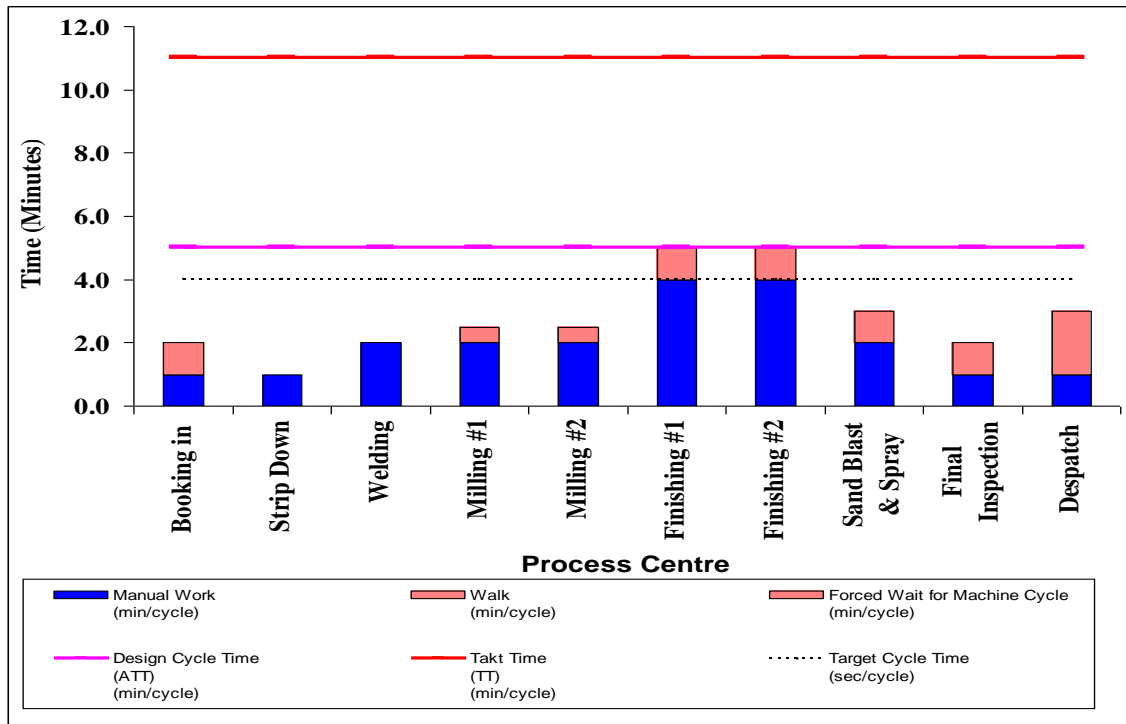


Figure 5.9b: Standard product line operator utilisation chart

5.4.3.2 Work combination table standard product line

Figure 5.10: work combination table of the Standard milling workstation, shows an initial detailed activity map which explains the sequence of operations within the process centre. From **Figure 5.10**, it's evident that the operator's cycle time is below the process takt time but the machine cycle time (as shown in **Figure 5.9a**) is operating above the takt time. This over-cycling is a function of the proportion of the process cycle time due to manual machine while waits. **Figure 5.10** further shows that the work elements responsible for this over-cycling is due to tool and machine set-ups hence the need for lean SMED (Single Minute Exchange of Die) and/or a 5's and continuous improvement strategies.

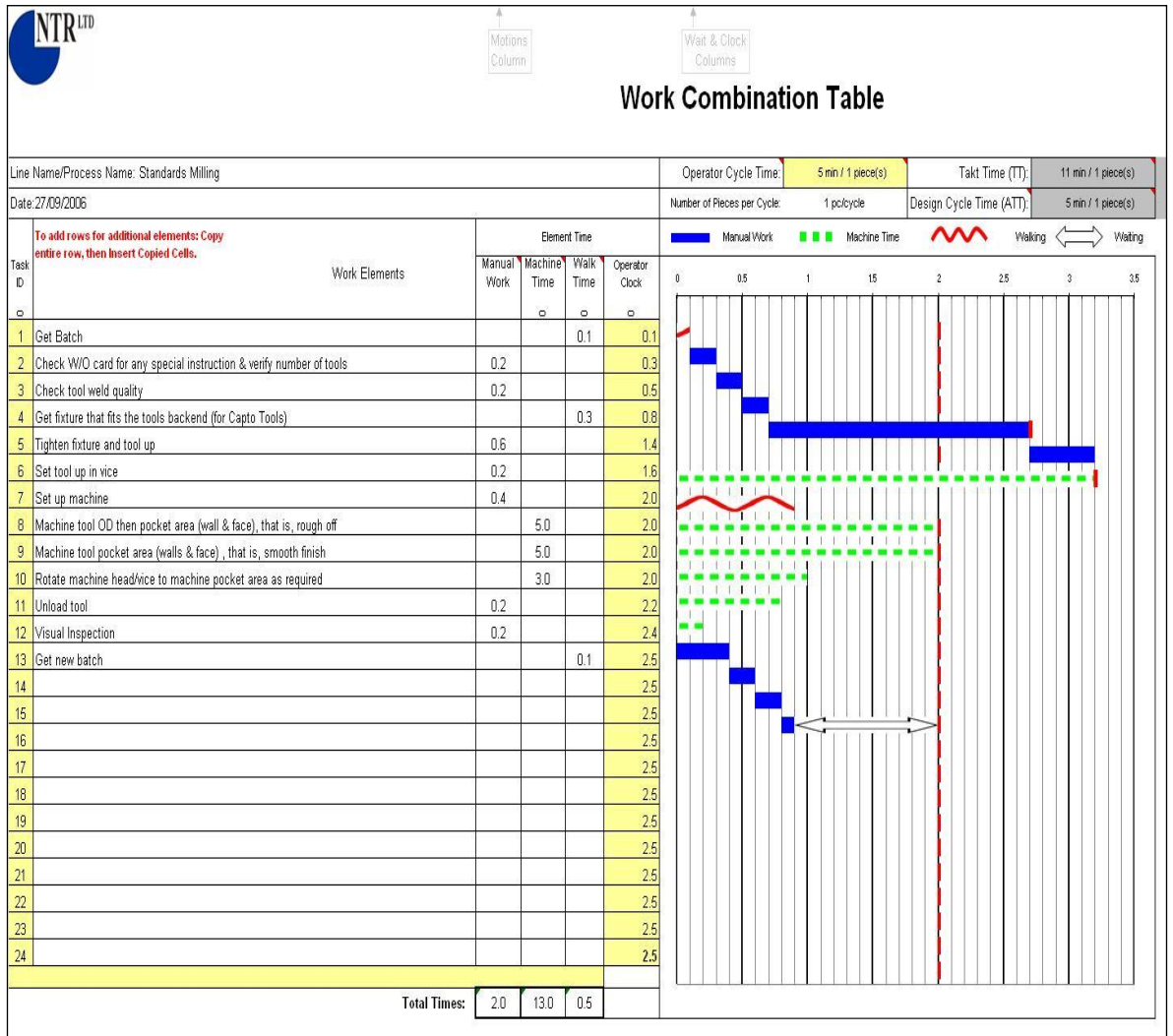


Figure 5.10: Work combination table of the standard milling workstation

5.5 Simulating the Current State Value Stream Map

Combining computer capability with the versatility of simulation techniques to assist in the design and evaluation of value stream maps provides an invaluable appreciation of manufacturing systems dynamic state modelling. The model presented in this section is built into the ARENA PC-compatible package (see **Appendix 5.10** for ARENA basic user guide). Modelling manufacturing systems with ARENA is most successful when it is performed in an interactive manner. The objective is starting with a static state value stream map (a working model that can be progressively refined until the desired level of

detail has been reached). The analysis presented in this section uses a triangular probability distribution data type, run over five (5) replications and 20 hours runtime and 7.75 simulation days. The purpose of using a triangular data type is to enable the dynamic modelling of different tool repair condition and damage extent (Section 4.3) across each of the product lines presented in Section 5.4. Key performance indicators from the simulation study are Systems Number In and Out at each process centre, waiting times at each process centre, and machine and operator utilisation.

5.5.1 CNC Product Line Simulation

Figure 5.11 shows the flow chart for the CNC product line simulation interface. The model uses two create module to represent two different entities (parts), that is, short hole drills and button tools. The short hole drill arrival rate is 4 parts every hour whilst the button tool arrival rate is 2 parts every hour with both entities having an infinite maximum arrival. This arrival rate is base on estimated demand volume (Section 4.2.1) used in determining the takt times in Section 5.4.

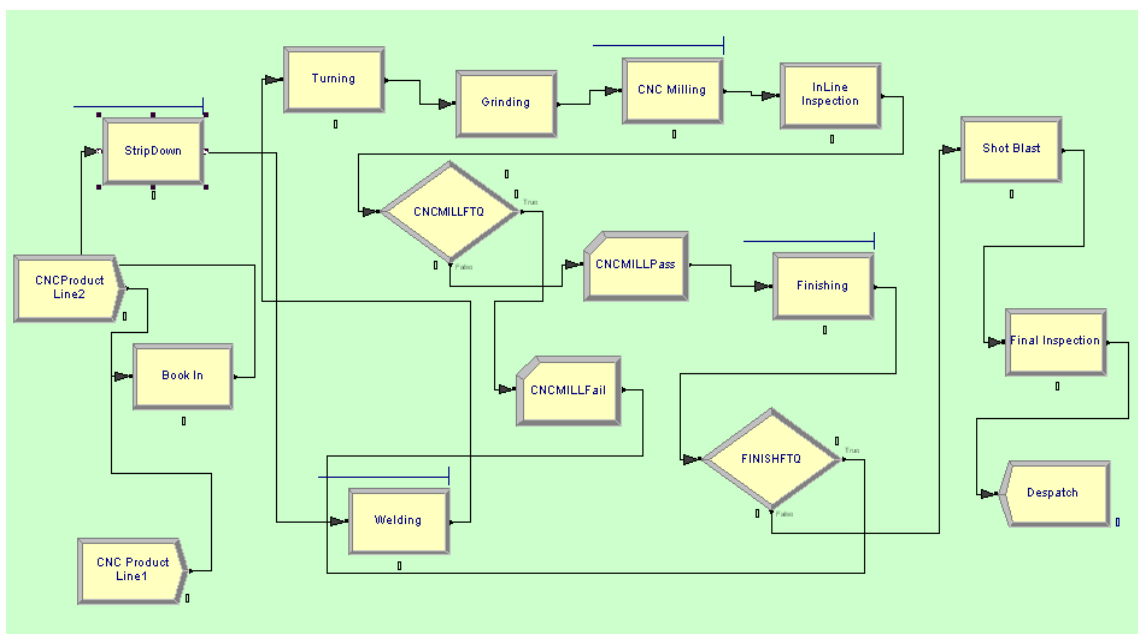


Figure 5.11: Flow chart CNC product line simulation interface (Appendix 5.11)

Figure 5.11 uses a seize-delay-release logic to model the strip-down, welding, CNC milling and finishing processing centres. Additionally, a decision module is also utilised after the CNC milling and finishing process centre to capture the systems first time quality (FTQ).

With the simulation running over 20 hour, 5 replications and 7.75 days, **Figures 5.12a & b**, illustrates the number of parts in the CNC product line. **Figure 5.12a** focuses on the number in per entity whilst **Figure 5.12b** shows the number of parts in each processing centre. From **Figure 5.12a**, it is evident that the average number of entities/parts in the system attributed to the short hole drill is 80 whilst the button tool is an average of 32.

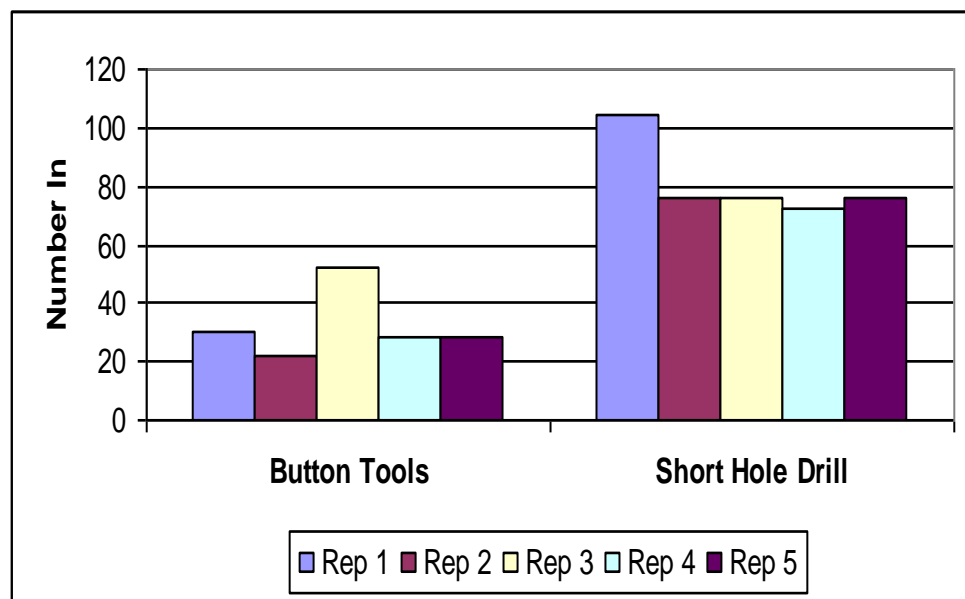


Figure 5.12a: CNC product line number in per entity

Moreover, **Figure 5.12b** demonstrates the distribution of number of entities/parts in the each process centre. From **Figure 5.12b** it is obvious that entities are not flowing evenly

through the system. This effect can be ascribed to the seize-delay-release logic that the strip-down and welding processes display. A greater effect of this logic is felt in the idle cost (although a real system will have parts already in the system) accumulated downstream of the product line by other workstations which ultimately lead to poor resource utilisation and extended queue.

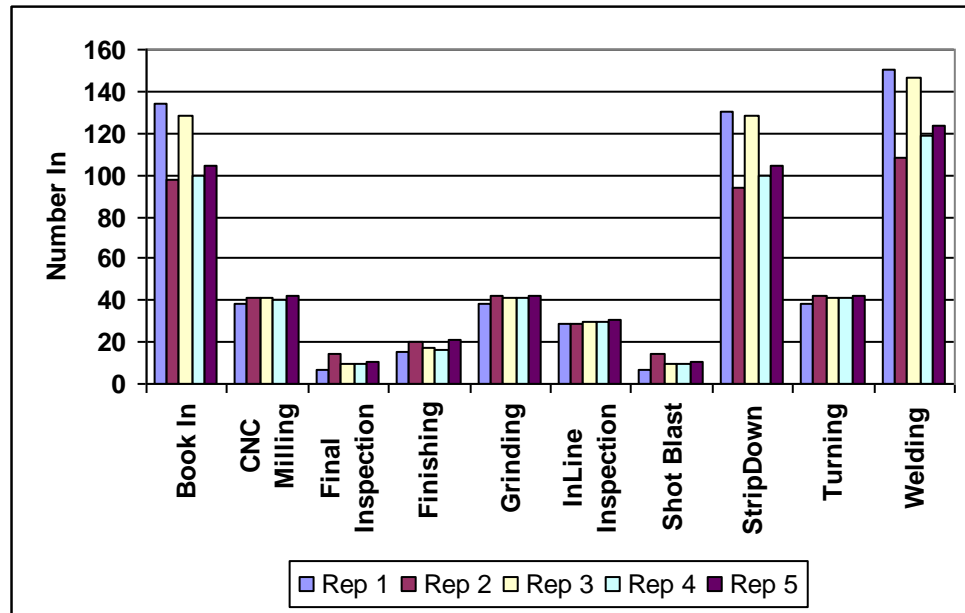


Figure 5.12b: CNC product line number in per process centre

Figure 5.13 illustrates the number of parts leaving each process centre for five (5) different replications. The overall systems output is 10 parts as against a systems input of about 112 parts (short hole drill and button tools). As seen from the graph, the welding section with an average number in of 80 parts has just an average of 40 parts output per replication, hence a queue of about 40 parts per replication. This illustration justifies the conclusion from Section 5.4.1 on the effect of “PUSHING” and accumulation of WIP inventory just before processing at the CNC milling workstation.

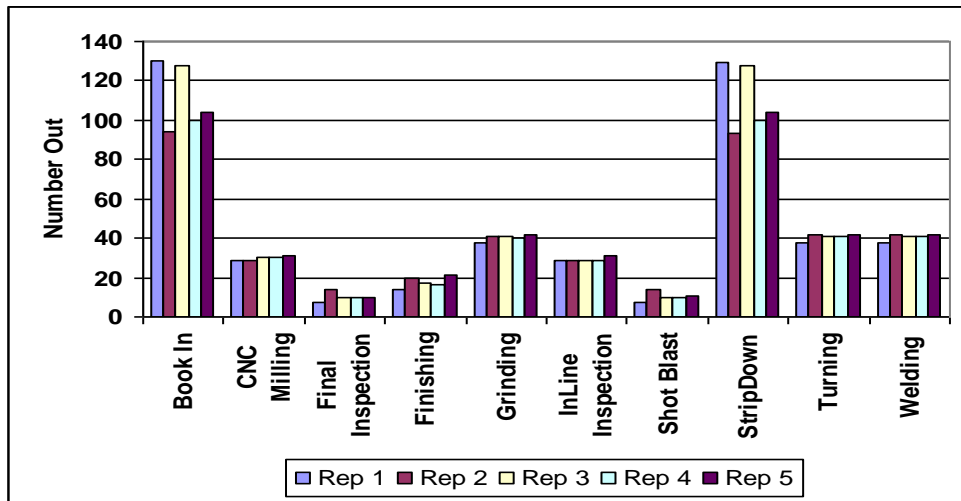


Figure 5.13: CNC product line number out per process centre

In order to further quantify the level of WIP per entity within the CNC product line **Figure 5.14** demonstrates the variation of WIP per entity per replication. On average across the 5 replications the entity: button tool has 15 parts in queue at the end of 20 hours of runtime whilst entity: short hole drill as 37 parts.

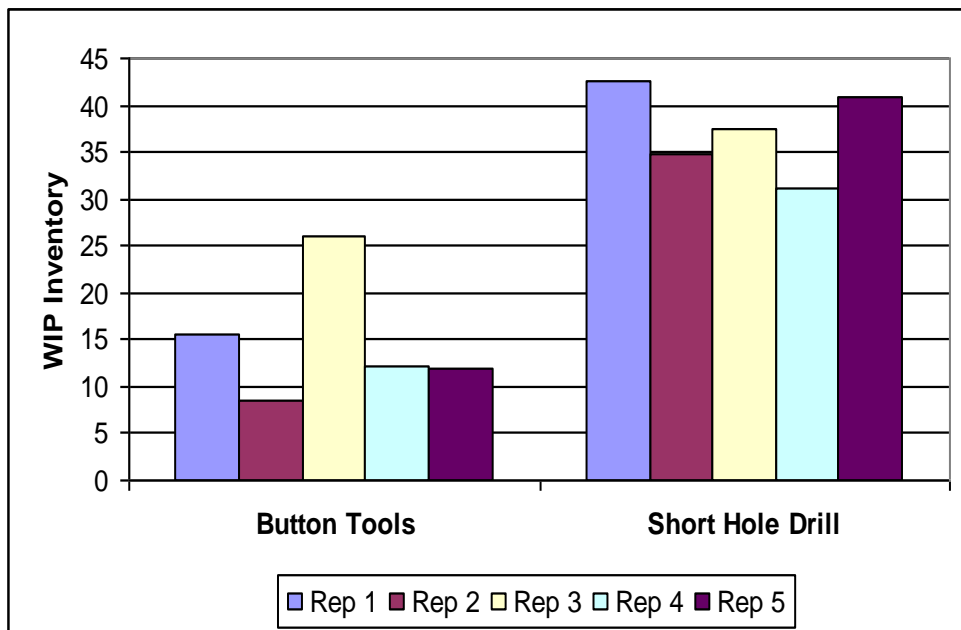


Figure 5.14: CNC product line WIP inventory per entity

5.5.2 Rotary Product Line Simulation

Figure 5.15 shows the flow chart for the rotary product line simulation interface. The model uses one create module to represent one entity that is, milling cutter. The milling cutter arrival rate is 3 entity/parts every hour with an infinite maximum arrival. This arrival rate is based on estimated demand volume (Section 4.2.1) used in determining the takt times in Section 5.4.

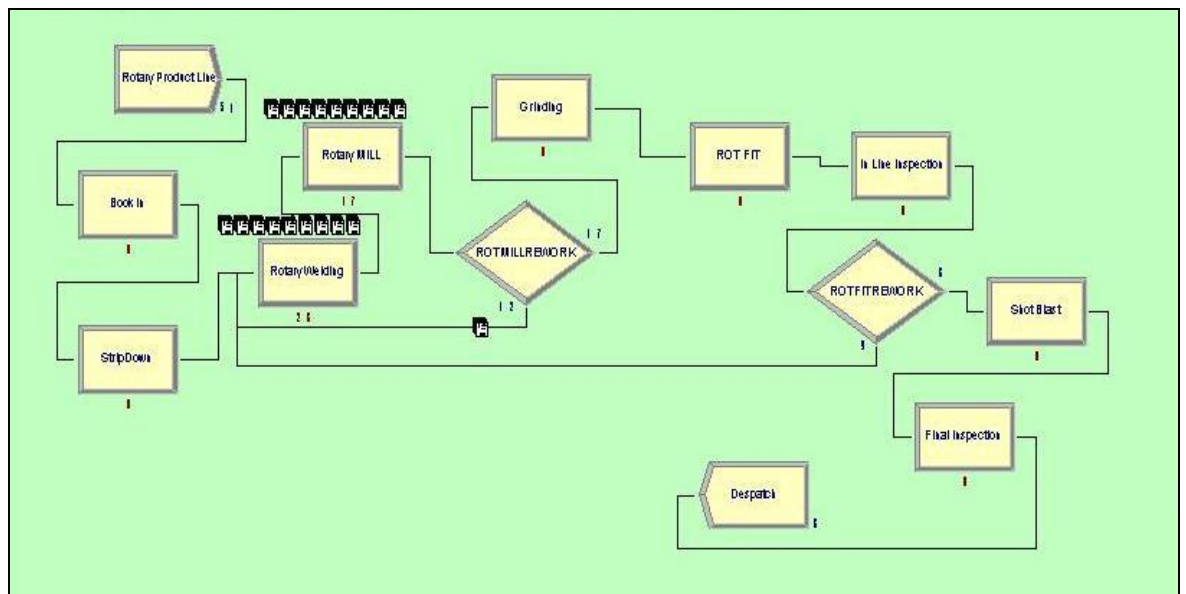


Figure 5.15: Flow chart rotary product line simulation interface (Appendix 5.12)

Figure 5.15 uses a seize-delay-release logic to model the strip-down, welding, rotary milling and finishing processing centres. Additionally, a decision module is also utilised after the rotary milling and finishing process centre to capture the systems first time quality (FTQ).

Figure 5.16 illustrates the ratio of input to output for a given entity (milling cutter) in the rotary product line. From **Figure 5.16**, it is evident that the average number of entities/parts inputted is 67 odd parts as against 10 going out of the system, given us a

ratio of 7:1. Additionally, **Figure 5.17** shows the WIP inventory per replication with an overall average of 31 parts.

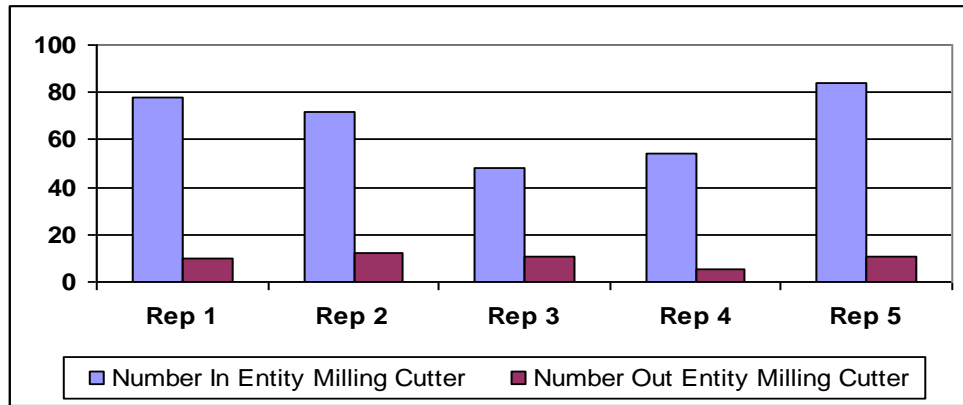


Figure 5.16: Input to output ratio for the rotary product line

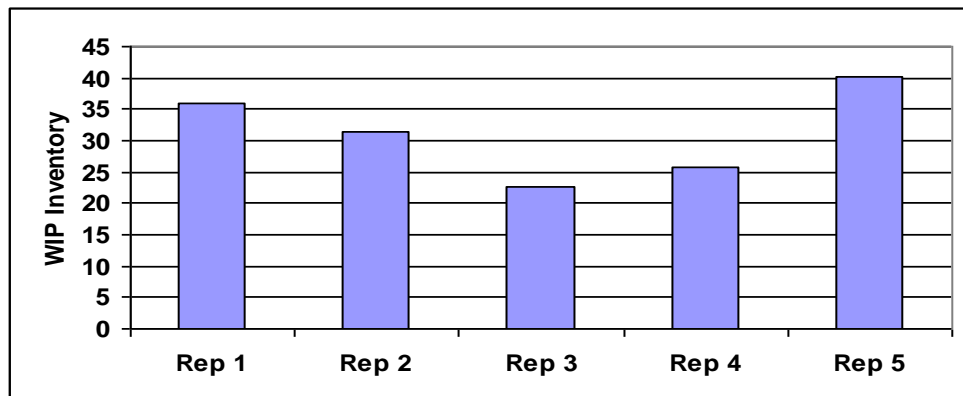


Figure 5.17: WIP inventory per replication for the rotary product line

In order to further understand the location of the WIP inventory and the high input to output ratio from **Figures 5.16** and **5.17** respectively, **Figure 5.18**, demonstrates the location of the parts. From the figure it is obvious that the rotary milling and rotary welding workstations on average accounts for about 50% and 49% of the queue within the rotary product line respectively.

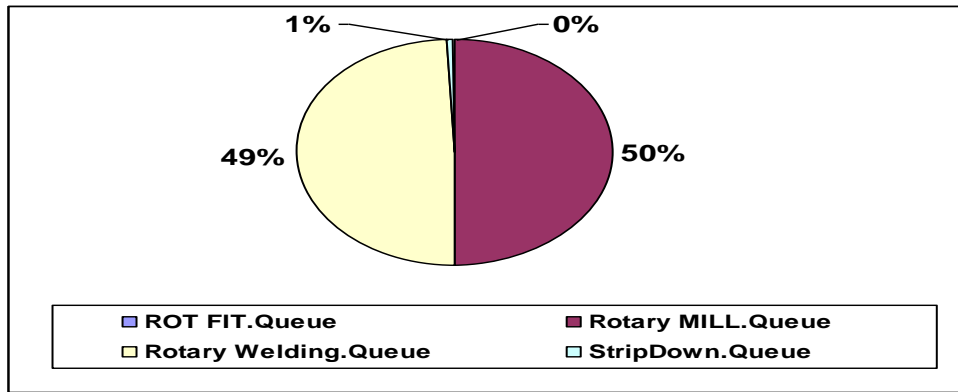


Figure 5.18: Queue location for the rotary product line

5.5.3 Standard Product Line Simulation

Figure 5.19 shows the flow chart for the standard product line simulation interface. The model uses one create module to represent one entity that is, toolholder. The toolholder's arrival rate is 6 entity/parts every hour with an infinite maximum arrival. This arrival rate is based on estimated demand volume (Section 4.2.1) used in determining the takt times in Section 5.4.

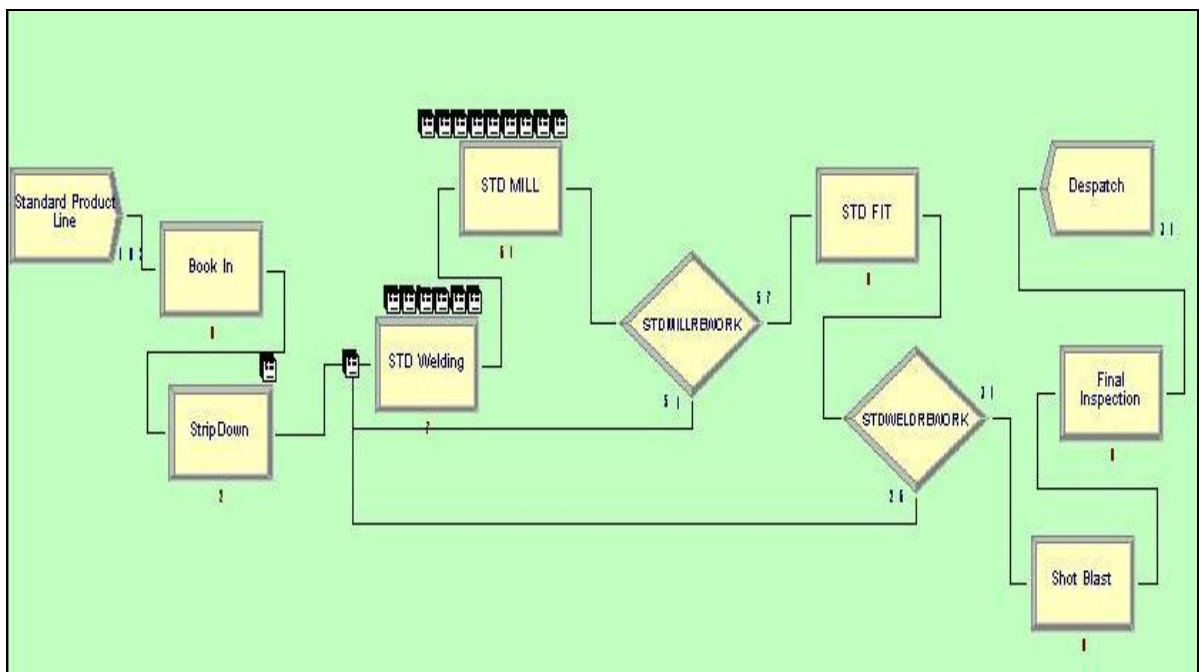


Figure 5.19: Flow chart standard product line simulation interface (Appendix 5.13)

Figure 5.19 uses a seize-delay-release logic to model the strip-down, welding, standard milling and finishing processing centres. Additionally, a decision module is also utilised after the standard milling and finishing process centre to capture the systems first time quality (FTQ).

Figure 5.20 illustrates the ratio of input to output for a given entity (Toolholder) in the standard product line. From **Figure 5.20**, it is evident that the average number of entities/parts inputted is 122 odd parts as against 31 going out of the system, given us a ratio of 4:1. Additionally, **Figure 5.21** shows the WIP inventory per replication with an overall average of 40 parts.

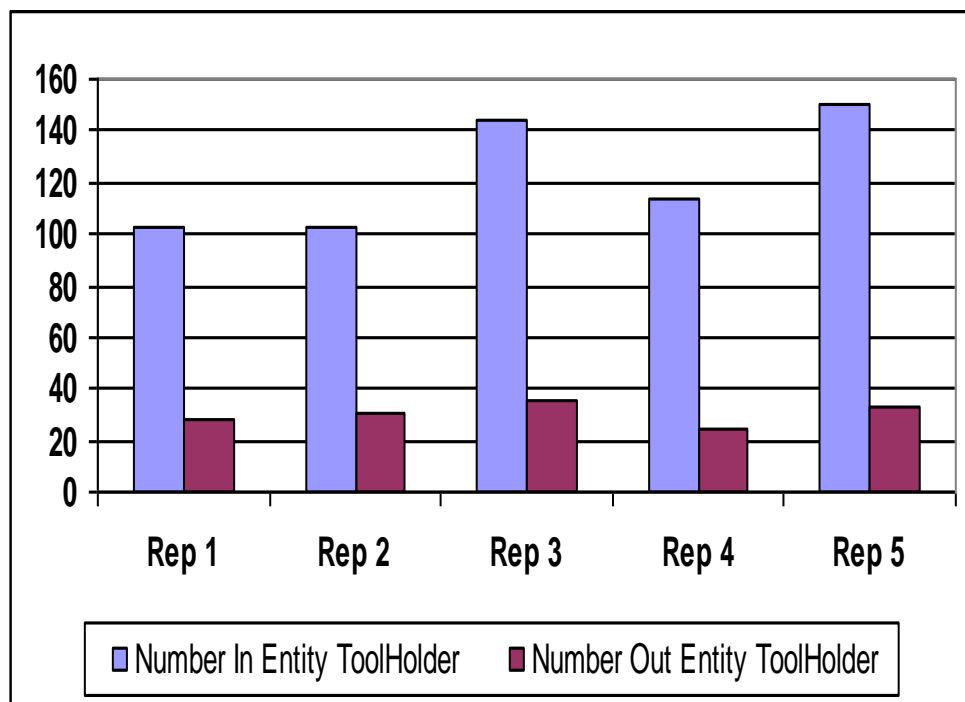


Figure 5.20: Input to output ratio for the standard product line

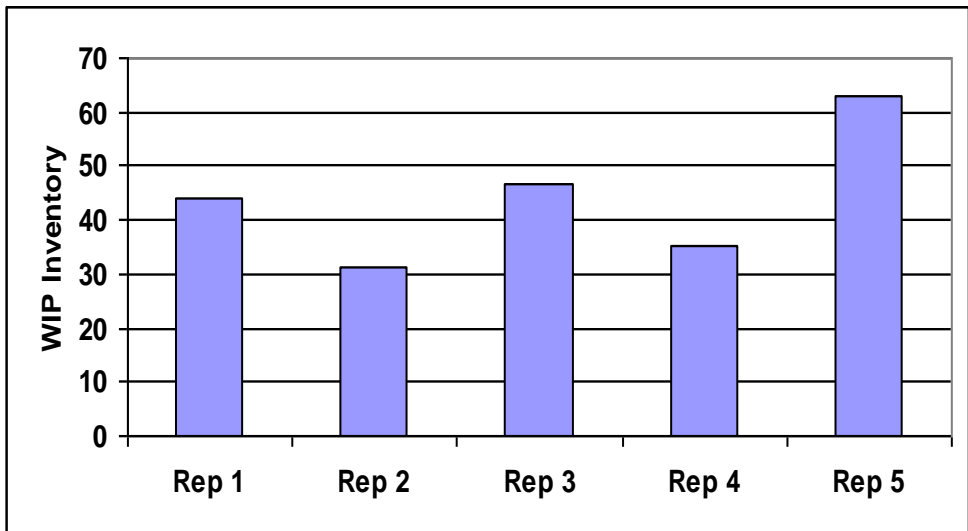


Figure 5.21: WIP inventory per replication for the standard product line

In order to further understand the location of the WIP inventory and the high input to output ratio from **Figures 5.20** and **5.21** respectively, **Figure 5.22**, demonstrates the location of the parts. From the figure it is obvious that the standard milling and standard welding workstations on average accounts for about 89% and 9% of the queue within the standard product line respectively.

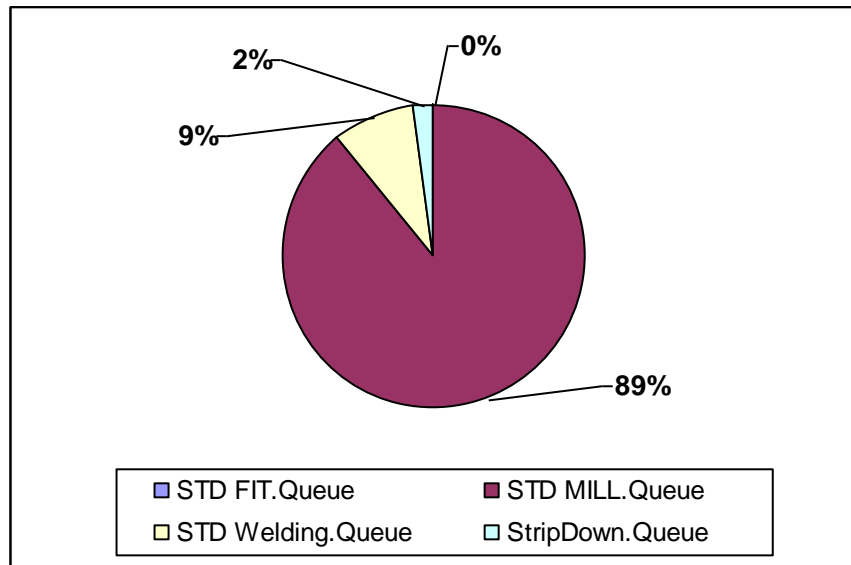


Figure 5.22: Queue location for the rotary product line

5.6 Summary

In this chapter lean manufacturing and resource planning has been defined using a mapping, audit and analysis framework. The chapter examined the application of a lean assessment system to the case company and returned a 46% score rating which showed that NTR Ltd has a fair understanding of lean manufacturing but guidance is required to reach the next level. The chapter further utilised a current state value stream map to generate a deeper understanding of the case company's manufacturing system. Key outputs from the current state map were: poor resource utilisation, poor FTQ and high level of WIP within the case company product lines. Due to the static nature of value stream maps, the chapter then further validated the current state value stream map through a simulation study (dynamic effects). The chapter concluded from the simulation of the three distinctive product lines within the case company's manufacturing system that constraints were due to lack of continuous flow, poor resource utilisation that then resulted in high levels of WIP inventory.

CHAPTER 6

CONTINUOUS IMPROVEMENT AT NTR LTD

6.1 Introduction

This chapter describes the application of a combination of DMAIC & Kaizen events in the effort to deploy lean manufacturing as a manufacturing strategy at the case company. The cases presented are illustrated using a project management framework that supports six sigma process improvement methodology—DMAIC and application of some of the components of the golden lean check matrix (Esan et al 2007) in particular work method issues. Other aspect of the golden lean check matrix was discussed in chapter 5 and more will be highlighted in Chapter 7. The chapter focus on creating a future state by exploiting continuous improvement philosophy of lean implementation from the base line strategic goals (Chapter 4) and current state value stream analysis in Chapter 5.

6.2 Application of DMAIC methodology to NTR Internal Defect Rate

A resource utilisation constraint within the manufacturing system is a culture of internal rework that emerged to be an acceptable norm within NTR Ltd's manufacturing systems. Although, the level of external returns had been oscillating between 1-2% for over 5 years the same cannot be said of the system's First Time Quality (FTQ) which was costing the company about £90,000 per year (at 12mins repair time/60mins * £55 hourly loaded rate * average defect rate of 180 parts/week * 45 weeks).

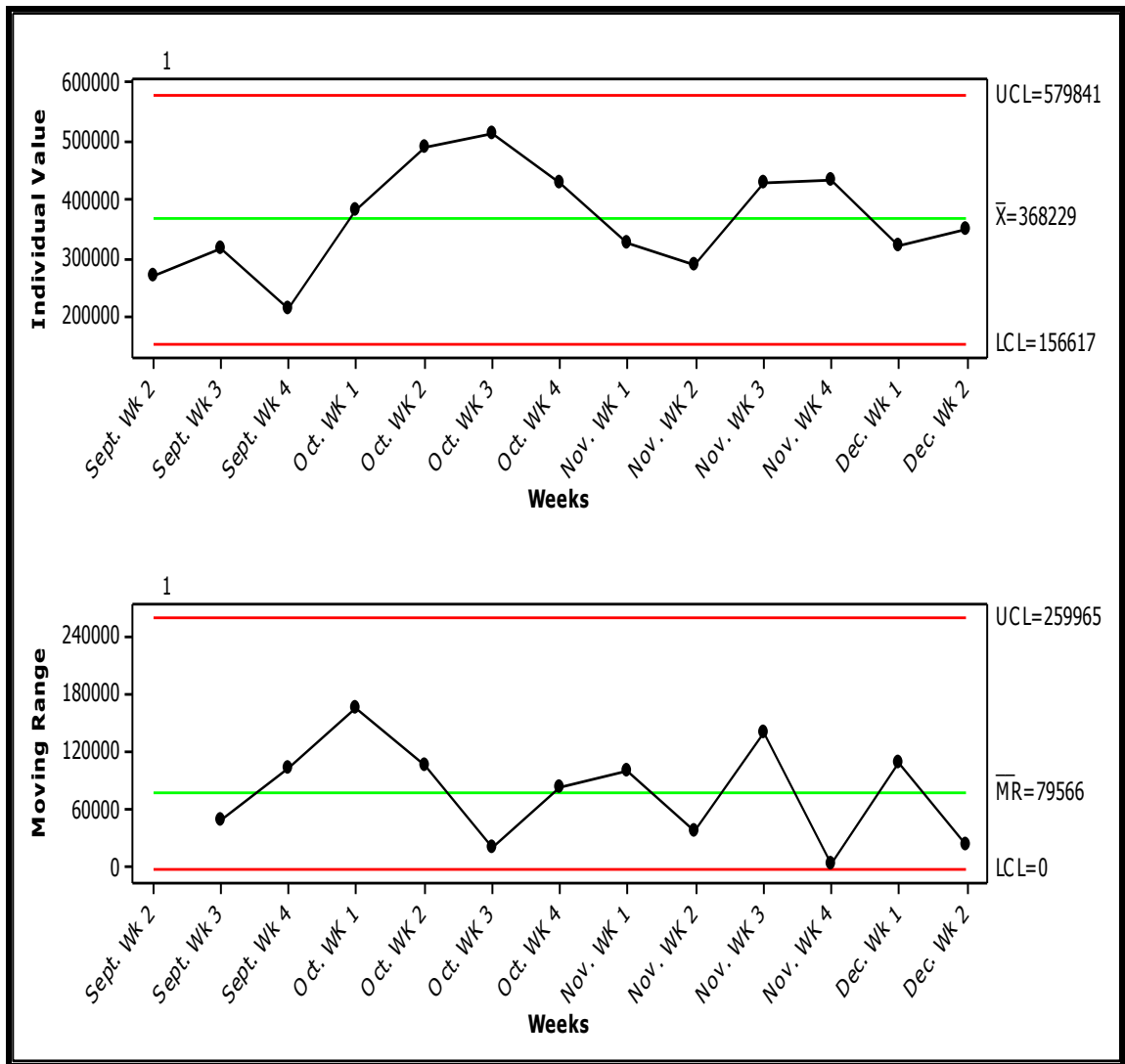


Figure 6.1: IMR chart Total Internal Defect Rate NTR LTD

Figure 6.2 below shows a Pareto chart of top issues contributing to the PPM values shown in **Figure 6.1**. Figure 6.2 is a snap shot of issues affecting the manufacturing system’s internal defect rate for week 2 in September 2006. The figure shows that the largest contributor to the defect rate is “lack of weld” with 36%. Discussed in the remainder of this chapter is application of the DMAIC process improvement methodology to resolving issues relating to “lack of weld”, FTQ data and other customer related defects.

ERNAL RETURNS WELD RELATED START OF DATA COLLECTION SEPTEMBER 2006

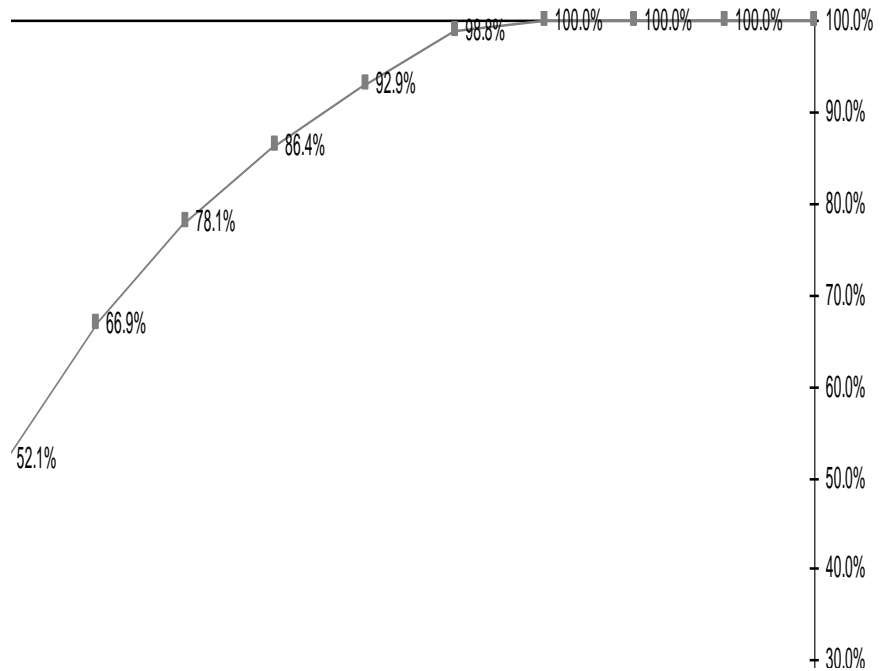


Figure 6.2: Pareto of internal defects NTR Ltd September 2006

6.3 Case one: Lack of weld internal defect rate reduction

The expression “lack of weld” is illustrated in **Figure 6.3**. The defect category refers to a part not welded at a Critical-To-Quality (CTQ) feature on that part. Estimated annualised Cost of Poor Quality (CTQ) attributed to this defect category is about £30,000 (at 60 defects per week*12mins repair time/60mins * £55 hourly rate * 45weeks).

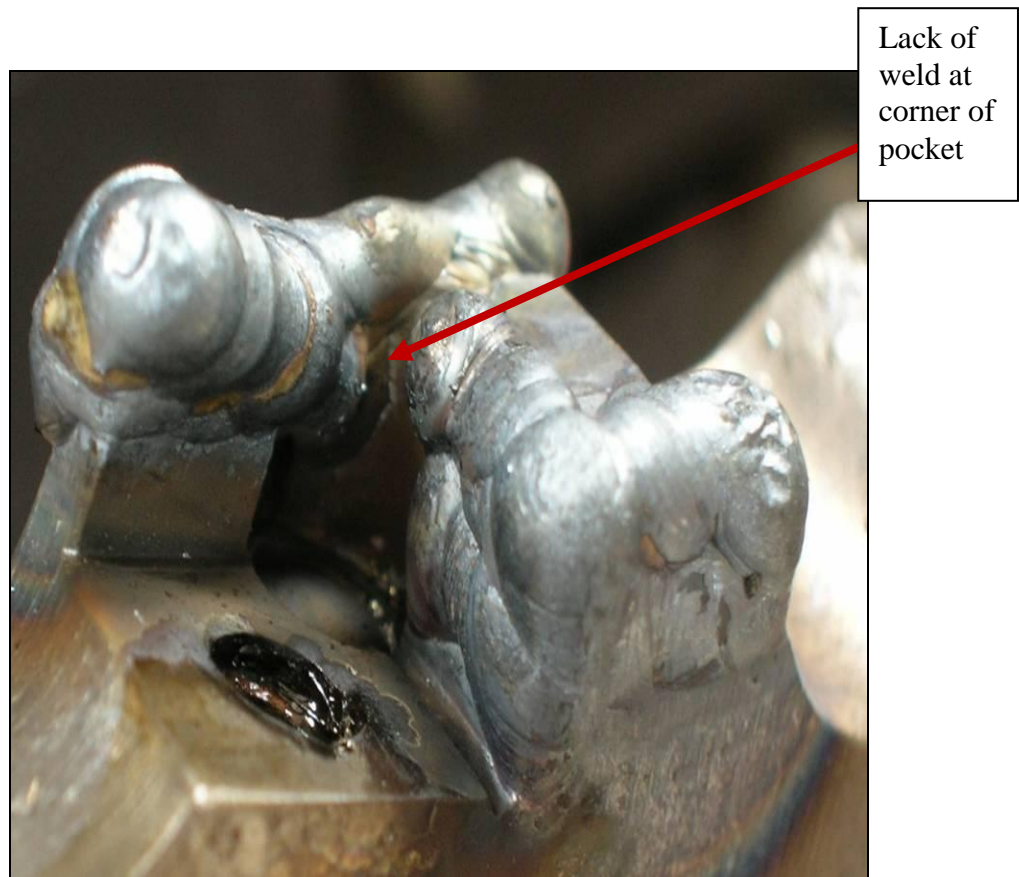


Figure 6.3: Typical part with lack of weld at corner of tool pocket

6.3.1 Define Stage: Lack of Weld Internal Defect Reduction.

Table 6.1 shows the Project Charter for the welding defect reduction project. The charter contains a problem statement, a Continuous Improvement (CI) team, project goals/objective and key deliverables. The team consisted of the operators directly responsible for welding the defective parts, a training champion, and several operators within the manufacturing system upstream the welding process.

<p>Problem Statement High Internal returns rate, with a total cost of of about £96,000. Internal returns due to lack lack of weld dominate the returns rate with a rate about 36% at a COPQ of £30,000</p>	<p>Team Craig Naylor – Sponsor Adedeji Esan– Black Belt Chris Morton– Training Champion Al Paylor—Team member STD MILL Phil Chew—Team member welding Mark Ibrahim—Team member CNC</p>
<p>Goal/Objective To create a process that will significantly reduce internal returns due to lack of weld by 50%</p>	<p>Deliverables - 90 day project 1) Reduce internal returns due to lack of weld by 50% 2) Increase operator knowledge of milling process and milling requirements 3) Streamline process</p>

Table 6.1: Project Chart Lack of Weld Defects Reduction Project

Figure 6.4 shows a process map developed by the team to identify all relevant elements of the affected process prior to any improvement project. The process map helps define the complexity of the project hence eliminating improper project scoping. The process Map provides additional detail on the current state value stream map defined in **Chapter 5**. From **Figure 6.4**, key outputs from the process map are no standard operating procedure for pre-inspection, strip down and welding and poorly pre-inspected part, poor strip down quality and foreign material left on part.

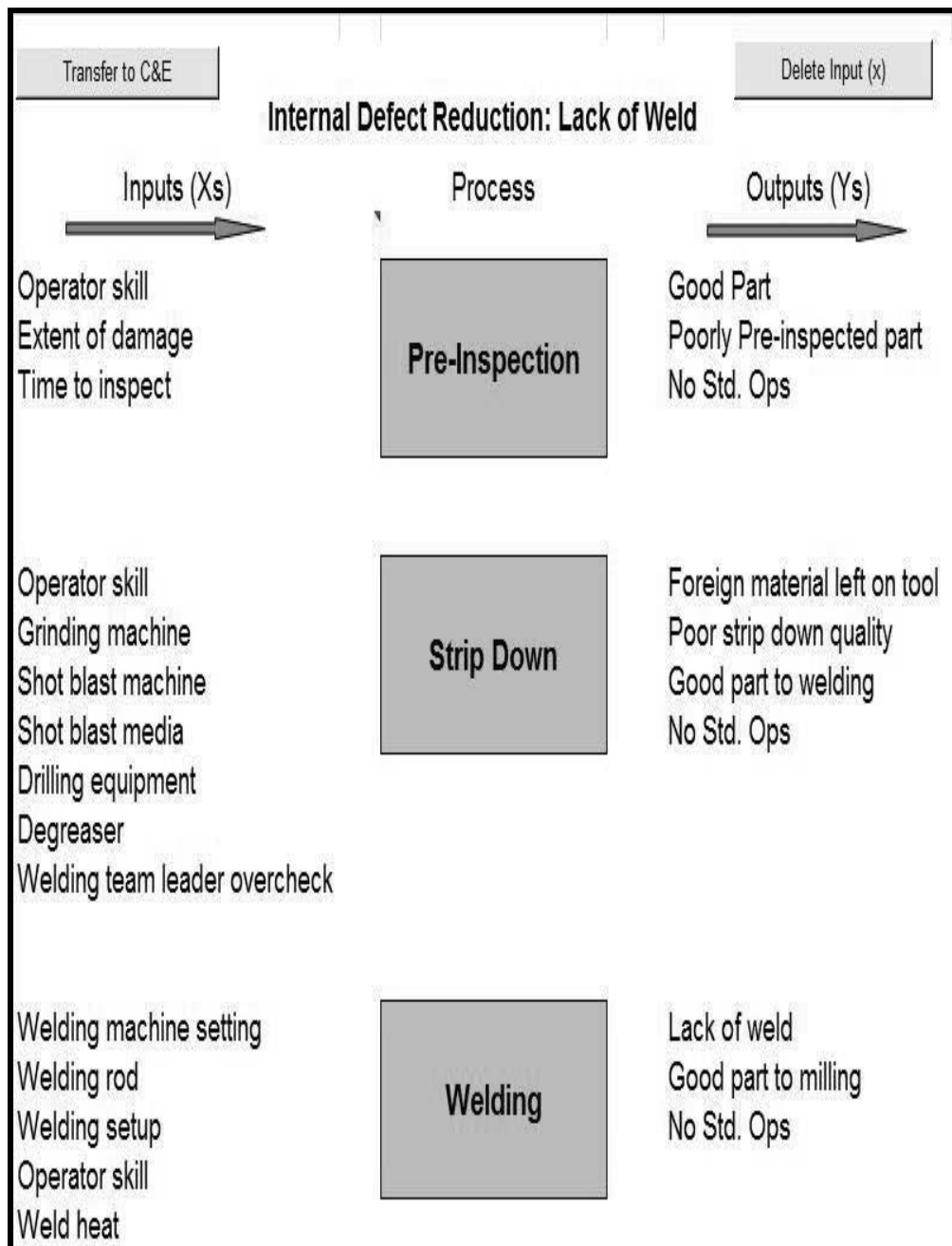


Figure 6.4: Process map Lack of Weld IDR project

6.3.2 Measure Phase: Lack of Weld Internal Defect Reduction.

Further to defining the project scope and limits, the data shown in **Figure 6.5** was collected over a 13weeks period prior to improvement and used to benchmark the current state of the manufacturing system’s internal defect related to the defect category “lack of weld”. The figure shows a P-Chart with a defective proportion value of 0.0973 (which equates to 97300PPM hence ~2.8 sigma) for the defect category “lack of weld”.

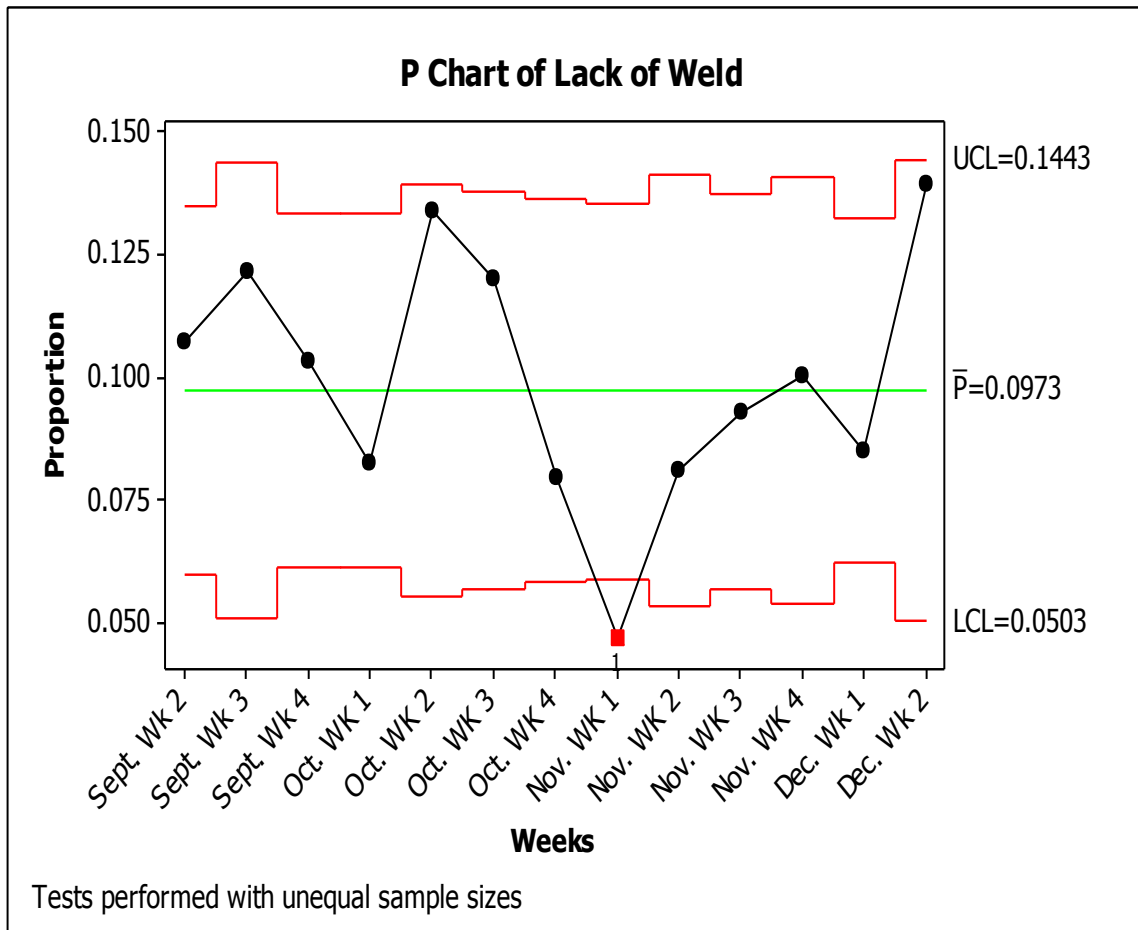


Figure 6.5: P-Chart lack of weld

6.3.3 Analysis: Lack of Weld Internal Defect Reduction.

To understand the root cause of the internal defect type, **Figure 6.6** shows a Cause and Effect analysis developed as part of a brainstorm session undertaken by the CI teams to identify potential x data of the defect—“lack of weld”. The CTQ—“lack of weld” is placed at the head of the fish bone structure with main categories People, Machine, Materials, Environment and Method.

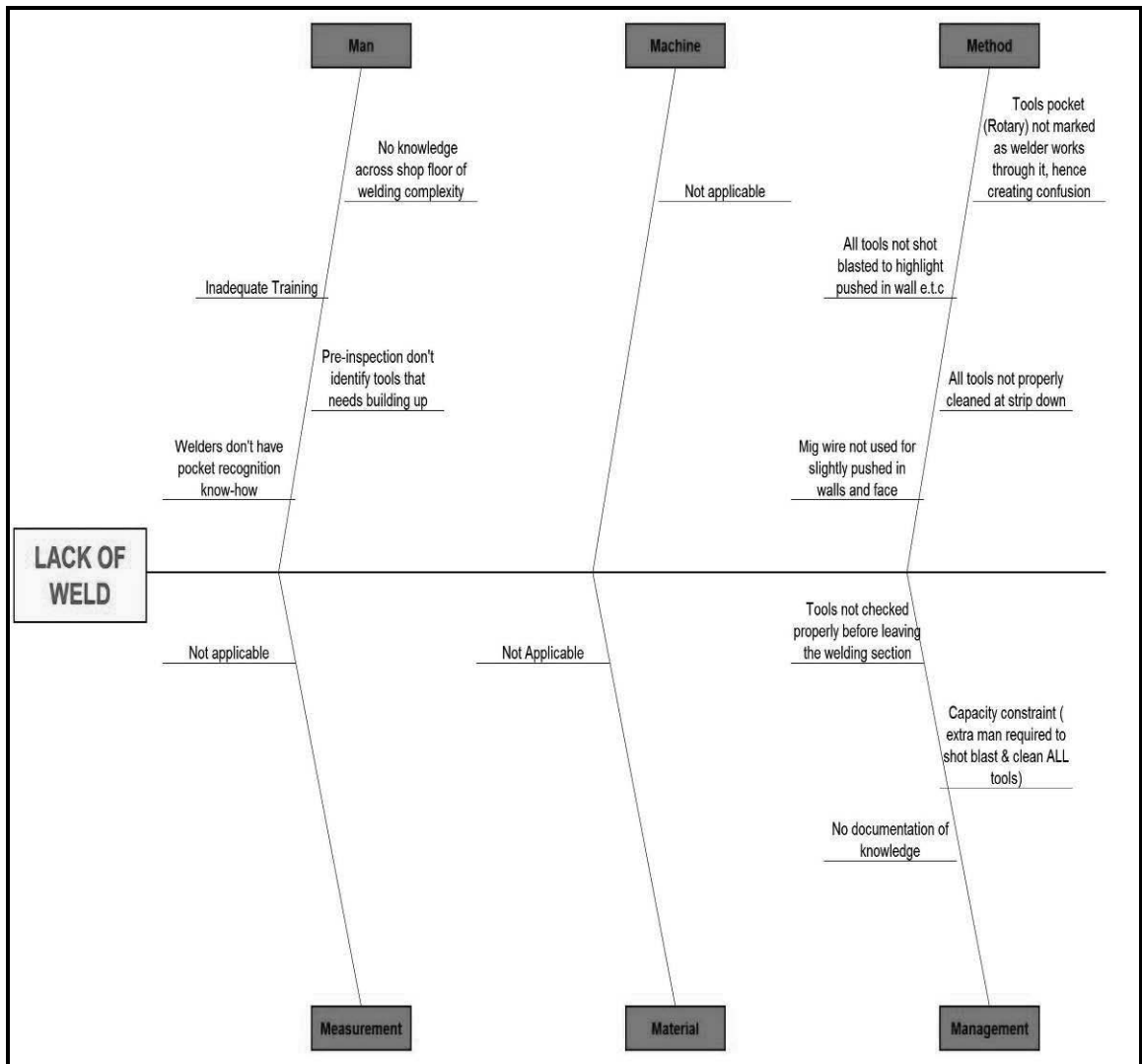


Figure 6.6: Cause & Effect diagram Lack of Weld IDR

Additional to establishing these categories the outputs from the sub categories of the Cause and Effect diagram in **Figure 6.6** and other potential x's that may affect the Big Y –“Lack of Weld” — and other small Y's (that is, poor strip down quality, part out-of-tolerance and good part) are listed in the third column of the Cause and Effect (C&E) Matrix in **Table 6.2**. The C&E matrix (rated by the project team as part of a brainstorm exercise) gives weights to each Y indicating the importance of that Y. Then each x is rated in terms of its correlation to each Y.

The scale used is from 1 to 10 where 1 indicates least important in terms relative importance and a 10 indicates the most important in terms of relative importance. The calculation presented in column 8 of **Table 6.2** is arrived at by multiplying each rating by the weight and sum across the row. The x's with the highest totals are the ones the team will be focusing on in the improvement and control phase of the DMAIC project.

		Cause and Effect Matrix					
Enter C&E Break Point:							
Rating of Importance to Customer			10	5	10	10	
			1	2	3	4	
	Process Step	Process Inputs	Lack of weld	Poor strip down quality	Part out-of-tolerance	Good part	Total
1	Pre-Inspection	Operator skill	9	1	9	9	275
3	Welding	Welding setup	9	0	9	9	270
2	Strip Down	Welding team leader overcheck	9	9	3	9	255
6	Strip Down	Operator skill	9	9	3	9	255
10	Welding	Welding rod	3	3	9	9	225
8	Welding	Weld heat	9	1	3	9	215
5	Welding	Welding machine setting	9	0	3	9	210
11	Strip Down	Shot blast media	9	9	3	3	195
4	Welding	Operator skill	9	0	9	0	180
7	Pre-Inspection	Extent of damage	3	3	3	9	165
12	Strip Down	Grinding machine	0	9	3	9	165
15	Pre-Inspection	Time to inspect	3	3	3	9	165
9	Strip Down	Drilling equipment	3	3	3	3	105
13	Strip Down	Shot blast machine	3	3	3	3	105
14	Strip Down	Degreaser	3	3	3	3	105
144							0
Total	First Process	First Input	90	56	69	102	

Table 6.2: Cause and Effect Matrix—Lack of Weld

6.3.4 Improve Phase: “Lack of Weld” Internal Defect Reduction

In the improve phase, the team has validated the causes of the problems in the process from the preceding measure and analysis phase and is ready to generate a list of solutions for consideration. The critical question during the phase that the team is required to answer is “What needs to be done” (McCarty et al., 2005) .Table 6.3 shows a Failure Mode Effect Analysis (FMEA) conducted using the key process output from the C&E matrix in Table 6.2. The actions and responsibilities are geared towards improving incidence related to “lack of weld”.

D&E Break 250		Process/Product Failure Modes and Effects Analysis (FMEA)														
Sort FMEA		Print FMEA		Prepared by: Adeje Esan		Page 1 of										
Process of Product Name: Lack of Weld Internal Defect Reduction				FMEA Date (Orig):				(Rev): 1								
Responsible: Production Management																
Process Step	Key Process Input	Failure Modes - What can go wrong?	Effects	S E V	Causes	O C C	Current Controls	D E T	R P N	Actions Recommended	Resp.	Actions Taken	S E V	O C C	D E T	R P N
Pre-Inspection	Operator skill	Damage not correctly identified	Part not stripped down properly-part reworked	8	Insufficient knowledge of strip down requirement	7	None	8	448	Pre-inspector to understand strip down requirement	All pre-inspectors	Training matrix updated	5	3	8	120
Pre-Inspection	Operator skill	Part not checked	Poor weld and strip down quality-part reworked	8	Throughput demand	3	None	8	192	Parts to be stamped and signed off after pre-inspector check	All pre-inspectors	Tags implemented	3	3	3	27
Pre-Inspection	Operator skill	Part not checked	Reduced throughput	8	Pre-inspector not available	3	None	8	192	Training more operators on how to pre-inspect part	Chris Morton	In-line inspector training on how to pre-inspect part	3	3	3	27
Pre-Inspection	Operator skill	Part not checked	Customer receives defective part	8	Pre-inspector not trained	3	Training matrix	8	192	Update training matrix and conduct training for identified laps...	A. Esan and Chris Morton	Training matrix updated	3	3	3	27
Strip Down	Welding team leader overcheck	Part not checked	Poor weld and strip down quality-part reworked	8	Welding team leader forgot to check part post strip down	5	None	10	400	Strip down operator and welding TL to sign off worksorder card prior to releasing part into welding	Dave Almond, Richard and Chris morton	Works order signoff implemented right across the manufacturing system	5	2	2	20
Welding	Welding setup	Damage not welded correctly	Poor weld quality-part reworked	8	Operator did not use correct setup procedure	5	Fixtures provided to aid set-up	5	200	Training matrix update. Welding operator to be re-trained on correct setup procedure	Dave Almond, Chris Morton and Phil Chew	Training conducted	3	5	2	30
Welding	Welding setup	Porosity in weld sub structure	Poor weld quality-part reworked	8	Poor welding travel speed and welding rod feed rate	5	None	5	200	Develop standard operating procedure for welding	A. Esan, Chris Morton, Dave Almond	Standard Ops created	3	5	2	30
Welding	Welding setup	Part not welded	Customer receives defective part	10	Poor vigilance by operator	2	None	5	100	Training matrix update.	A. Esan and Chris Morton	Training matrix updated	3	5	2	30
Welding	Welding setup	Damage not welded correctly	Customer receives defective part	8	Poor knowledge of shop operations and milling requirements	8	None	8	512	Welding operator to spend time at milling, grinding, and finishing workstations	Chris Morton, Phil Chew, Adrian Warrington and Dave Almond	Training conducted	3	2	2	12
Welding	Operator skill	Damage not welded correctly	Poor weld quality-part reworked	8	Poor welding speed and welding rod control	5	None	5	200	Training for welding operator on speed and welding feed rate	Phil Chew and Chris Morton	Training conducted	3	2	2	12
Welding	Operator skill	Damage not welded correctly	Customer receives defective part	8	Insufficient tooling knowledge	5	None	5	200	Welding operator to spend time at milling, grinding, and finishing workstations	Chris Morton, Phil Chew, Adrian Warrington and Dave Almond	Training conducted	3	2	2	12
Welding	Welding rod	Damage not welded correctly	Porosity in weld	7	Foreign material in part reacts with welding rod	5	Part degreasing at strip down	5	175							
Welding	Welding rod	Part not welded correctly	Poor weld quality-part reworked	7	Poor welding travel speed and welding rod feed	5	None	10	350							
Strip Down	Shot blast media	Part not shot blasted	Poor stripdown quality	7	No requirement for operator to shot blast part	5	None	10	350							
Strip Down	Shot blast media	Part shot blasted in Aluminium Oxide	Poor weld quality-part reworked	8	Foreign material impregnated on part	5	None	10	400	Source new shot blast media	A. Esan	New shot blast media sourced (Grit -Calcium carbonate-blast media)	2	1	2	4
Welding	Welding machine setting	Weld arc difficult to start	Poor weld quality-part reworked	8	No standard welding machine setting parameter	5	None	5	200	Develop standard welding parameter for GTAW and conduct experimental design to determine optimum setting levels	A. Esan and Dave Almond					
Welding	Welding machine setting	Wrong welding machine setting	Poor weld quality-part reworked	8	No standard welding machine setting parameter	5	None	5	200	Develop standard welding parameter for GTAW and conduct experimental design to determine optimum setting levels	A. Esan and Dave Almond					
Strip Down	Operator skill	Damage not ground off pocket area	Poor stripdown quality	5	Insufficient tooling knowledge by strip down operator	5	None	10	250	Create tooling recognition flow chart	A. Esan and Chris Morton	Tooling recognition flow chart created	3	2	2	12
Strip Down	Operator skill	Excessive tool pocket area ground off	No original to work to at milling	6	Insufficient tooling knowledge by strip down operator	5	None	10	300	Create tooling recognition flow chart	A. Esan and Chris Morton	Tooling recognition flow chart created	3	2	2	12

Table 6.3: FMEA Lack of weld Internal Defect Reduction (Appendix 6.1)

Major categories of actions from the FMEA are operator training, development of tooling damage recognition flow charts, welding team paper work sign off post strip down, source for alternative welding rods and shot blast media. These actions are denoted by the high Risk Priority Number (RPN). Detailed in **Table 6.4** is a training plan for the welding operator. The training plan clearly states the training requirements, roles and responsibilities, training pre-requisites, and a training curriculum.

Training Requirements	Training Pre-requisites & Techniques and Tools
<ul style="list-style-type: none"> • Gain advanced knowledge of welding set-up procedure and basic welding machine settings. • Gain basic knowledge of machining. • Gain in-depth know-how on the effect of “lack of weld” on tool finishing quality. • Recognize the cost impact of lack of weld on the organisation & operator’s bonus. • Create an understanding of mutual working relationship & team work. 	<ul style="list-style-type: none"> • Welding Basics • Basic tool knowledge • Basic knowledge of pocket shape/geometry. • Self-paced written manual, • Peer training, • hands-on practical sessions • Welding machine, Milling machine & tools (as appropriate)
Roles and Responsibilities	Training Curriculum (6/12/2006 to 22/12/2006)
<ul style="list-style-type: none"> • Chris Morton to champion the training of the trainee (Phil Chew). • Dave Almond to provide training support with regards to welding technology (welding setup, rods, gases, tools & equipments, welding methods-how to achieve clean weld, welding training manual and photographic details). • Adrian Warrington to provide support for the training within the Manual Milling section. • AE to facilitate training procedure, document training and establish other support structures that required for effective training. 	<ul style="list-style-type: none"> • Visit to welding by CM—Spend time with DA(1/2hr) & other welding team (10mins each) • Appreciation of the effect of “Lack of Weld” on upstream operators, that is, Millers and what is “Lack of Weld” • Tool recognition: • Pocket shape/geometry • Special tools welding • Damage recognition • Knowledge of shop floor: Trainee to spend 10-15mins with each operator in milling, finishing and grinding.

Table 6.4: Lack of welding training plan

Furthermore **Figure 6.7** shows a tooling damage recognition flow chart. The significance of this flow chart is that it provides guidance to the pre-inspectors, strip

down operator and welding operator on how to examine a part critically and logically. The flow chart provides and highlights the CTQ features of a part; hence helps reduce/eliminate any ambiguity as to what is critical and what is not during the part's pre-inspection, strip down and consequentially the welding stage. The tooling damage recognition flow chart does not only serve the purpose of the case study ("lack of weld internal defect reduction) but will act as a guide for all operators (New and Old) within NTR Ltd's manufacturing system.

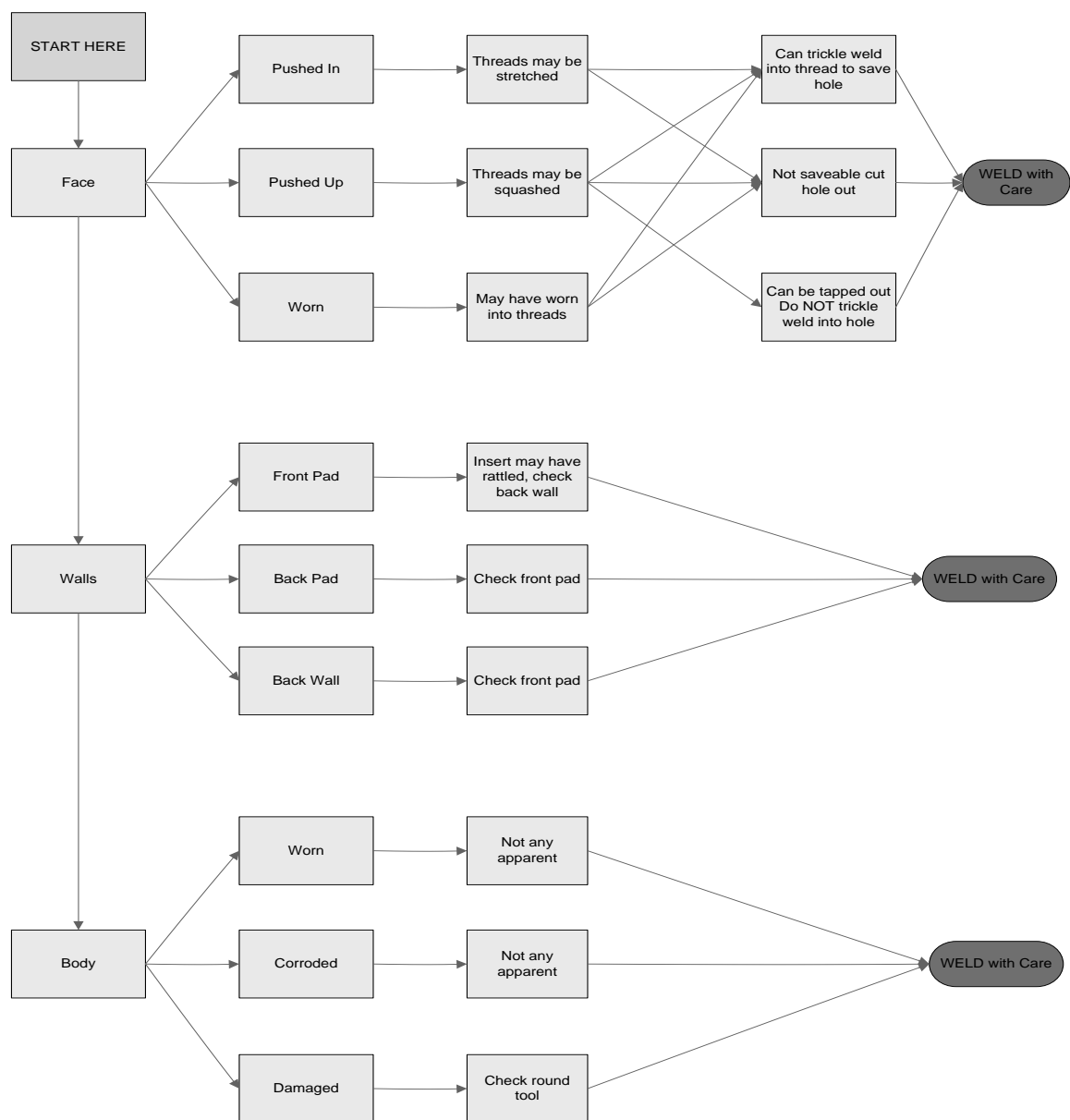


Figure 6.7: Tooling damage recognition flow chart

6.3.5 Control Phase: “Lack of Weld” Internal Defect Reduction

In this phase of the project the emphasis is on a sustaining the improvement from the improve phase of the DMAIC project. A typical strategic framework implore in making sure this is the case in NTR Ltd’s manufacturing system is the utilisation of a questionnaire/check sheet to measure/capture operator’s understanding, that is, what did the operator gain and was the training useful/effective? A scoring system was used on the check sheet to measure which particular aspect of the training was most effective for the purpose of future training and serves as a “look across” (system wide implementation) strategy.

Table 6.5 show a typical training questionnaire for the “lack of weld” internal defects reduction project at NTR Ltd. Key phases of the questionnaire are operator’s appreciation of effect of “lack of weld” on the manufacturing system, tooling damage recognition and knowledge of the shop floor (this is required so that the welding operator can appreciate requirement upstream of his process).

Post "Lack of Weld" Training Questionnaire				
Using the point system below, kindly rate the "Lack of Weld" training procedure & effectiveness				
1-- Poor 2 -- Average 3 -- Good 4 -- Excellent				
Appreciation of Lack of Weld	1	2	3	4
Were you able to understand the cost impact of "Lack of Weld"?				
Were you able to appreciate the effect of "Lack of Weld" on tool quality?				
Did the training give better appreciation of "Lack of Weld" effect on millers & fitters?				
Damage recognition	1	2	3	4
Did the training give you a better understanding of "pushed-in-face"?				
Did the training give you a better understanding of "pushed-in-walls"?				
Did the training give you a better understanding of "worn tool body"?				
Did the training give you a better understanding of "damaged thread"?				
Did the training give you a better understanding of "corrosion on tool"?				
Knowledge of shop floor	1	2	3	4
Was this aspect of the training any use?				
Will frequent (2-3months interval) team building exercise be of any benefit?				
Overall assessment	1	2	3	4
Where you satisfied with the training curriculum and general conduct of the training?				
Total				
Comments (Kindly fill this section as all your thought might not have been covered by this questionnaire)				

Table 6.5: Post lack of weld questionnaire (**Appendix 6.2** for form completed by operator and a welding training Assessment)

In other to continuously monitor the process for any out-of-control condition, **Table 6.6** shows a control plan for the “lack of weld” IDR project. The training champion and the team leader for welding will continuously monitor and implement on a weekly basis a

preventive and/or reaction plan for any out-of-control condition through refresher training and utilisation of the welding training assessment form.

Process	Step	Output	Input	Process Spec.	Capability /Date	Measurement Technique	Sample Freq.	Control Method	Reaction Plan
Y = Number of incidence relating to lack of weld per week	Welding	Weld quality	Operator skill	USL 60 LSL 0 Target 30	Ppk 1.02 February WK2 '07	Defects per week (taken from the internal returns database)	Once Per Week	I-MR Chart	Operator training and training assessment matrix
X1— Welding	Welding machine setting	Weld quality	Welding gas and current	100% uptime (as a % of time lost versus running hours)	100% February WK2 '07	Welding setting and readings log	Once per week	IMR Chart	Contact Welding Team leader
X2— Strip down	Tooling strip down	Strip down quality	Operator skill	USL 3 LSL 1 Target 2.5 skill level	Operator skill level =2 @ February Wk2 '07	Training matrix rating	Once per weeks	Training matrix	Contact Training Champion

Table 6.6: Lack of Weld IDR project control plan

Other preventative plans will be to consistently monitor the welding machine settings and welding gas flow rates for any out-of-control condition. Additionally, other controls put in place to sustain the gain from the “lack of weld” IDR project include the welding team leader and strip down operator to sign off works Order card after strip down, and strip down operator tool damage recognition training and training matrix.

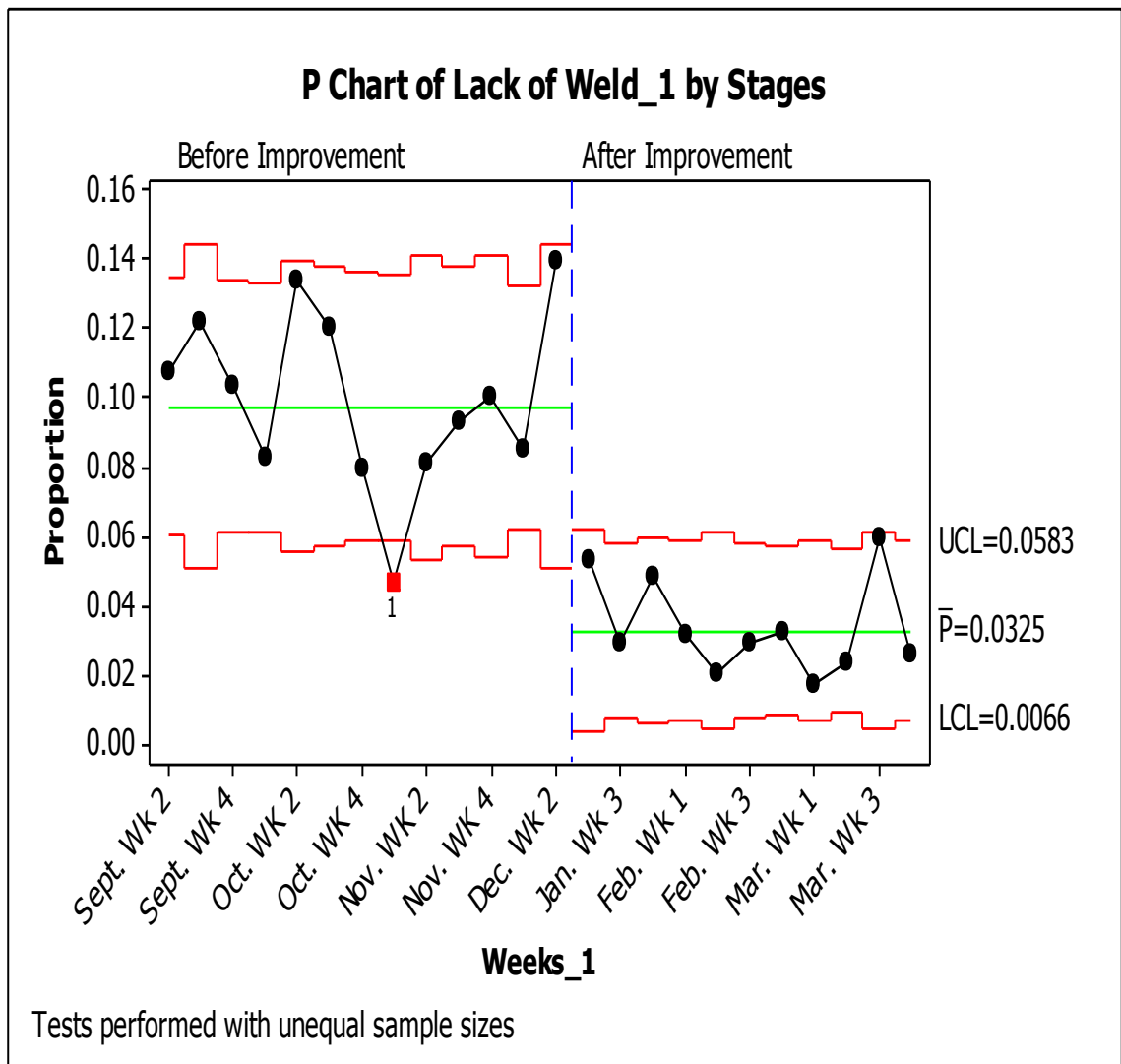


Figure 6.8: P-Chart of Lack of Weld PPM Split by improvement stage

Figure 6.8 shows a control chart developed to measure the big Y in **Table 6.6**. The control chart is split into 2 regions to show a pre-improvement and post improvement trend on the P-Chart. The P-Chart shows a marked proportion defective improvement from initial 0.0937 to 0.0325, (that is 93700PPM to 32500PPM with associated sigma level improvement from 2.8 to 3.3) hence a **63.12%** improvement which is greater than the project goal of 50% improvement. **Figure 6.9** shows a Pareto chart for the overall internal defect rate within NTR Ltd’s manufacturing system for February.

INTERNAL RETURNS WELD RELATD FEBRUARY 2007 (POST IMPROVEMENT)

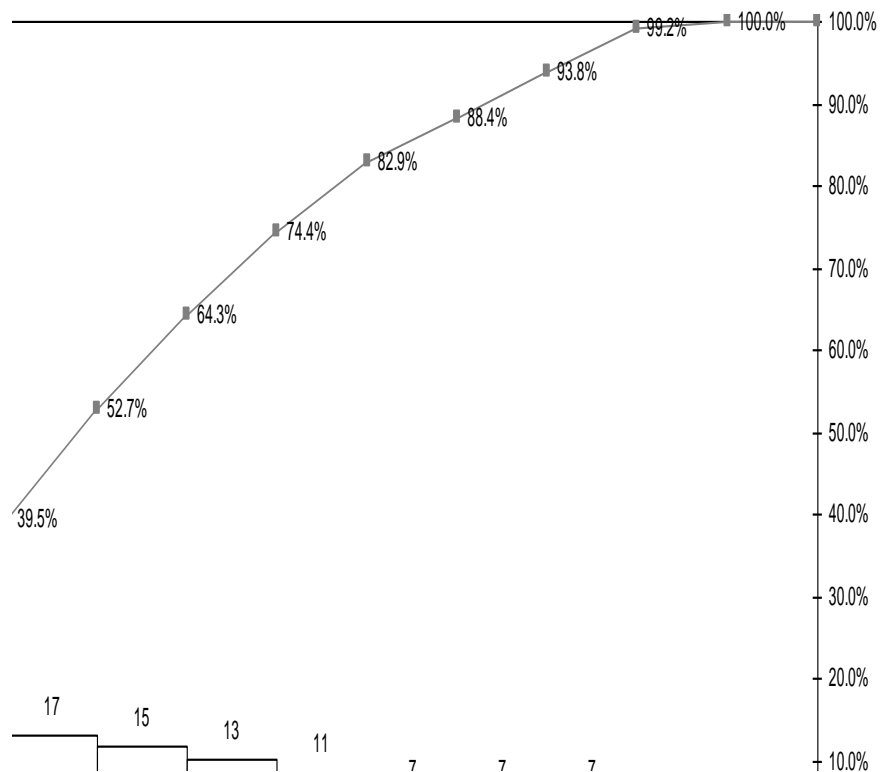


Figure 6.9: Pareto of internal defects NTR Ltd February 2007

The defect category “lack of weld” now accounts for just about 7% of the total IDR and a defect rate of 7 parts as at February 2007. Based on this value the estimated annualised saving from this project is approximately £25,000. The real lessons learnt from the case study is that operator involvement is key to improvement and that effective communication, provision of detailed training plan and schedule and knowledge sharing are effective tools for process improvement.

6.4 Case Two: Heat Treatment Defects Reduction

Based on output from the FTQ data presented in the value stream (appendix 6.4) a high level of rework is prevalent at NTR Ltd heat treatment facility hence constituting a resource constraint. **Figure 6.10** show the process flow diagram of parts reworked at the CNC product line.

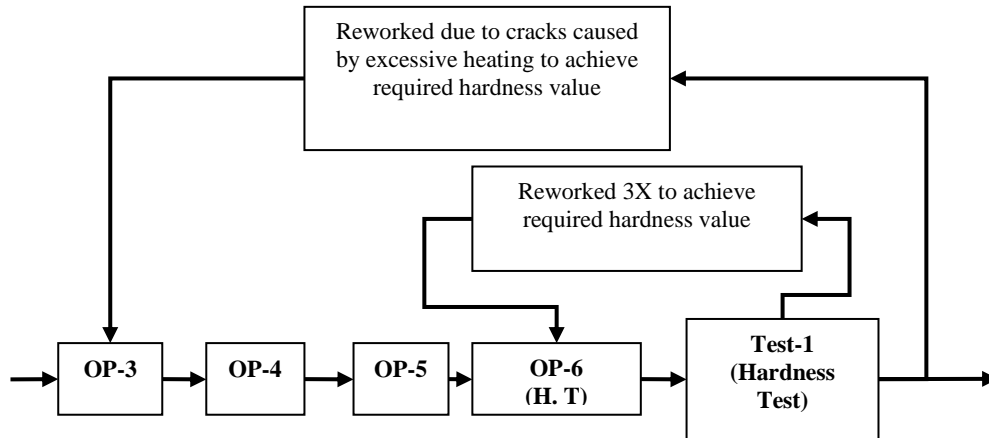


Figure 6.10: Process flow diagram of tools been reworked on the CNC product Line

The heat treatment method is flame hardening (Oxy-Acetylene torch). It's used within NTR Ltd's manufacturing system for localised heating of tools 'reclaimed' on the CNC product line. The nature of constraint exhibited by the facility was its inability to guarantee reproducibility and repeatability of tools been heat treated. Parts had to be heat treated thrice (reworked) to achieve the required hardness level (38-60HRC). Inevitably, this causes the tools to crack hence results in rework right through the process. Discussed below is the application of the DMAIC methodology to resolving this anomaly.



Figure 6.11 (a): The heat Treatment Bay



Figure 6.11 (b): The heat Treatment Bay and part set-up (U-Drill)



Figure 6.11 (c): The heat Treatment part been heated



Figure 6.11 (d): The hardness Tester

6.4.1 Define Phase: Heat Treatment Internal Defect Reduction

Table 6.7 shows the Project Charter for the heat treatment defect reduction project. The charter contains a problem statement, a CI team, project goals/objective and key deliverables. The team consisted of the operator directly responsible for heat treating the parts, a welder and the chief inspector.

<p>Problem Statement Customer complaint on tool hardness: hardness value lower than 38HRC. This can result in possible loss of customer, due to poor in tool service. Customer estimate annual volume £20,000 and internal returns due to crakes £7500</p>	<p>Team Craig Naylor – Sponsor Adedeji Esan– Black Belt Dave Almond– Welding Team Leader (Expert) Mohan Uppal—Inspection Team Leader Ian Binns—Heat treatment operator and Team member milling</p>
<p>Goal/Objective To create a process that will significantly eliminate the compliant and reduce internal returns due to hardness defect by 90%</p>	<p>Deliverables - 60 day project 1) Eliminate customers compliant 2) Reduce internal returns due to hardness by 90% 3) Increase operator knowledge of heat treatment process 4) Streamline process</p>

Table 6.7: Project Chart Heat Treatment Defects Reduction Project

In **Table 6.8** a Supplier- Input-Process-Output-Customer (SIPOC) analysis developed by the team to identify all relevant elements of the heat treatment process improvement project before work begins. It helps define the complexity of the project hence eliminating improper project scoping. The SIPOC is similar and related to Process Mapping and 'In/Out Of Scope' tools, but provides additional detail. From **Table 6.8**, key outputs from the process are low hardness, cracks and poor in-service performance of part heat treated at NTR Ltd.

S	I	P	O	C
Suppliers	Inputs	Process	Outputs	Customers
Welding	Welded in SD3 Welding Rod and under goes series of heat transformations	Parts Arrive from Finishing	Low hardness	End Customer
Milling	Pocket machining	Load part and secure in vice	Poor in-service performance	Final Inspection
Turning	Cyclical stress	Set Acetylene Welding Machine Up	Cracks	
Grinding	Cyclical stress	Heat Treat part: No Standard Procedure	Good hardness	
Heat Treatment	Heat	Measure part using Hardness Tester If < 38HRC then		
Finishing	Deburring	Re-heat part		
		Re-Measure part using Hardness Tester: IF > 38HRC pass to Shot Blast Section.....		

Table 6.8: SIPOC Heat Treatment Process

6.4.2 Measure Phase: Heat Treatment Internal Defect Reduction

Prior to any improvement and analysis a Measurement System Analysis (MSA) was carried out on the gauge (hardness tester) used for validating the heat treatment process

output. The aim of the gauge study was to understand the extent of repeatability and reproducibility of the measurement system. For the purpose of the study three different parts (standard measurement blocks) were chosen. Part 1, has a nominal value of 45HRC, while parts 2 and 3 have nominal values of 35HRC and 65HRC respectively. The parts chosen cover possible under-specification, nominal specification and over-specification.

The process of conducting the gauge R&R study involved two operators measuring the same part twice and in succession, with five replications and total runs of 30. **Figure 6.12** shows the gauge R&R study result for the heat treatment defects reduction project. **Figure 6.12** shows a good fit between operators to part interaction and a mean measurement by operators as 50HRC, hence suggesting consistency in the measurement system. For further examination of **Figure 6.12**, **Tables 6.9a & b** shows the components of variation.

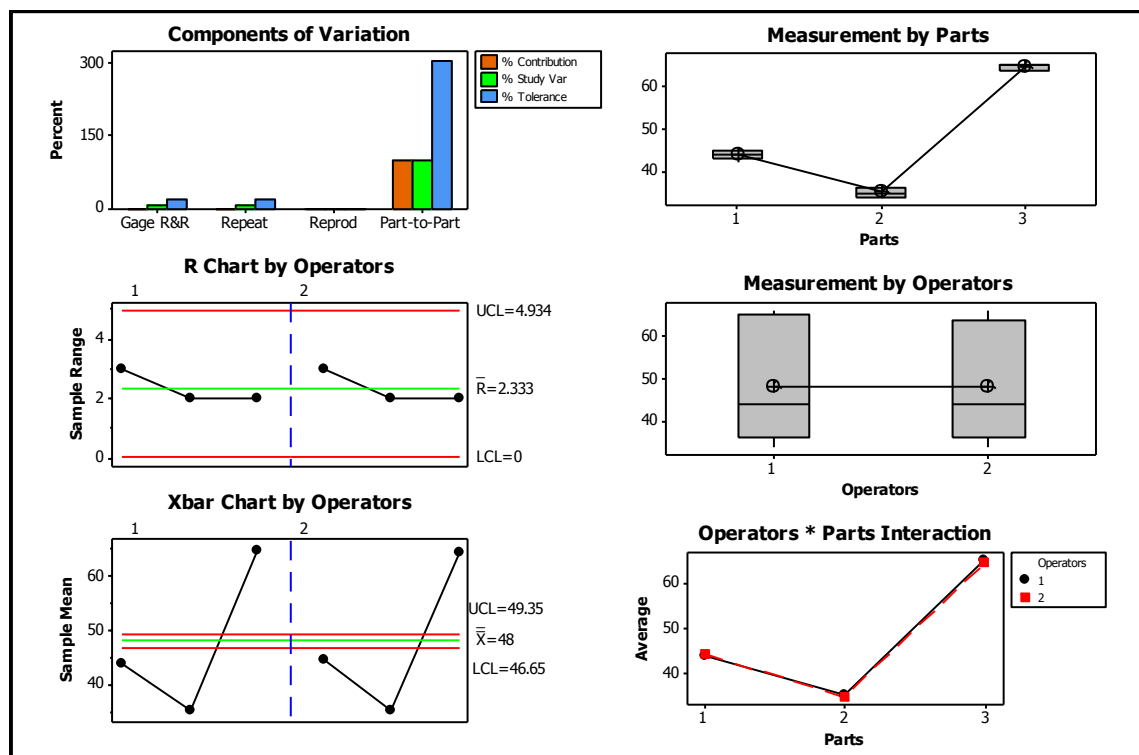


Figure 6.12: Gauge R & R heat treatment defects reduction project

Table 6.9a & b shows a part-to-part and total contribution and study variations of 99.58%, 100% and 99.79%, 100% respectively. This is expected since the parts chosen for analysis varies considerably. The purpose of this variation study as stated earlier is to replicate possible under-specification and over-specification situation that NTR Ltd’s customers might experience due to in-consistency in the heat treatment methods. Furthermore, using a typical acceptance criterion shown in **Appendix 6.3**, it can be concluded from **Table 6.9a** that the gauge is acceptable because the total gauge R&R % contribution is 0.42% (<2% acceptance criteria).

Source	VarComp	%Contribution (of VarComp)
Total Gauge R&R	0.977	0.42
Repeatability	0.977	0.42
Reproducibility	0.000	0.00
Operators	0.000	0.00
Part-To-Part	231.832	99.58
Total Variation	232.809	100.00

Table 6.9a: Gauge R& R study HT defects reduction project—% VarComp

Moreover, **Table 6.9b** further validates the acceptability of the measurement system (based on **Appendix 6.3**) because it suggests that the number of distinct categories is 21 which is greater than 10 specified in acceptance criteria. Furthermore, with a total gauge R&R tolerance of 19%, this further confirms the acceptability of the measurement system based on **Appendix 6.3** marginal acceptance criteria for gauge R&R % tolerance of 10%—30%.

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gauge R&R	0.9884	5.9304	6.48	19.77
Repeatability	0.9884	5.9304	6.48	19.77
Reproducibility	0.0000	0.0000	0.00	0.00
Operators	0.0000	0.0000	0.00	0.00
Part-To-Part	15.2260	91.3562	99.79	304.52
Total Variation	15.2581	91.5485	100.00	305.16

Table 6.9b: Gauge R& R study HT defects reduction project—% study variation

Further to accepting the measurement system the next issue was to understand the actual work method of the heat treatment facility at NTR Ltd. For this purpose, the operator that does the heat treatment was asked to demonstrate the way in which parts are currently heat treated using a sample number of 15 and a sample size of 5. **Figure 6.13** shows the output from this initial work method study (process capability study).

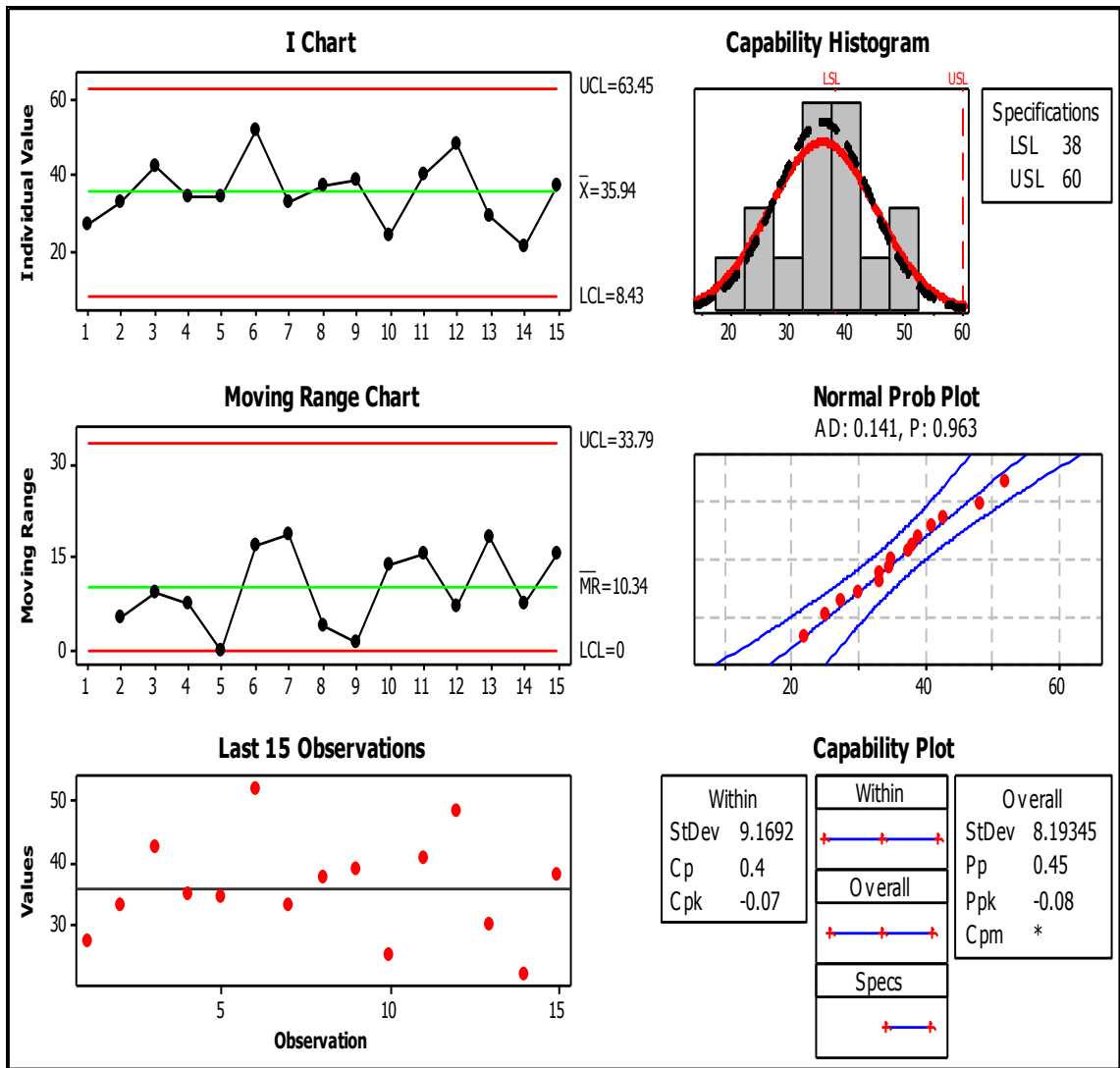


Figure 6.13: Process Capability Study of the HT method before improvement

An outstanding observable during the process capability study was that there was no Standard Operating Procedure (SOP) in place that provides operator with guide line on how to heat treat parts, rather the process was more intuitive than objective. **Figure 6.13** further confirms this observation with a process capability index (CPk) (means process not capable or centred on its mean) of -0.07, and a standard deviation “within” of 9.2 which signifies excessive/high process spread. The mean value from the I-chart in **Figure 6.13** is 35.95HRC suggesting that a bulk of heat treated part within NTR Ltd manufacturing system do not achieve the required minimum specification of 38HRC.

6.4.3 Analysis Phase: Heat Treatment Internal Defect Reduction

Based on the preceding measure phase and the main observable of no SOP from the heat treatment process, key affect on the hardness value of the part are the diameter of the part been heat treated, time to heat treat, and the torch cone length. In other to understand the relationship between these key inputs that affects the hardness value, an experimental design was setup. The experimental design was necessary as there are currently no literature and/or industrial standard methods because the heat treatment process is specialist to NTR Ltd's process. Conventional heat treatment process usually involved furnaces, or induction heating.

Table 6.10 show the layout of the experimental design. The experimental design uses a 2 by 3 factorial design. The 3 factors are diameter of the part (Short hole drill) to heat treat (high level= 40mm and low level=16mm), time span to heat treat the part (high value=80secs and low value=10secs), and the length of the acetylene torch's cone (high level=2mm and low level=1mm). Factors held constant during the experimental design are the number of turns in oil (6 turns) and water (6 turns).

Std Order	Run Order	Center Pt	Blocks	Diameter	Time	Cone Length	HRC	Comments
1	1	1	1	16	10	1	39	Good
2	2	1	1	40	10	1	34	Poor
3	3	1	1	16	80	1	55	Potential to crack
4	4	1	1	40	80	1	38	Fairly Good
5	5	1	1	16	10	2	52	Potential to crack
6	6	1	1	40	10	2	37	Poor
7	7	1	1	16	80	2	59	Crack
8	8	1	1	40	80	2	47	Good

Table 6.10: Heat Treatment Experimental Design

Figure 6.14 shows the main effect plot of the experimental design. From the graph it can be inferred that hardness property of the part increases with decreasing diameter, whilst an increase in hardness property of the part is directly proportionally to increasing heat treatment time and cone length of the acetylene torch.

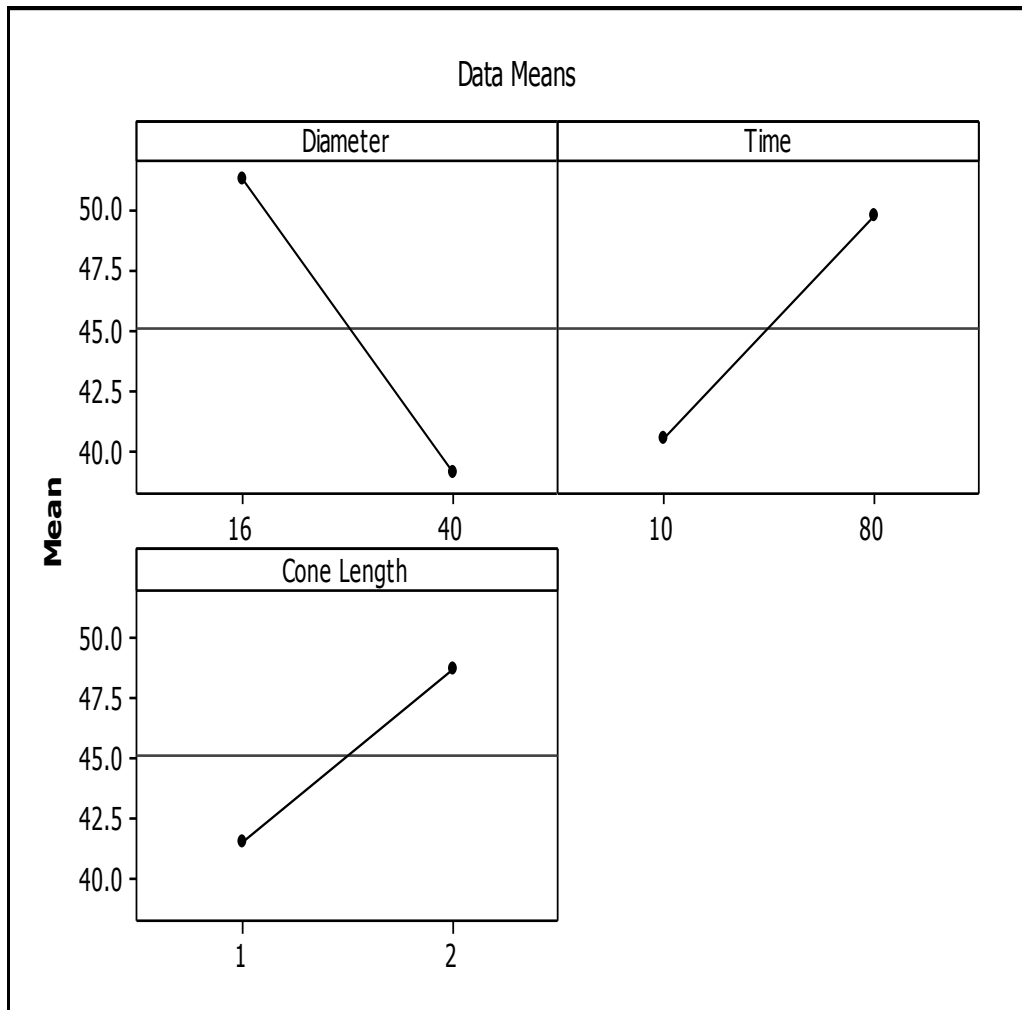


Figure 6.14: Main effect plot of diameter, time and cone length.

To further validate the main effect plot, **Figure 6.15** shows a contour plot of hardness value (HRC) at a cone length of 2mm (high level). **Figure 6.15** examines the relationship between the part's diameter and time to heat treat. The figure implies that at high level setting of cone length the hardness property of the part increases with

increasing time whilst the hardness property of the part decreases with increasing diameter of the part.

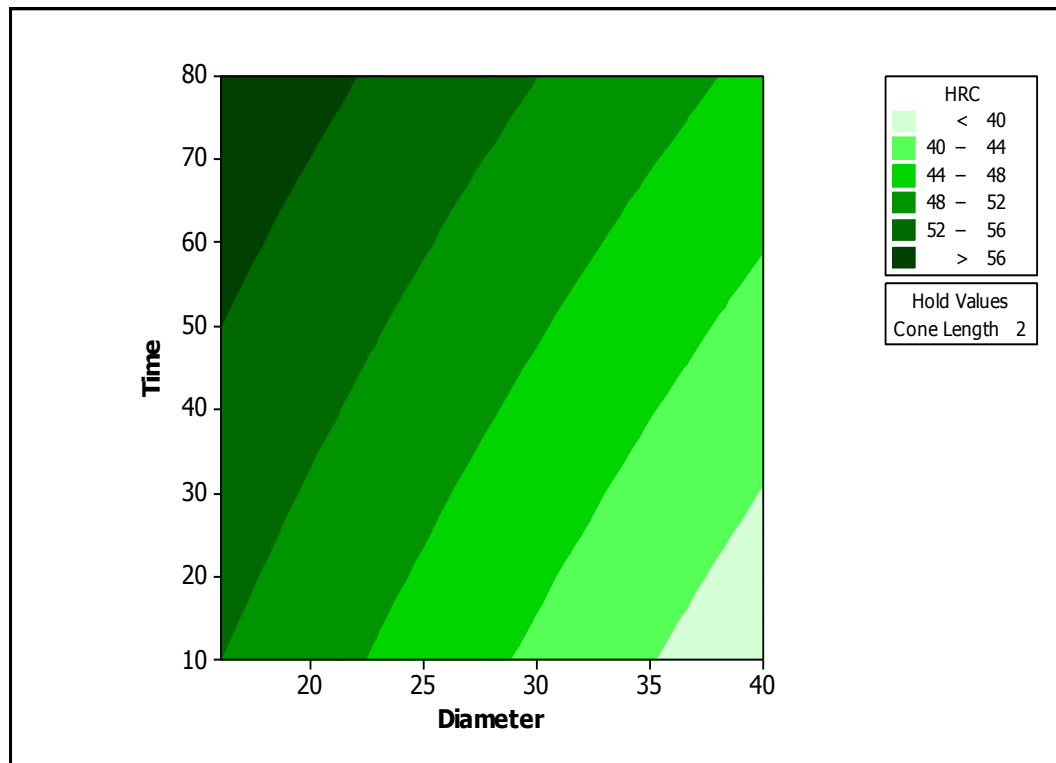


Figure 6.15: Contour plot of HRC Vs Diameter, Time

Due to the effects noted in **Figures 6.14 and 6.15** it is therefore necessary to understand the optimum settings of the various factors in order to continuously guarantee that parts are heat treated correctly and within specification. **Figure 6.16** shows the response optimisation for the experimental design. The goal of the response optimisation is to determine the optimal setting of the 3 factors used in the experimental design to achieve a nominal hardness value of 45HRC.

The individual desirability for hardness property of the part is 1. The individual durability assesses how well a combination of input variables satisfies the goal defined for the response. In addition, individual desirability (d) evaluates how the settings

optimise a single response within a range of 0 to 1. One represents the ideal case; zero indicates that one or more responses are outside their acceptable limits. To obtain this desirability the factor levels are set to the values highlighted in **Figure 6.16**. That is, diameter of part would be set at 38.4462mm, heat treatment time at 60 seconds, and an acetylene cone length of 2mm.

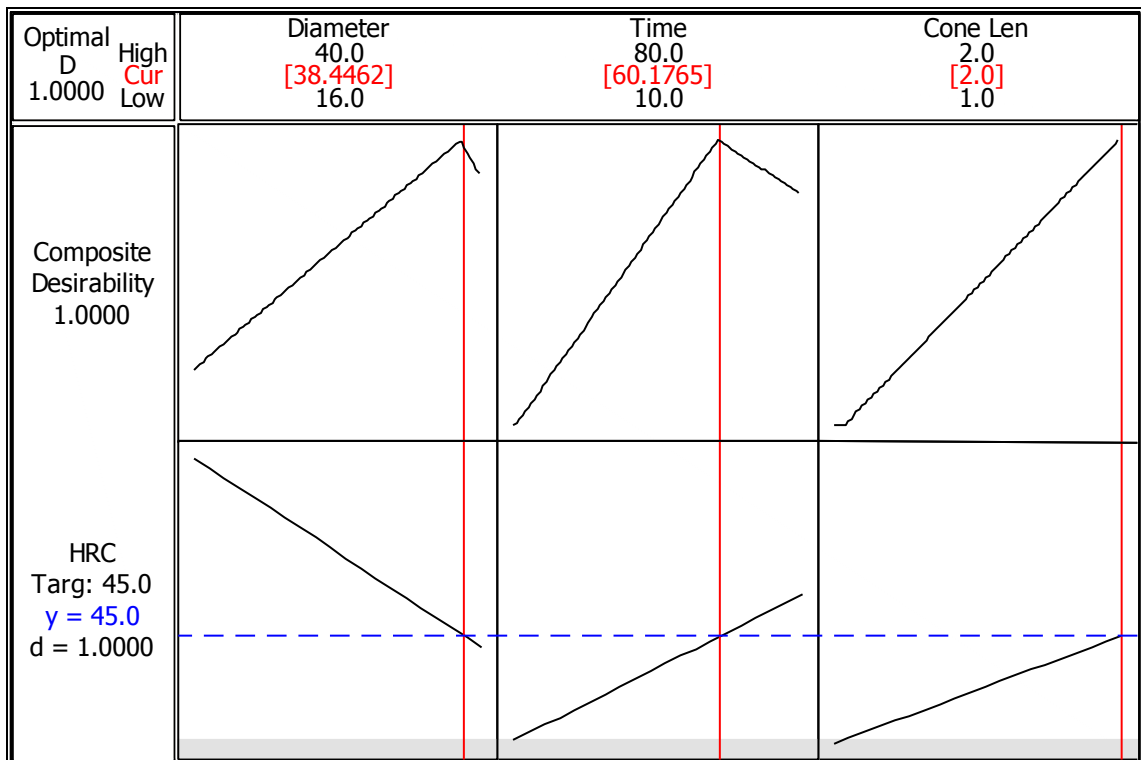


Figure 6.16: Response optimisation HT experimental design

In other to validate the output from **Figure 6.16**, the heat treatment operator and an expert were used to verify the correct way to heat treat parts using a sample size of 15 (each) and based on output from **Figure 6.16**. In effect, the validation was carried out using a short hole drill size of 38mm, heat treatment time of 60 seconds, and a cone length of 2mm with variables such as 50mm distance of acetylene torch to tool pocket area, 6 turns in oil and 6 turns in water kept constant.

Figure 6.17 shows a box plot comparing the expert's and operator's heat treated parts with a P-Value of 0.840. The mean values for the two tests are 45HRC with equal outliers of 42HRC and 48HRC however, the lower and upper quarter of the expert's distribution is 44HRC and 47HRC respectively whilst the operator's distribution is 43HRC and 46HRC respectively. Hence, the expert's method preferred.

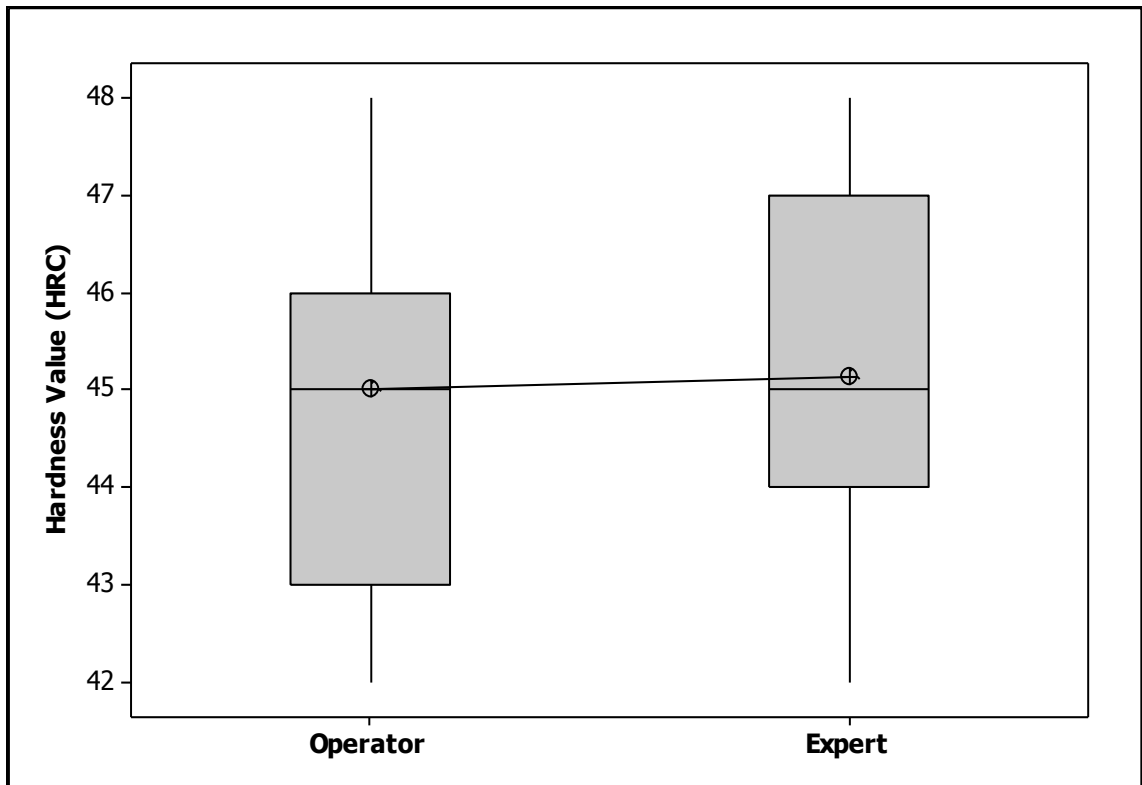


Figure 6.17: Box plot of expert Vs operator for HT process

6.4.4 Improve Phase: Heat Treatment Internal Defect Reduction

The details provided in **Table 6.11** shows a list of solution generated as a pilot study for the heat treatment internal defect reduction project.

Name	Explanation of Responsibility	Time Line	Review Date
SDA, MSU & AE	SDA to provide Heat Treatment training for MSU. AE to document the training procedure.	11/12/2006 to 15/12/2006	15/12/2006
SDA & AE	Investigate and order alternative welding rod with high hardness properties for experimental purposes.	11/12/2006	12 /01/2006
IB, SDA & AE	Using output from conducted experimental design on heat treatment method to determine the optimum way to heat treat short hole drill with target HRC of 45	11/12/2006	15/12/2006
AE	Study destructive testing method & where to conduct this experiment (Toughness/Hardness comparison)— Craftsman Tool, UoB, BETL	2/01/2007 to 12/01/2007	12/01/2007
SDA, IB, & AE	Create colour chart for different stages of HT & also generate a standard method accessible to ALL	11/12/2006	15/12/2006
AE	Investigate infra-red temperature measuring device	15/12/2007	12/01/2007
SDA & AE	Explore localised HT method (Induction heating) and also quantify how much it will cost to implement this procedure in NTR.	02/01/2007 to 12/01/2007	12/01/2007

Table 6.11: Heat treatment IDR project Implementation plan

In this improve phase of the DMAIC methodology, the team's major output from the list in **Table 6.11** includes the expert providing extensive training for an operator based on the experimental design in the analysis phase, development of a standard operating

procedure for heat treating part, and sourcing alternative welding rod with good hardness properties. **Figure 6.18** shows the standard operating procedure developed as part heat treatment IDR project.

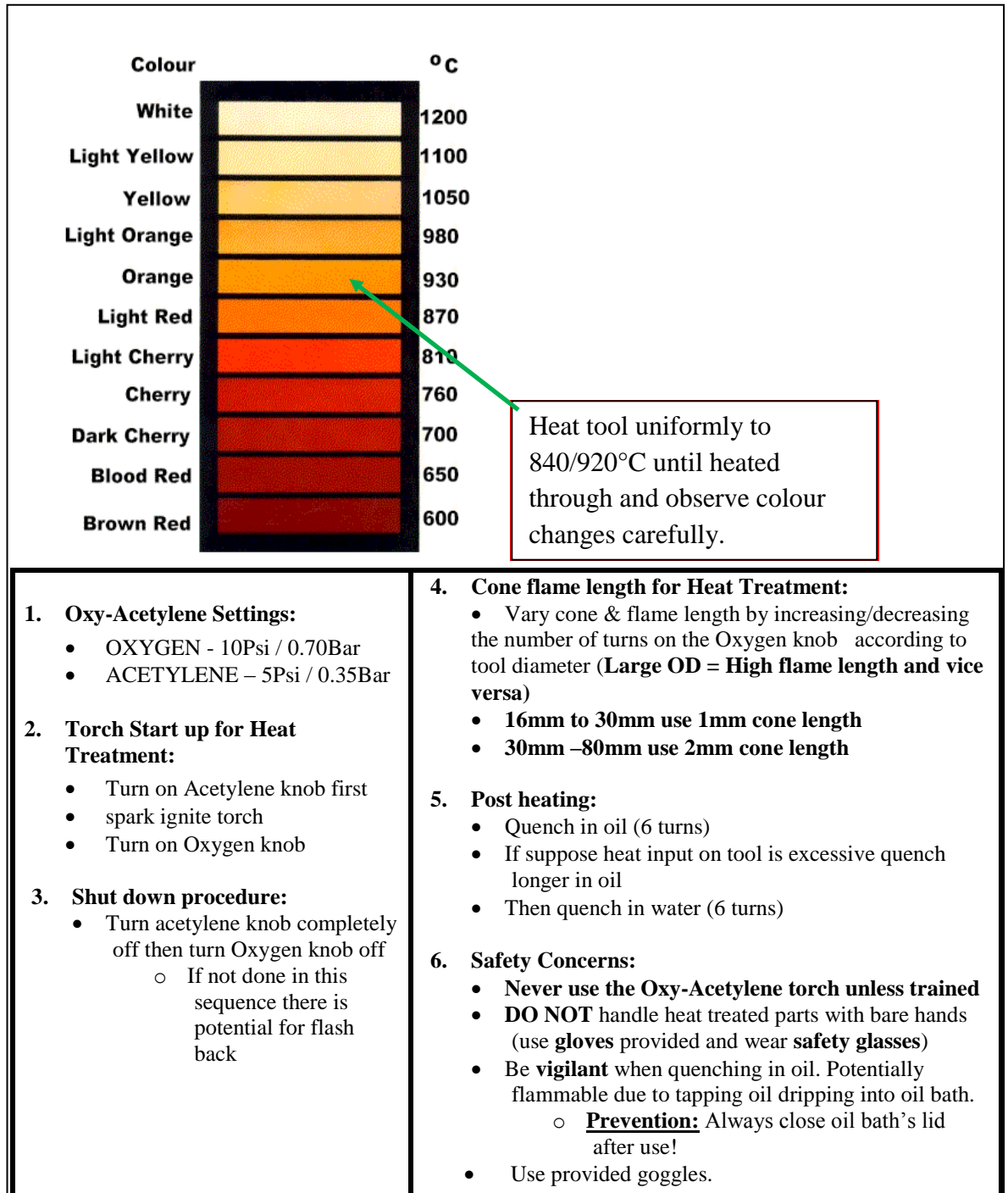


Figure 6.18: Heat Treatment Colour Chart and Hardening Procedure

Furthermore, **Figure 6.19** below shows a trial study post operator training. The training was conducted by the expert using the heat treatment colour chart and hardening standard operating procedure. The trial study uses a sample of 15 parts with a sample size of 5. Output from the trial shows a process capability index of 1.13 and a long term process capability study (Ppk) of 1.03 which suggests an improvement of about 1.11 ppk over the old process.

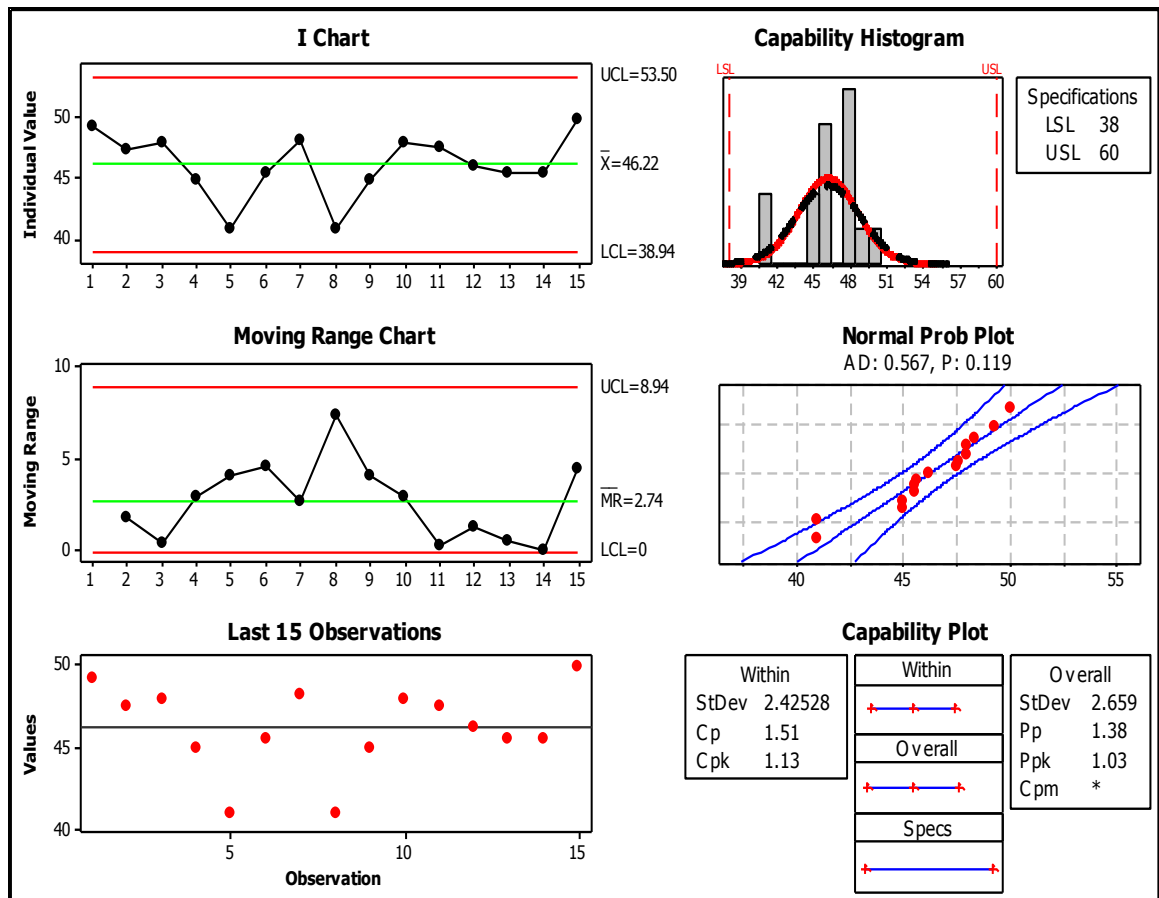


Figure 6.19: Process Capability Study of the HT method after improvement

In reference to **Table 6.11**, and the other actions outlined, the destructive experiment was not conducted because of resource constraints and lack of customer support to conduct the experiment. Additionally, the infra-red, and localised heat treat investigation (induction heating) cost benefit analysis were carried out and output from this

investigation is detailed in **Appendix 6.4**—Induction heating. Also included in the action item is the sourcing of alternative welding rod with good hardness and impact resistivity properties. The details of the chemical and physical properties of the welding rods are documented in **Appendix 6.5**. The appendix also shows a comparison between existing welding rod and the NEW welding rod.

6.4.5 Control Phase: Heat Treatment Internal Defect Reduction

In this phase of the project the emphasis is on a sustaining the improvement from the improve phase of the DMAIC project as iterated in section 6.3.4. A typical strategic framework implore in making sure this is the case in NTR Ltd’s manufacturing system is the utilisation of a control plan. **Table 6.12** shows a control plan for the heat treatment defect reduction project. In appendix 6.6 is a training matrix for monitoring and the control plan shown in **Table 6.12**.

Process	Step	Output	Input	Process Spec.	Capability /Date	Measurement Technique	Sample Freq.	Control Method	Reaction Plan
Y = Number of incidence relating to low hardness per week	Heat treatment	Hardness quality	Heat	USL 60 LSL 38 Target 49	Ppk 1.03 Dec. WK2 '07	Defects per week (taken from the internal returns and customer compliant database)	Once Per Week	I-MR Chart	Operator training and training assessment matrix
X1— heat treatment operator	Heat treat	Hardness quality	Operator skill	USL 3 LSL 1 Target 2.5 skill level	Operator skill level =2 @ Dec. WK2 '07	Training matrix rating	Once per weeks	Training matrix	Contact Training Champion
X2— Welding	Welding	Weld quality	Welding heat	100% uptime (as a % of time lost verus running hours)	100% Dec. WK2 '07	Welding setting and readings log	Once per week	IMR Chart	Contact Welding Team leader

Table 6.12: Heat treatment IDR project control plan

The estimated cost savings from this project can be projected using the mean value from moving range in **Figure 6.13** and **Figure 6.19** respectively. The mean value from **Figure 6.13** is 10.34 whilst **Figure 6.19** is 2.74. In effect a reduction of about 7 defect part per 30 study parts (5 sample size and 15 samples: process capability study before and after). So for an average 12 minutes repair time per part by 7 parts saved (total volume of part produced in 2007 is estimated at 5098, based on Table 4.1, which is about 23 parts per day (45 weeks and 5 days) hence, the cost saving is estimated at £18,000 per annum.

6.5 Summary

In this chapter the application of lean manufacturing and continuous improvement has been defined using a DMAIC framework and application of the golden lean check matrix. Two case studies were presented in this chapter to validate the application of this frameworks in NTR Ltd. Cases one and two, examined the application of the DMAIC methodology in reducing internal defect rate attributed to lack of weld and heat treatment respectively.

Case one—Lack of weld, which refers to a part not welded at a Critical-To-Quality (CTQ) feature on that part was estimated to cost the company in terms of Cost of Poor Quality (CTQ) of up-to £30,000 per year. The Define phase of the project focused on a goal statement of creating a process that will significantly reduce internal returns due to lack of weld by 50% within a 90 days' timeline and with every support requirement clearly detailed.

Furthermore, a process map was developed as part of the Define phase, with key process defined, that is, welding, and strip down. In the Measure phase a C&E matrix

was outline and rating developed. The highest occurring causes, such as, welding operator's skill, welding team leader over-check, pre-inspector skill e.t.c were transferred into the FMEA. The FMEA was then rated and the highest RPN's were action by the team. Key actions from the FMEA include operator training, welding team leader workorder's sign off post strip down and tooling damage recognition.

Following a well structured training programme and development a tooling damage recognition flow chart a IMR chart was set-up as part of the Control phase to measure any out-of-control condition that may affect the big Y-which post training had earn a cost savings of about £25,000.

Case two—heat treatment defect reduction—the heat treatment method is flame hardening (Oxy-Acetylene torch). It's used within NTR Ltd's manufacturing system for localised heating of tools 'reclaimed' on the CNC product line. The nature of constraint exhibited by the facility was its inability to guarantee reproducibility and repeatability of tools been heat treated. Parts had to be heat treated thrice (reworked) to achieve the required hardness level (38-60HRC).

The result from the measure phase of case two's gauge R&R that the gauge is acceptable because the total gauge R&R % contribution is 0.42% (<2% acceptance criteria). Furthermore, the gauge system was validated as acceptable because it suggests that the number of distinct category is 21 hence greater than 10 specified in acceptance criteria. Additionally, with a total gauge R&R tolerance of 19%, this further confirmed the acceptability of the measurement system.

Based on the measure phase key affect on the hardness value of the part were identified as the diameter of the part been heat treated, time-to-heat treat, and the torch cone length. In other to understand the relationship between these key inputs that affects the hardness value, an experimental design was setup. The experimental design used a 2 by 3 factorial design. Furthermore, the main effect plot of the experimental design inferred that the hardness property of the part increased with decreasing diameter, whilst an increase in hardness property of the part is directly proportionally to increasing heat treatment time and cone length of the acetylene torch.

In the improve phase of the DMAIC methodology, the major output were provision of extensive training for an operator based on the experimental design result, development of a standard operating procedure for heat treating part, and sourcing alternative welding rod with good hardness properties. Post training of a process capability index of 1.13 achieved over an initial index of -0.07 post improvements. Finally, the cost saving attributed to case two was £18,000 per annum.

CHAPTER 7

CONTINUOUS IMPROVEMENT AT NTR LTD (2)

7.1 Introduction

This chapter is a continuation of application of the DMAIC and Kaizen process improvement methodologies from Chapter 6. The chapter investigates and presents solutions to systems issue foundation and work methods issues as detailed in **Table 3.10**—the golden lean check matrix—the matrix provides guidance for intermediate measure for lean policy deployment in NTR Ltd. Furthermore, the Chapter uses a case by case (in continuation of the case study approach used in Chapter 6) approach to present some of the solutions to systems and work method issues at NTR Ltd.

7.2 Case Three: Delivery rate improvement

This case study examines the ship window compliance of NTR Ltd manufacturing system. The base line data presented in **Figure 7.1** shows a PPM value of the delivery rate between the first weeks of September 2006 to second week of November 2006. The mean delivery rate over these periods is 186771, which is about 2.4 Sigma.

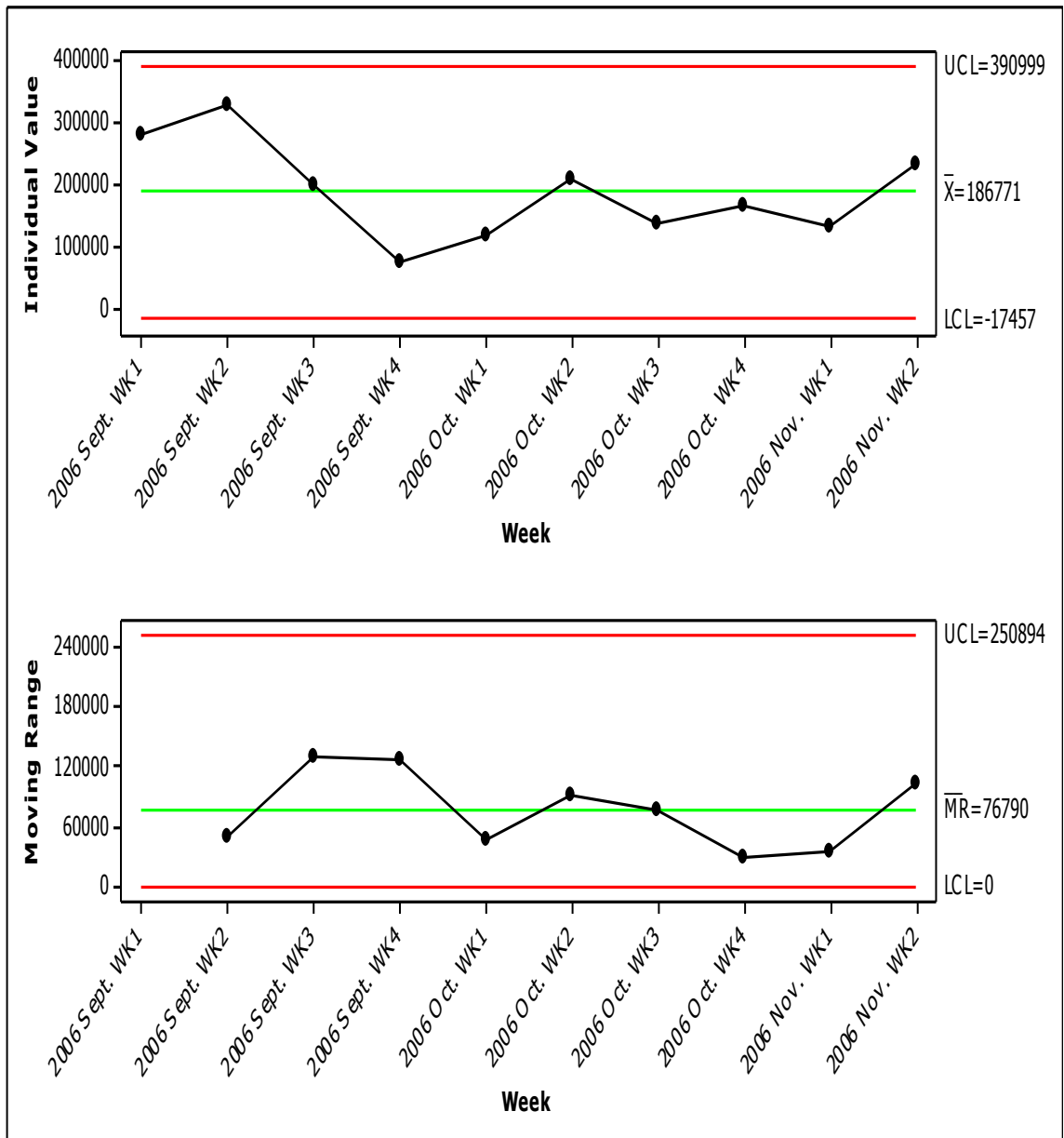


Figure 7.1: I-MR chart Delivery Rate PPM

7.2.1 Define Stage: Delivery rate improvement

Table 7.1 shows the Project Charter for the delivery rate improvement project. The charter contains a problem statement, a CI team, project goals/objective and key deliverables. The team consisted of the operator directly responsible for goods outwards section, a customer service representative, booking-in personal, and a utility personal.

<p>Problem Statement Extended delivery dates—customers receive products over the 2 weeks promised by the company.</p> <p>Additionally, poor quality results from rushing orders through the system when it is month end.</p>	<p>Team Craig Naylor – Sponsor Adedeji Esan– Black Belt Angela McGowan– Customer Rep Norman Clark—Goods Outwards Derek Sanderson—Booking in Les Paul—Utility</p>
<p>Goal/Objective To create a process that will significantly increase delivery rates to > 90% and also reduce the panic at month-end.</p>	<p>Deliverables - 45 day project 1) Increase delivery from current 81% to >90% 2) Reduce internal disruption at month end 3) Streamline process</p>

Table 7.1: Project Chart Delivery Improvement Project

Figure 7.2a&b shows process maps developed by the team to identify all relevant elements of the affected process prior to any improvement project. **Figure 7.2a** show a high level process map whilst **Figure 7.2b** shows a level 2 process map of the delivery rate improvement project. The process map helps define the complexity of the project hence eliminating improper project scoping.

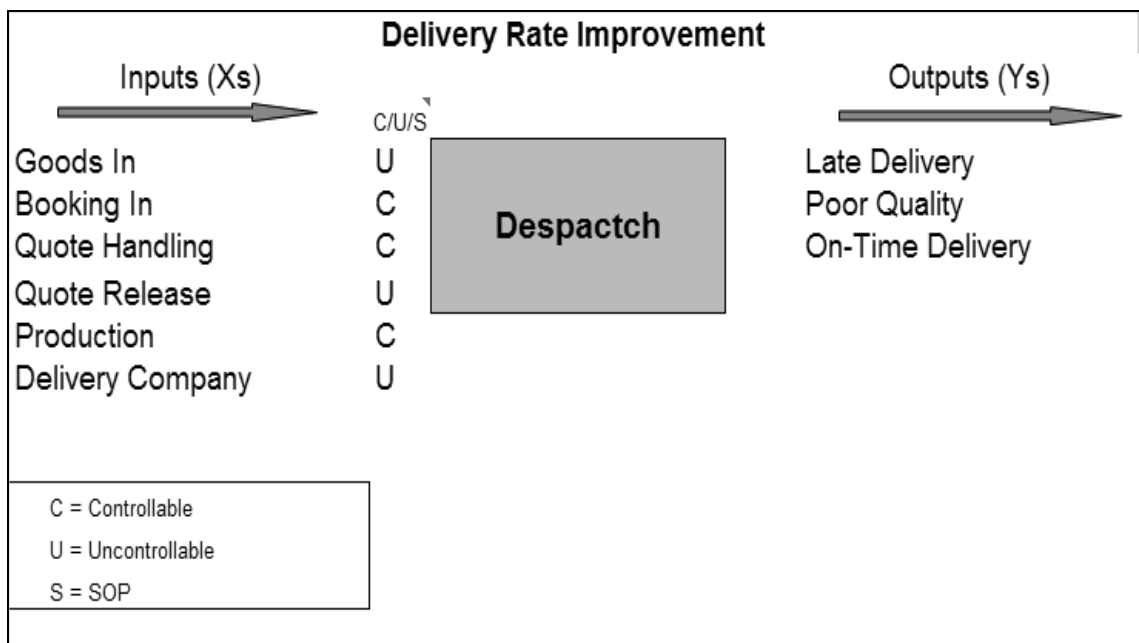


Figure 7.2a: 5,000ft process map—Delivery rate improvement project

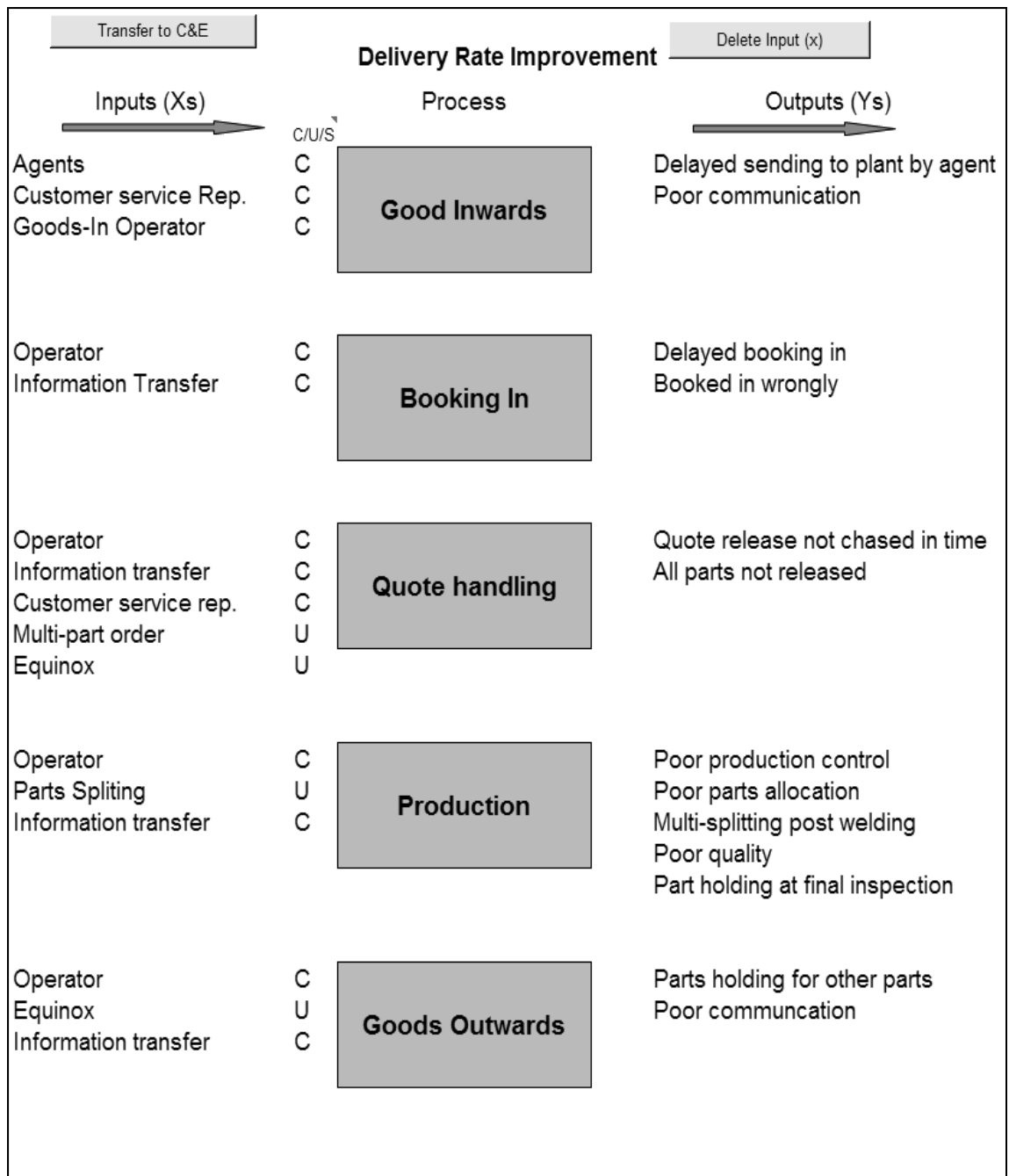


Figure 7.2b: Level 2 process map for the delivery improvement project

7.2.2 Measure Phase: Delivery rate improvement

Table 7.2 shows a sample of the data collection plan for the delivery improvement project. The data collection method used in this measure phase is a discrete data type.

The data type takes a unique set of values, that is, the number of orders that did not

Table 7.4 below shows a Cause and Effect (C &E) matrix for the delivery improvement project. The table rates the Key Process Inputs Variables (KPIV) against the Key Process Output Variables (KPOV). The KPOV being level of important of delivery rates and quality of parts produced at NTR Ltd. Key output from the C&E matrix are poor information transfer within NTR Ltd manufacturing system, multi-part order, and parts splitting.

Enter C&E Break Point:		130															
		Cause and Effect Matrix															
Rating of Importance to Customer		10	10	10													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Process Step	Process Inputs	Late Delivery	Poor Quality	On-Time Delivery													Total
1	Production	Information transfer	9	9	9												270
2	Production	Operator	9	9	9												270
3	Booking In	Information Transfer	9	3	9												210
4	Quote handling	Customer service rep.	9	3	9												210
5	Quote handling	Multi-part order	9	3	9												210
6	Production	Parts Splitting	9	3	9												210
7	Goods Outwards	Information transfer	9	1	9												190
8	Booking In	Operator	9	1	9												190
9	Quote handling	Information transfer	9	1	3												130
10	Good Inwards	Goods-In Operator	9	1	3												130
11	Quote handling	Equinox	3	1	9												130
12	Goods Outwards	Operator	3	3	3												90
13	Quote handling	Operator	3	1	3												70
14	Good Inwards	Customer service Rep.	3	1	3												70
15	Good Inwards	Agents	1	1	1												30
16	Goods Outwards	Equinox	1	1	1												30
17																	0

Table 7.3: Cause and Effect Matrix—Delivery Improvement Project

7.2.3 Analysis Phase: Delivery rate improvement

Further to the data collection plan above, **Figure 7.3** shows a process capability study conducted on the dispatch record of NTR Ltd for 10 weeks period. The Lower Control Limit (LCL) of 90% on-time delivery is based on the project objective of achieving greater than 90% delivery rate whilst the Upper Control Limit (UCL) is set at an arbitrary value of 95%. **Figure 7.3** shows both the X chart and the R chart, the points are randomly distributed between the control limits, implying a stable process. In order to further justify this conclusion a comparison of points on the R chart with those on the X chart is conducted to see if the points follow each other.

These points do not, which again implies a stable process. The points on the chart of the last 10 subgroups make a random horizontal scatter, with no trends or shifts, which also indicates process stability. On the capability histogram, the data approximately follow the normal curve. On the normal probability plot, the points approximately follow a straight line and fall within the 95% confidence. These patterns indicate that the data are normally distributed.

But, from the capability plot, it can be seen that the interval for the overall process variation (Overall) is wider than the interval for the specification limits (Specs) with a Cpk value of -0.42 and Ppk value of -0.37, which suggests that the current process is not capable. The Ppk value is considered as the actual process performance as it is based on the long term estimate of the standard deviation whilst the Cpk value is what the process is capable of doing if there is no between subgroup variability.

order's production instruction field. These actions are denoted by their high Risk Priority Number (RPN).

SME Breakdown		Process/Product Failure Modes and Effects Analysis (FMEA)														
Start FMEA		FMEA Data (Orig): Nov-56											Page			
Process or Product Name		Prepared by: Aisling Egan											of			
Responsible		Delivery Rate Improvement														
Process Step	Key Process Input	Failure Modes - What can go wrong?	Effects	SE	Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SE	OCC	DET	RPN
Production	Information transfer	Parts machined incorrectly	Poor quality and delayed delivery	10	Customer requirements not cascaded from service personnel	3	None	10	300	Daily production and productivity meeting to cascade customer requirements to all team leaders	A. Egan, C. Naylor and Angela McCowan	Daily meeting scheduled and implemented	1	3	1	3
Production	Information transfer	100% inspection not carried out	Poor quality	10	Customer requirements not communicated effectively by service personnel	2	Agent writes requirements on works order sometimes	7	140	Database to store information on customer requirements and information to be printed on works order card	Derek Sanderson, A. Egan, Angela McCowan and	New database to be developed. Booking in operator to update customer requirements in production instruction field on works order card	1	2	4	8
Production	Information transfer	Parts not worked on in time	Delayed delivery	10	Urgent delivery not highlighted correctly	1	Red Sleeves	4	40				1	4	3	12
Production	Information transfer	Parts rushed through production	Poor quality	10	Month and figures	8	None	10	800	Implement split handling system to reduce month and panic.	A. Egan, Norman Clark, and Angela McCowan	New split handling system created and monitoring procedure implemented	1	4	3	12
Production	Information transfer	Parts machined incorrectly	Poor quality	10	Wrong set of spare in box and/or operator used wrong plans/instructions	2	None	10	200							
Production	Operator	Parts machined incorrectly	Poor quality and delayed delivery	10	Inadequate training	4	None	10	400							
Production	Operator	Parts welded incorrectly	Poor quality and delayed delivery	10	Inadequate training	4	None	10	400							
Production	Operator	Parts stripped down incorrectly	Poor quality and delayed delivery	10	Inadequate training procedure and poor welding and machining requirements knowledge	2	None	10	200							
Production	Operator	Parts not finished to spec	Poor quality and delayed delivery	10	Inadequate operator	2	None	10	200							
Booking In	Information Transfer	Parts booked in incorrectly	Poor quality and delayed delivery	10	Inadequate training and poor operator vigilance	2	None	10	200							
Booking In	Information Transfer	Parts not booked in on-time	Delayed delivery	10	No standard operating procedure	9	None	10	900	Implement time frame for delivery processing at goods inward	A. Egan, C. Naylor, and Angela McCowan	2 hour maximum wait time at goods inward implemented	1	3	4	12
Booking In	Information Transfer	Parts booked in incorrectly	Customer receives wrong part	1	Inadequate tooling	1	None	10	100							
Quote handling	Customer service rep.	Parts incorrectly quoted	Reduce profit margin	4	Inadequate knowledge of manufacturing cost	4	None	10	400	Re-emphasise to Customer service existing procedure for new job quoting and also develop a manufacturing costing database	A. Egan, Chris Motion, and Angela McCowan	Manufacturing cost database developed and implemented	1	2	4	8
Quote handling	Customer service rep.	Parts incorrectly quoted	Delayed delivery	10	Inadequate knowledge of process requirements	5	None	10	500	Re-emphasise to Customer service existing procedure for new job quoting and also develop a manufacturing costing database	A. Egan, Chris Motion, and Angela McCowan	Manufacturing cost database developed and implemented	1	2	4	8
Quote handling	Customer service rep.	Parts not released timely	Delayed delivery	10	Customer service rep. Did not generate quote and release note immediately after getting confirmation from customer	2	None	10	200							
Quote handling	Customer service rep.	Multiple parts not released at once	Delayed delivery	10	Human error and poor database architecture	2	None	10	200							
Quote handling	Multi-part order	Only one or two parts released from a three part order	Delayed delivery	10	Human error and poor database architecture	7	None	10	700	Operator training on quote handling and release into shop floor procedure	A. Egan and Angela McCowan	Training conducted	1	3	4	12
Quote handling	Multi-part order	Parts located separately	Delayed delivery	10	Multiple parts of different process centres located in quote shelf	10	None	10	1000	Implement split handling system to reduce month and panic.	A. Egan, Norman Clark, and Angela McCowan	New split handling system created and monitoring procedure implemented	1	4	3	12
Production	Parts Splitting	Parts incorrectly located	Delayed delivery	10	Multiple parts of different process centres located in one bin	1	None	10	100							
Production	Parts Splitting	Parts damaged	Poor quality and delayed delivery	10	Operator splitting parts and using pallet to handle part with care	2	None	10	200							
Production	Parts Splitting	Excessive splitting time	Reduced throughput and skilled operator caring for MVA activity	10	Parts not split up from booking in	1	None	10	100							
Production	Parts Splitting	Parts stored at final inspection not used to pull other batch from same works order	Delayed delivery	10	Parts stored at final inspection not used to pull other batch from same works order	10	None	10	1000	Create extra processing centre in order to eliminate standard tools being processed as a unit with rotary tools	A. Egan, Angela McCowan, Chris Motion, and Derek Sanderson	New processing centre created for rotary tools	1	4	3	12
Goods Outwards	Information transfer	Missed shipment	Delayed delivery	10	Goods outward operator not made aware of urgent order	8	None	10	800	Introduce clip system to indicate urgent orders that needs to meet delivery on same day and production control to inform goods outward operator of urgent deliveries	Norman Clark, A. Egan, and Angela McCowan	Clipping system introduced and daily productivity meeting to highlight urgent orders	1	4	2	8
Goods Outwards	Information transfer	Missed shipment	Loss of business	10	Urgent delivery not highlighted correctly	3	Red Sleeves	3	60							
Goods Outwards	Information transfer	Parts not delivered to customer	Delayed delivery	10	Delivery company did not deliver order in regular book time	2	Order tracking system	2	40							
Goods Outwards	Information transfer	Parts not delivered to customer	Delayed delivery	10	Delivery company did not book up to collect order	2	For UK part delivery is made by relevant staff	5	100							
Quote handling	Information transfer	Parts not released from the quote shelf	Delayed delivery	10	Quote release operator did not receive quote release service rep.	3	None	10	300							
Quote handling	Information transfer	Incorrect part released	Delayed delivery	10	Inadequate training procedure	7	None	10	700	Operator training on quote handling and release into shop floor procedure	Angela McCowan, Les Paul and A. Egan	Training conducted	1	4	3	12
Quote handling	Information transfer	Incorrect/incorrect amount of part released	Delayed delivery	10	Inadequate training procedure	9	None	10	900	Operator training on quote handling and release into shop floor procedure	Angela McCowan, Les Paul and A. Egan	Training conducted	1	4	2	8
Quote handling	Information transfer	Incorrect amount of part released	Delayed delivery	10	Information on quote release note state to release on part of a order	5	None	10	500	Operator training on quote handling and release into shop floor procedure and develop new procedure for validating correctness of information from customer service	Angela McCowan, Les Paul and A. Egan	Training conducted and new validated procedure implemented	1	2	2	4
Good Inwards	Goods In Operator	Inward goods not checked on-time	Delayed delivery	10	No standard operating procedure	10	None	10	1000	Implement time frame for delivery processing at goods inward	A. Egan, C. Naylor and Angela McCowan	2 hour maximum wait time at goods inward implemented	1	3	4	12
Good Inwards	Goods In Operator	Inward goods not checked	Poor quality	10	No standard operating procedure	2	None	10	200	Implement time frame for delivery processing at goods inward	A. Egan, C. Naylor, and Angela McCowan	2 hour maximum wait time at goods inward implemented	1	3	4	12
Quote handling	Operator	Parts not released from the quote shelf	Delayed delivery	10	Inadequate operator training	8	None	10	800	Operator training on quote handling and release into shop floor procedure	Angela McCowan, Les Paul and A. Egan	Training conducted	1	4	2	8
Quote handling	Operator	Multiple parts not released at once	Delayed delivery	10	Inadequate operator training	10	None	10	1000	Operator training on quote handling and release into shop floor procedure	Angela McCowan, Les Paul and A. Egan	Training conducted	1	4	2	8
Quote handling	Operator	Parts not released from the quote shelf	Delayed delivery	10	Operator not available	2	None	10	200							
Goods Outwards	Operator	Parts not shipped	Delayed delivery	10	Operator using own initiative to ship multiple parts	5	None	10	500	Introduce clip system to indicate urgent orders that needs to meet delivery on same day and production control to inform goods outward operator of urgent deliveries	Norman Clark, A. Egan, and Angela McCowan	Clipping system introduced and daily productivity meeting to highlight urgent orders	1	4	2	8
Goods Outwards	Operator	Wrong/wrong amount of part shipped	Poor quality	10	Floor operator vigilance	3	None	10	300							
Goods Outwards	Operator	Parts damaged	Poor quality	10	Part packaging	1	None	10	100							
Goods Outwards	Operator	Part not shipped and wrong part shipped	Poor quality and delayed delivery	10	Parts not packaged in time been operator running behind shipment schedule	2	None	10	200	Introduce clip system to indicate urgent orders that needs to meet delivery on same day and production control to inform goods outward operator of urgent deliveries	Norman Clark, A. Egan, and Angela McCowan	Clipping system introduced and daily productivity meeting to highlight urgent orders	1	4	2	8
Quote handling	Equinox	Multiple parts not released at once	Delayed delivery	10	System not capable	4	None	10	400							
Quote handling	Equinox	Parts not booked in on-time	Delayed delivery	10	System down	4	None	10	400							

Table 7.4: FMEA delivery rate improvement (Appendix 7.1)

Figure 7.4 below shows a detailed process map of a new process centre created as part of the improvement to NTR Ltd manufacturing system's delivery process. The first stage of the process involves the goods-in process to actively process all new goods-in the shop floor in a timely manner. A maximum of 2 hours waiting time is given for all new goods-in to the goods-in process centre. The thought behind this strict timeline is

that the earlier goods are booked-in the greater the chances of completing orders with the company's 2 weeks delivery deadline.

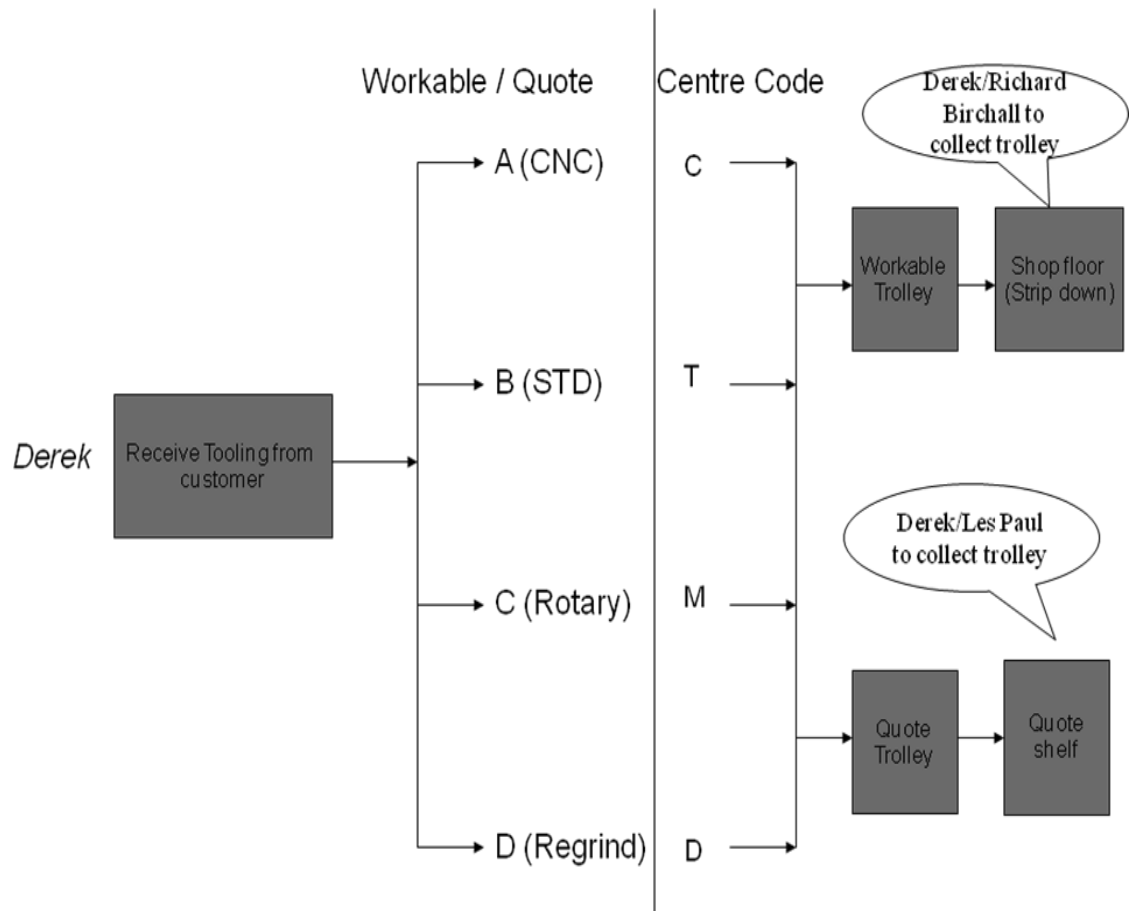


Figure 7.4: Detailed process map of new process centre operating procedure

In event of resource constraint (due to inadequate capacity to meet demand) at the goods-in process centre, an extra operator is drafted in from other sections (strip down, goods-outward and inspection) of the shop floor to reduce any resource limitations thereby increasing the effective utilisation of the process centre. Furthermore, the responsibility of making sure the new procedure at the goods-in department lies with both the operator responsible for the process and also the team leader (to recognise capacity and resource utilisation issues), hence given them a sense of ownership and the desire to see the initiative sustained.

To further improve the despatch rate, a prominent issue as highlighted in the C&E matrix in **Table 7.3** and the FMEA is part splitting post booking in. To eliminate this Non Value Added (NVA) step which takes place after the parts as been welded a new process centre was created in the database (Equinox) which enables orders for standard products to be processed independently of the rotary products at the booking in stage. Gains from this new procedure includes elimination of part splitting post welding which consequentially eliminates about 2 hours spent by a highly skilled operator (rotary team leader) everyday on part splitting thereby providing more opportunity to increase/improve the effective utilisation of the highly skilled operator in Value Adding activities (VA).

Another improvement opportunity exploited in the effort to improving NTR Ltd delivery rate involved re-training and re-focusing on the quote handling process. The flow diagram in **Figure 7.5** shows the route map for the quote handling process. Typical constraints in this process are release of parts from the quote shelf in a timely manner and management of multi-part orders. In order to mitigate the multi-part order mismanagement during the quote release process, the quote release operator (Les Paul) was re-trained on how to make sure that all part from an order was released accordingly.

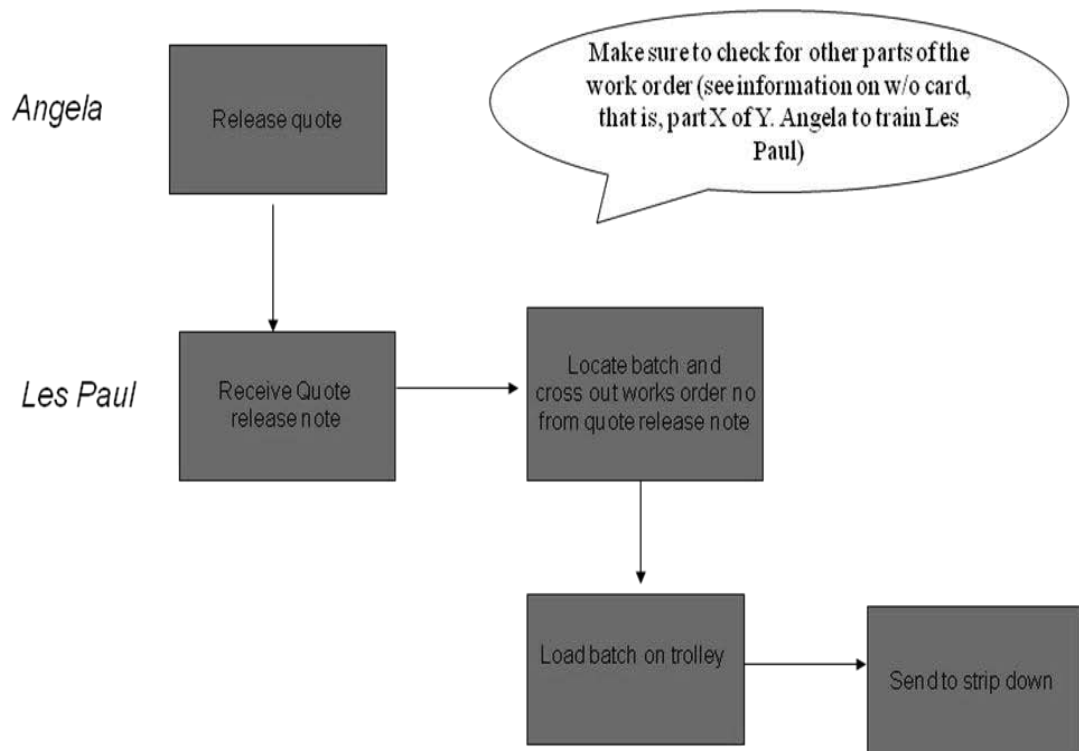


Figure 7.5: Route map for the quote handling process

The key focus during the training was how the operator can physically make sure that the all parts of an order were released. **Figure 7.6** highlights how to spot a multi-part order on the workorder card. In event were other parts of an order was not generated on the quote release notes by the database (Equinox), the customer representative is required to communicate this verbally and as an attachment with the quote release note sent to the quote release operator/bay.

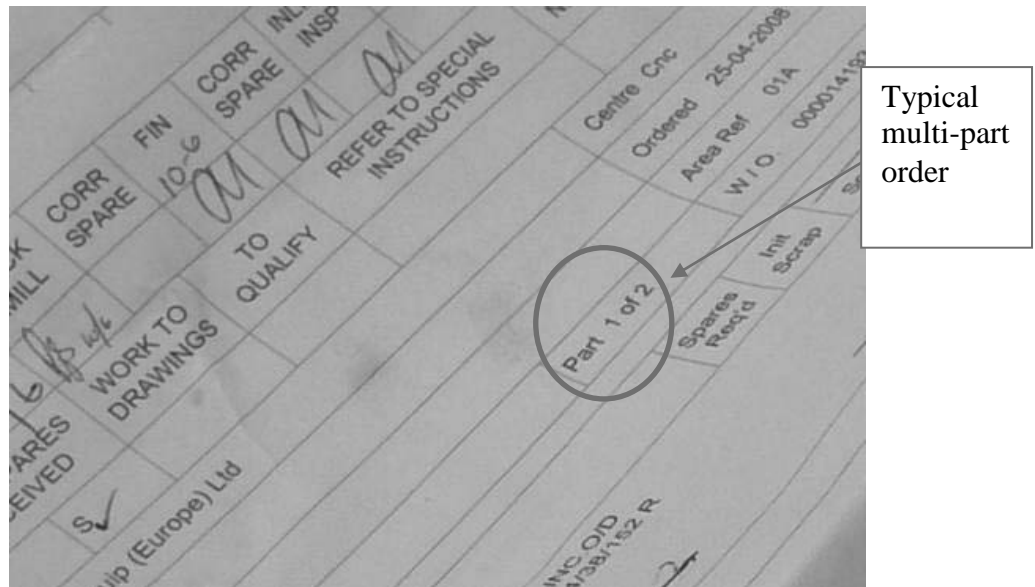


Figure 7.6: Multi-part order highlighted on workorder card

Other KPIV affecting the delivery rate at NTR Ltd and as noted on the FMEA are delayed parts at goods-outwards, poor information transfer between goods-outwards and customer service, and missed shipments. In order to reduce the occurrences of this failure modes, **Figure 7.7** shows a process map developed as part of a new splits handling process. Key output from the new process is creation of centralised holding area for multi-part orders at goods outwards. The new process eliminates multiple holding at both final inspection and goods outwards.

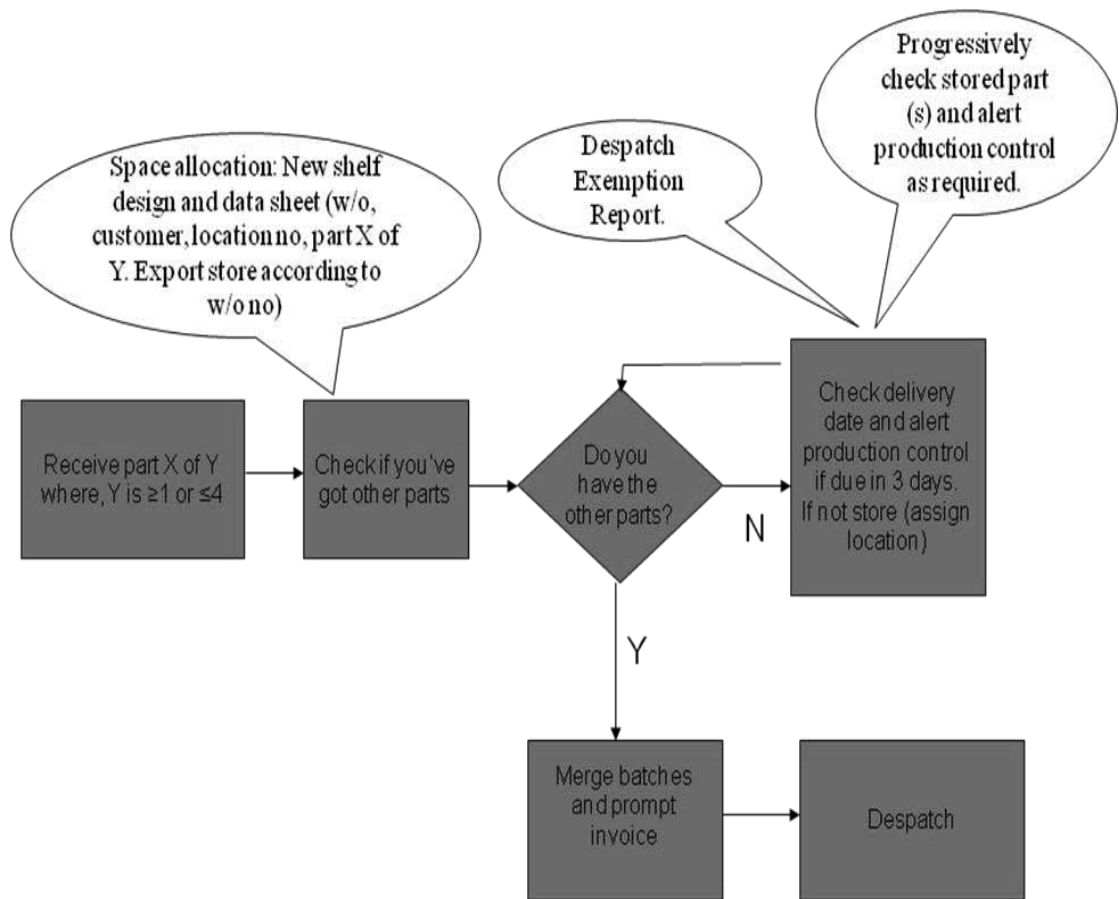


Figure 7.7: New split's handling process map for goods outwards

More importantly, the holding area also serves as a trigger point for production control. The new splits handling process helps improve the communication between goods outwards and customer service by constant feedback process incorporated into the production control function. The goods outwards section is required to work closely with production control function by progressively checking stored parts and alerting production control of split orders due within the next 3 days. This feedback system gives the shop floor time to react to possibly late deliveries. Furthermore, **Figure 7.8a & b** shows the initial layout and new layout of the despatch department to accommodate the new splits handling shelf.



Figure 7.8a: Despatch department layout before improvement



Figure 7.8b: Despatch department layout after improvement

7.2.5 Control Stage: Delivery rate improvement

Table 7.5 shows a control plan for the delivery rate improvement project. The control method in **Table 7.5** will be continuously monitored by the training champion and the

production engineer/manager on a weekly basis. A preventive and/or reaction plan for any out-of-control condition through refresher training on the quote handling process, re-iteration of the need for a maximum of 2 hours for goods in process and effective utilisation of the split handling process.

Process	Step	Output	Input	Process Spec.	Capability /Date	Measurement Technique	Sample Freq.	Control Method	Reaction Plan
Y = Number of incidence relating to late delivery per week	Dispatch	Delivery rate	Shop operations	USL 60 LSL 38 Target 49	Ppk 1.03 Dec. WK2 '07	Delivery rate per week (taken from the ship compliance database)	Once Per Week	I-MR Chart	Operator training and training assessment matrix
X1— Quote handling operator	Quote release	Quote release quality	Operator skill	USL 3 LSL 1 Target 2.5 skill level	Operator skill level =2 @ Dec. Wk2 '07	Training matrix rating	Once per weeks	Training matrix	Contact Training Champion
X2—Good inward	Order booking in	Booking in rate	Goods in operator	100% uptime (as a % of time lost versus running hours)	100% Dec. WK2 '07	Booking in cycle time	Once per week	VSM	Contact production engineer
X3— Goods outwards	Splits handling	Delivery rate	Split orders	100% uptime (as a % of time lost versus running hours)	90% Dec. WK2 '07	Delivery rate per week (taken from the ship compliance database)	Once per week	Splits handling Record	Contact Production controller

Table 7.5: Delivery rate improvement project control plan

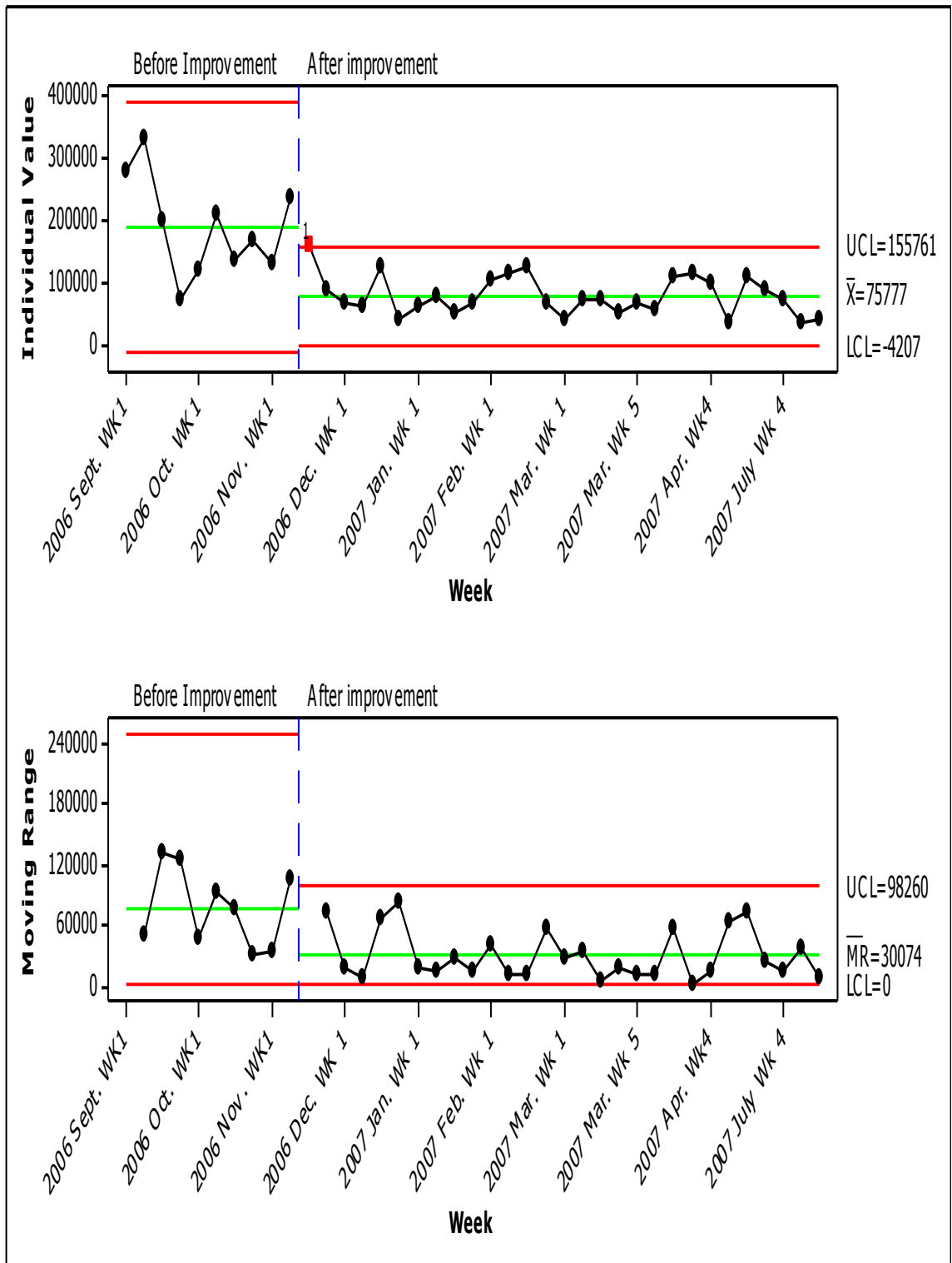


Figure 7.8: IMR chart delivery improvement project after improvement

7.3 Case Four: Productivity improvement

This case study examines the productivity of NTR Ltd manufacturing system based on base line information presented in chapter 5—Lean manufacturing and resource planning. The case presents some of the solutions to resolving issues relating to extended queues and poor machine and operator utilisation. Furthermore, the case discusses wider implementation of a 5S programme at NTR Ltd, shop floor re-layout to improve communication within teams, creation of a training centre, development and implementation of training programme for multi-functionality, and other initiatives undertaken to improve NTR Ltd manufacturing system's productivity.

7.3.1 Creating a productivity index for NTR Ltd

The need to create an individual and collective productivity index for NTR Ltd's manufacturing system is necessary to create awareness of most problems work group experiences, because without measure in place, there is no way for them to know the relative importance of those problems. More importantly, the productivity index was required to complement the old styled daily and monthly financial index. The financial index is useful but in itself, doesn't show where opportunities for improvement exist within the manufacturing system. In effect with the individual and collective productivity index this will allow the effective management and understanding high performers and mediocre production staffs so that they can be targeted for reward and recognition and provision of comprehensive training and mentoring respectively.

Using the manufacturing cost and time database created in Chapter 4 and a detailed analysis of respective product cluster's production volumes, base functions for productivity measure was established across NTR Ltd's core processes (Welding, Rotary Milling, Standard Milling, CNC Milling, Standard Finishing, and Rotary

Finishing). The discussion of the development of the productivity index will be limited to the Rotary Milling section but outputs, actions and solutions from the entire productivity constraints for all the sections/departments within NTR Manufacturing system will be discussed.

Table 7.7 shows the base measure for the Rotary Milling section of the production floor. Column two in **Table 7.7** shows average process times per piece for a medium damaged tool whilst column three shows a point system developed as baseline for measure. The table shows the base product— Milling Cutter (M/C) — representing one point and every other product produced with the section is then made a fraction/ratio of the base product.

	Medium Damage	Fraction of Base
BASE M/C <= 8PKTS	35.0 min/pc	1.00
M/C (Qual.)	45.0 min/pc	1.29
EndMill	25.0 min/pc	0.71
EndMill (Qual.)	35.0 min/pc	1.00
B/Nose	25.0 min/pc	0.71
U-Drill	18.0 min/pc	0.51
Porky	35.0 min/pc	1.00
SLIT./Cutter	25.0 min/pc	0.71
Std. & C.Unit & Weld	8.0 min/pc	0.23
Special (SP)	70.0 min/pc	2.00

Table 7.7: Rotary Milling Productivity index

In other to compensate for products requiring further quality check (referred to as Qual., i.e. M/C (Qual.) means Milling Cutter Qualified), extra 10minutes is added to the processing times. Furthermore, **Figure 7.9** shows volume distribution of products across the Rotary Milling section from 3rd January 2006 to 22nd December 2006. The figure shows that from the 6706 total volume production within the department, milling cutter (group 20) accounts for about 42% as against about 39% for the endmill (group 17).

Hence, the milling cutter product type is the highest produced product within the section which makes it the obvious choice for the base product.

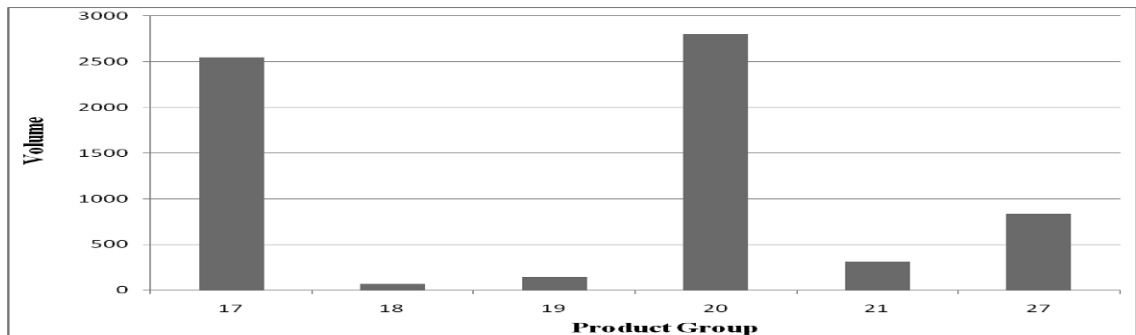


Figure 7.9: Product volume distribution across the rotary milling section

To further establish what the nominal processing time for the base product should be

Figure 7.10 show the distribution of products within product group 20. The figure show that product demand pattern within the group is typically higher for product within the 50mm to 80mm bracket. Hence, using information provided in the manufacturing cost and time database presented in Chapter 4 and **Appendix 4.2, Table 7.8** shows the processing times for product group 20's medium damaged category.

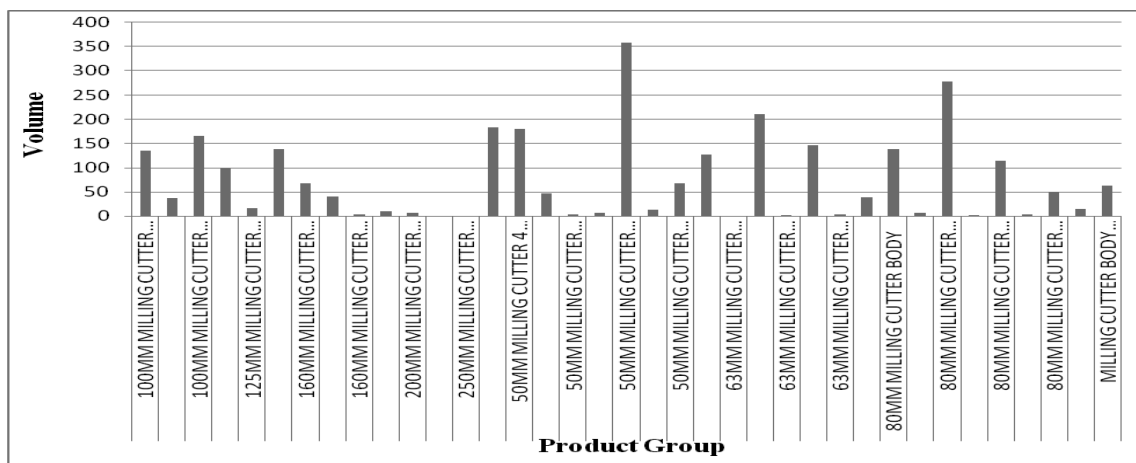


Figure 7.10: Product volume distribution within rotary product group 20

The information contained in the table includes individual set-up times, actual processing/machining times, walk times and self inspection times for each product size within the product group. The average total Processing Times (PT) for products within 50mm and 80mm is about 35minutes hence given us our base processing time in **Table 7.8**

Section	Size in mm	50mm	63mm	80mm	100mm	125mm	160mm	200mm	250mm	315mm
Rotary Manual Milling	Setup	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	PT	25.00	30.00	33.00	35.00	35.00	38.00	42.00	45.00	50.00
	Walk Time	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	Line Inspection	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	Total PT	31.40	36.40	39.40	41.40	41.40	44.40	48.40	51.40	56.40

Table 7.8: Processing times for rotary product’s group 20

7.3.2 Utilising the productivity index

In utilising the productivity index to drive improvements in capacity and resource utilisation within NTR Ltd’s manufacturing system a database (excel spreadsheet) was created with a log of key operations and operators. The spreadsheet uses macros to simplify the process of logging, calculating and presenting information generated by the productivity database. **Figure 7.11** shows the layout of this productivity database.

ROTARY MILL PRODUCTIVITY		
Available Time		
Mon-Thu	465 mins	
Friday	378 mins	
	Medium Damage	Fraction of Base
BASE M/C <= 8PKTS	35.0 min/pc	1.00
M/C (Qual.)	45.0 min/pc	1.29
EndMill	25.0 min/pc	0.71
EndMill (Qual.)	35.0 min/pc	1.00
B/Nose	25.0 min/pc	0.71
U-Drill	18.0 min/pc	0.51
Porkey	35.0 min/pc	1.00
SLIT.Cutter	25.0 min/pc	0.71
Std. & C.Unit & Weld	8.0 min/pc	0.23
Special (SP)	70.0 min/pc	2.00

NEW RECORD
GRAPH

DATE:	ID	Expected	M/C	M/C (Q)	E/M	E/M (Q)	B/Nose	U-Drill	Porkey	S/C	Std	SP	EndMill 2 B	E/M (Q) 2 B	M/C (Q) 2 B	B/Nose 2 B	U-Drill 2 B	Porkey 2 B	S/C 2 B	Std 2 B	SP 2 B	
	IF	13											0	0	0	0	0	0	0	0	0	0
	CM	13											0	0	0	0	0	0	0	0	0	0
	CK	13											0	0	0	0	0	0	0	0	0	0
	SHoward	13											0	0	0	0	0	0	0	0	0	0
	GB	13											0	0	0	0	0	0	0	0	0	0
	TOTAL	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DATE:	ID	Expected	M/C	M/C (Q)	E/M	E/M (Q)	B/Nose	U-Drill	Porkey	S/C	Std	SP	EndMill 2 B	E/M (Q) 2 B	M/C (Q) 2 B	B/Nose 2 B	U-Drill 2 B	Porkey 2 B	S/C 2 B	Std 2 B	SP 2 B	
	IF	13											0	0	0	0	0	0	0	0	0	0
	CM	13											0	0	0	0	0	0	0	0	0	0
	CK	13											0	0	0	0	0	0	0	0	0	0
	SHoward	13											0	0	0	0	0	0	0	0	0	0
	Gery	13											0	0	0	0	0	0	0	0	0	0
	TOTAL	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DATE:	ID	Expected	M/C	M/C (Q)	E/M	E/M (Q)	B/Nose	U-Drill	Porkey	S/C	Std	SP	EndMill 2 B	E/M (Q) 2 B	M/C (Q) 2 B	B/Nose 2 B	U-Drill 2 B	Porkey 2 B	S/C 2 B	Std 2 B	SP 2 B	
	IF	13											0	0	0	0	0	0	0	0	0	0
	CM	13											0	0	0	0	0	0	0	0	0	0
	CK	13											0	0	0	0	0	0	0	0	0	0
	SHoward	13											0	0	0	0	0	0	0	0	0	0
	Gery	13											0	0	0	0	0	0	0	0	0	0
	TOTAL	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DATE:	ID	Expected	M/C	M/C (Q)	E/M	E/M (Q)	B/Nose	U-Drill	Porkey	S/C	Std	SP	EndMill 2 B	E/M (Q) 2 B	M/C (Q) 2 B	B/Nose 2 B	U-Drill 2 B	Porkey 2 B	S/C 2 B	Std 2 B	SP 2 B	
	IF	13											0	0	0	0	0	0	0	0	0	0
	CM	13											0	0	0	0	0	0	0	0	0	0
	CK	13											0	0	0	0	0	0	0	0	0	0
	SHoward	13											0	0	0	0	0	0	0	0	0	0
	Gery	13											0	0	0	0	0	0	0	0	0	0
	TOTAL	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DATE:	ID	Expected	M/C	M/C (Q)	E/M	E/M (Q)	B/Nose	U-Drill	Porkey	S/C	Std	SP	EndMill 2 B	E/M (Q) 2 B	M/C (Q) 2 B	B/Nose 2 B	U-Drill 2 B	Porkey 2 B	S/C 2 B	Std 2 B	SP 2 B	
	IF	11											0	0	0	0	0	0	0	0	0	0
	CM	11											0	0	0	0	0	0	0	0	0	0
	CK	11											0	0	0	0	0	0	0	0	0	0
	SHoward	11											0	0	0	0	0	0	0	0	0	0
	GB	11											0	0	0	0	0	0	0	0	0	0
	TOTAL	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All Wk	ID	Expected	M/C	M/C (Q)	E/M	E/M (Q)	B/Nose	U-Drill	Porkey	S/C	Std	SP	EndMill 2 B	E/M (Q) 2 B	M/C (Q) 2 B	B/Nose 2 B	U-Drill 2 B	Porkey 2 B	S/C 2 B	Std 2 B	SP 2 B	Training and Admin	Target @ 75% Capacity
	IF	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
	CM	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
	CK	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
	SHoward	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
	GB	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
	TOTAL	320	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37

Figure 7.11: Productivity database layout

The database uses available production minutes per day to calculate expected (theoretical) number of parts to be produced. Individual days in a week are plotted against each respective operator’s ID. Using the operator’s log sheet (**Appendix 7.2**), parts produced on a daily bases are inputted in relevant field in the database and the total is then calculated automatically in ALL WK section of the database. **Equation 7.1**

shows an example (Endmill) of calculations used in obtaining the total parts produced within each product category per operator on a weekly basis.

$$T_{EM}Wk_x = T_{EM} * T_{EM2B} \dots \dots \dots \text{Equation 7.1}$$

N

Where, $T_{EM} = \sum_{i=1}^N EM$, where N= production days in a week, that is, Monday—Friday

i=1

and T_{EM2B} = ratio of Endmill PT to the benchmark—Milling Cutter PT

In **Figure 7.12**, output of the productivity database spreadsheet is presented in graphical format. The graph shows volume produced through week 24 for the rotary milling section against operators ID. Additionally, the database output uses a stacked column graph and a colour scheme that enable differentiation of individual product category. The data used in the output graph is the values from the fractionated volume produced per week within each product category. Furthermore, **Figure 7.12** also shows two line graphs representing a target line (based on 75% theoretical volume) and theoretical volume per week respectively. In other to further understand recurring production issues affecting operator performance, “callout” are placed against each affected operator. Typical issues addressed in the “callouts” include, quality, sickness and absenteeism, and multifunctional capability of affected operator.

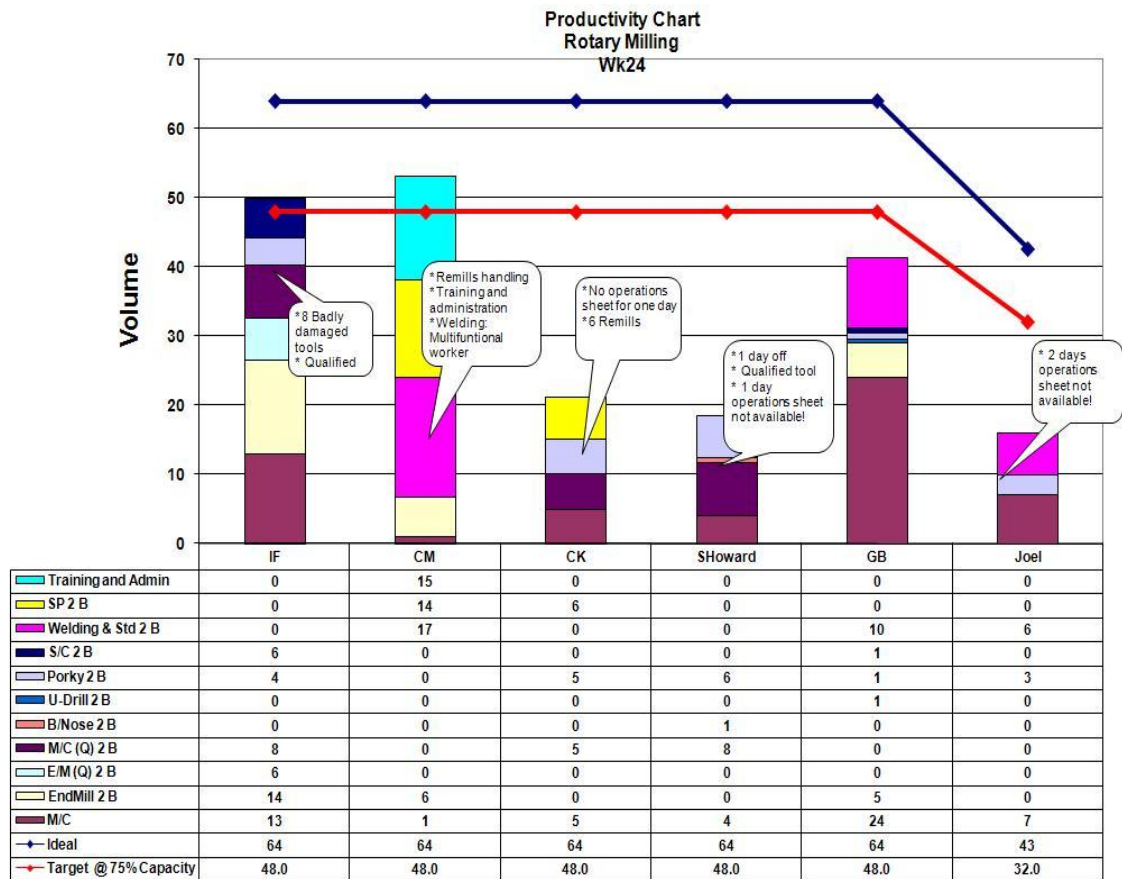


Figure 7.12: Graphical output of the productivity database

Further to developing the aforementioned productivity framework for NTR Ltd’s manufacturing system, utilising the information produced by database to drive productivity was paramount. Typical methods utilised to this effect include, creation of visual and self awareness (self drive for improvement) of the performance measurement framework by placing the output on the shop floor on a weekly basis using a KPI dash board.

Moreover, the information (callouts and gaps between target and actual parts produced) produced by the productivity index was also used to inform a training plan across the shop floor to improve overall shop operations performance, thereby improving productivity. The remaining sections of this project—Case four: Productivity

Improvement— briefly enunciated some of the initiatives taken to improve NTR Ltd productivity. As delivery improvements and quality improvements are discussed in other cases studies, discussion on productivity improvements will be limited to creation of training plans to improve multi-functionality, hence productivity and also shop floor redesign to improve information and material flow and operators’ interaction.

7.3.3 Creation of a multifunctional work force—Productivity improvement

Table 7.9 below shows a skill matrix for NTR Ltd’s shop operations. The matrix lists all shop floor operators against operations within the manufacturing system. The current % multi-skilled operation is 47%. Furthermore, the skill matrix uses a point system to rate each operator against the operations. The point system ranges from 3—Advanced to 0—No experience.

Skills Matrix															Max. Score Obtainable	54					
Names	Pre-Inspection	Booking on	Strip down	Welding	STD Milling	Rotary Milling	Finishing	CNC Milling	CNC Grinding	Turning	Grinding	Line Inspection	Final Inspection	Shot Blasting	Spraying	Despatch	Heat Treatment	Hardness Testing	Scores	Rating (%)	Key: 3=Advanced, 2=Medium, 1=Low, 0=No Experience
Derek Sanderson	0	3	1	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	8	15	cover in despatch. Requirments?
Richard Birchall	0	0	3	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	7	13	damage recognition.
David Almond	3	0	3	3	0	0	0	0	0	0	0	0	1	3	2	0	3	3	21	39	pass on knowledge to PC
Gerry Bavester	0	0	2	2	3	3	0	0	0	0	1	2	0	3	0	0	0	0	16	30	quality
Ian Binns	0	0	2	1	3	1	0	0	0	0	2	1	0	3	3	1	2	3	22	41	2 in welding and cutters
Craig Bishop	3	2	0	0	0	0	0	1	3	0	1	3	3	0	0	3	0	0	19	35	ongoing cnc milling. More time.
Norman Clark	0	0	0	0	0	0	0	0	0	0	0	1	2	2	3	0	0	0	8	15	2 final inspection
Ian Fawcett	0	0	2	0	0	3	0	0	0	0	1	2	0	3	0	0	0	0	11	20	grinding (o/t). Welding
Jonny Hill	0	0	3	1	0	0	3	0	0	0	1	1	0	3	0	1	0	0	13	24	2 in grinding and welding. Milling cover?
Steve Hilton	3	0	2	2	0	0	3	0	0	0	1	2	0	3	0	0	0	0	16	30	pass on knowledge.
Steve Howard	0	0	0	1	0	3	0	0	0	3	1	2	0	3	0	0	0	0	13	24	?
Mark Ibrahim	0	0	0	0	0	0	2	0	2	2	1	0	2	0	0	0	0	0	9	17	welding
Kevin Keogan	0	0	0	0	0	0	0	0	0	0	3	3	3	2	0	0	1	12	22	?	
Chris Kirby	0	0	1	0	0	2	0	0	0	0	2	0	3	0	0	0	0	0	8	15	welding. 3 in milling. (speed)
Chris Morton	3	0	3	2	1	3	3	0	0	2	3	3	0	3	0	0	1	27	50	pass on knowledge.	
Andy Mulholland	1	1	0	1	2	1	0	2	0	2	2	2	0	3	0	0	0	0	16	30	time needed in milling keep up to speed
Paul O'Toole	0	0	0	1	0	0	2	0	0	2	0	0	0	3	0	0	0	0	8	15	grinding drills. 3 in finishing
Les Paul	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	6	11	lot on in spare time. Heat treat?
Alan Paylor	2	0	2	1	3	0	1	0	0	0	2	0	3	0	0	0	0	0	14	26	2 in welding. And learn cutters
Mohan Uppal	1	0	2	0	0	0	0	0	0	2	3	3	3	1	0	1	3	19	35	?	
Adrian Warrington	3	2	3	2	1	3	3	0	0	3	3	3	0	3	3	0	1	1	34	63	pass on knowledge.
Keith Wilks	0	0	2	0	0	0	3	0	0	0	0	2	0	3	0	0	0	0	10	19	welding. Milling cover?
John Wilson	0	0	0	0	0	0	2	0	2	2	2	0	3	0	0	0	0	0	11	20	?
Gav Lumley	0	1	0	0	0	0	2	0	0	0	2	0	3	0	0	0	0	0	8	15	welding. 3 in finishing
Ray Dickenson	0	2	0	0	0	0	2	0	0	0	2	2	3	2	1	0	2	16	30	3 in inspections. Time in finish for cover	
Paul Buckerley	0	1	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	5	9	3 in grinding. Welding?
Joel Smith	0	1	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	4	7	2 in milling
Steven Atkinson	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6	ongoing
Richard Waddington	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	ongoing welding.
Depth of Experience	19	14	32	18	12	21	23	5	5	14	24	40	13	73	19	11	7	14	364		Current % multiskilled
No. of People with some training	7	4	11	11	6	8	10	3	2	6	12	18	5	25	8	6	4	4			47.4
Number in section	4	1	1	4	2	6	6	3	2	1	1	3	3	1	1	1	1	1			
Cover	3	4	10	3	1	2	3	0	0	5	7	2	2	28	5	2	2	3			
Company requirements	21	21	80	55	38	63	80	38	38	21	46	21	55	84	46	21	21	21	768.6		
Training Gap	9	11	59	48	32	50	67	36	35	13	34	1	47	36	35	16	18	11			

Table 7.9: Skill matrix of NTR Ltd’s shop operations

Additionally, a sum of overall depth of experience within each operation, number of operators within each operation, current number of multi-skilled operators, company requirements, and training gaps are identified in **Table 7.9**. In recognition of the gaps between the company's multi-skill requirements and current depth of experience within the manufacturing system the last column in **Table 7.9** highlights opportunity for improvements. Furthermore, **Table 7.10** shows a training plan to improve NTR productivity and create a multi-functional workforce. The plan includes brief details of affected operator, operation requiring development, resource allocation, training objectives and key requirements for achieving the objectives.

Operator	Development	Key Requirements	Training Objective	Resources
Richard Birchall	Strip down	Damage recognition	Gain knowledge of basic welding, machining & fitting knowledge to improve operator's appreciation of other departments. Increase independence of strip down operator hence reducing impact on production staff.	Pocket recognition chart Tool damage recognition flow chart
Ian Birns	Rotary milling	Additional cover for rotary milling	To create additional cover within Milling section by developing operator's skill level and knowledge of machining by concentrating on a set of high value tools (50mm Milling Cutters and End Mills)	Milling machine
Keith Wilkis	Rotary milling	Additional cover for rotary milling	To create additional cover within Milling section and Increase his skills level, knowledge and speed of machining by concentrate on a set of high value tools (80mm porkies)	Milling machine
Paul O'Toole	Welding	Additional cover for welding	* To create additional cover for welding. * Gain advanced knowledge of pocket geometry & damage recognition * Increase knowledge and speed of welding * Broaden range of tools * Improve competency in dealing with returns	Welding machine, pocket recognition chart, welding training manual
Andy Mulholland	Rotary milling	Additional cover for rotary milling	* To create additional cover within Milling section * Maintain and improve his skills level, knowledge and speed of machining * Concentrate on rotary tools	Milling machine
Ray Dickinson	Goods in, Inspection, Heat treatment and pre-inspection	Succession planning for chief inspector	* Review training against plan Key areas include: * Gain knowledge of Booking in * Gain knowledge of Final Inspection * Gain knowledge of tools Heat treatment * Gain knowledge of tools pre-inspection Training required for succession planning for Mohan Uppal (Chief Inspector)	Tooling damage recognition flow chart, Trimos, Hardness tester, shadow graph, PC, Equinox, heat treatment bay, and other inspection equipment
Joel Smith	Rotary milling	Trainee development programme	* Develop a comprehensive training plan * Weekly review against plan * Increase knowledge, skill and speed in milling through intensive training. * Minimise returns * Concentrate on first time quality * Increase confidence * Agree timescales and targets each month	Milling machine
Steve Atkinson	Welding	Trainee development programme	* Develop a comprehensive training plan * Weekly review against plan * Increase knowledge, skill and speed in welding through intensive training. * Concentrate on first time quality * Increase confidence * Build welding knowledge * Agree timescales and targets each month	Damage recognition flow chart, welding machine, welding training manual,
Craig Bishop	CNC Milling	Additional cover for CNC milling	* Gain knowledge of CNC milling machine operation * Gain knowledge of milling short hole drill * Gain knowledge of short hole drill in-line inspection * Gain knowledge of short hole drill insert	CNC milling machine, Trimos, inserts
Paul Buckley	CNC re-grind	Additional cover for CNC re-grind	* Gain knowledge of CNC re-grind machine operation * Gain knowledge of milling endmill drills * Gain knowledge of edge preping endmill * Gain knowledge of short hole drill insert	CNC re-grind machine, Edge preping machine

Table 7.10: NTR Ltd training plan

However, prior to developing and starting off the training programme, a training champion was inaugurated to lead all training initiatives. The training champion's roles and responsibilities include defining, developing and monitoring training throughout the shop floor. Due to the specialist nature of some operation the training champion will also need to work with respective trainers to ensure effective implementation of training, monitor progress through feedback & reports and assist in any areas of training where KPI's aren't being met to ensure continuous improvement.

Following the successful inauguration of the training champion, development and implementation of the training plan the projected improvement in the level of multi-functionality is from initial **47% to 54%** which represent a **7%** increase in multifunctional worker within NTR Ltd's manufacturing system. Key areas of the shop floor where significant improvement was made are rotary milling, CNC milling, and welding. These improvements help compliment resource constraint issue within the said operations as they represent bottlenecks within the manufacturing system.

In CNC milling operation in particular, the number of WIP inventory was reduced from 8hours to 4hours by providing training for an operator upstream (Finishing) in turning operation. This was necessary because the VSM showed that WIP inventory accumulates after welding and before CNC milling for the CNC product line. The principal reason for this being that there was limited number of operators skilled in turning that was NOT constrained by other operation. But by training the operator responsible for CNC products finishing (a process after CNC milling) in turning operation (cycle time for CNC finishing is 8minutes whilst cycle time for CNC milling 55minutes) a 50% reduction in WIP inventory was achieved.

Another initiative undertaken in creating a multifunctional workforce in NTR Ltd included the creation of a training centre for the manual milling/finishing operations. The emphasis on the operations aforementioned is due to their integral nature to capacity and resource improvement (from chapter 5: the work centres (milling in particular) showed to be over-cycling with high WIP) within the manufacturing system. **Figure 7.13a & b**, below shows a layout improvement within the rotary milling section to create a new training centre.

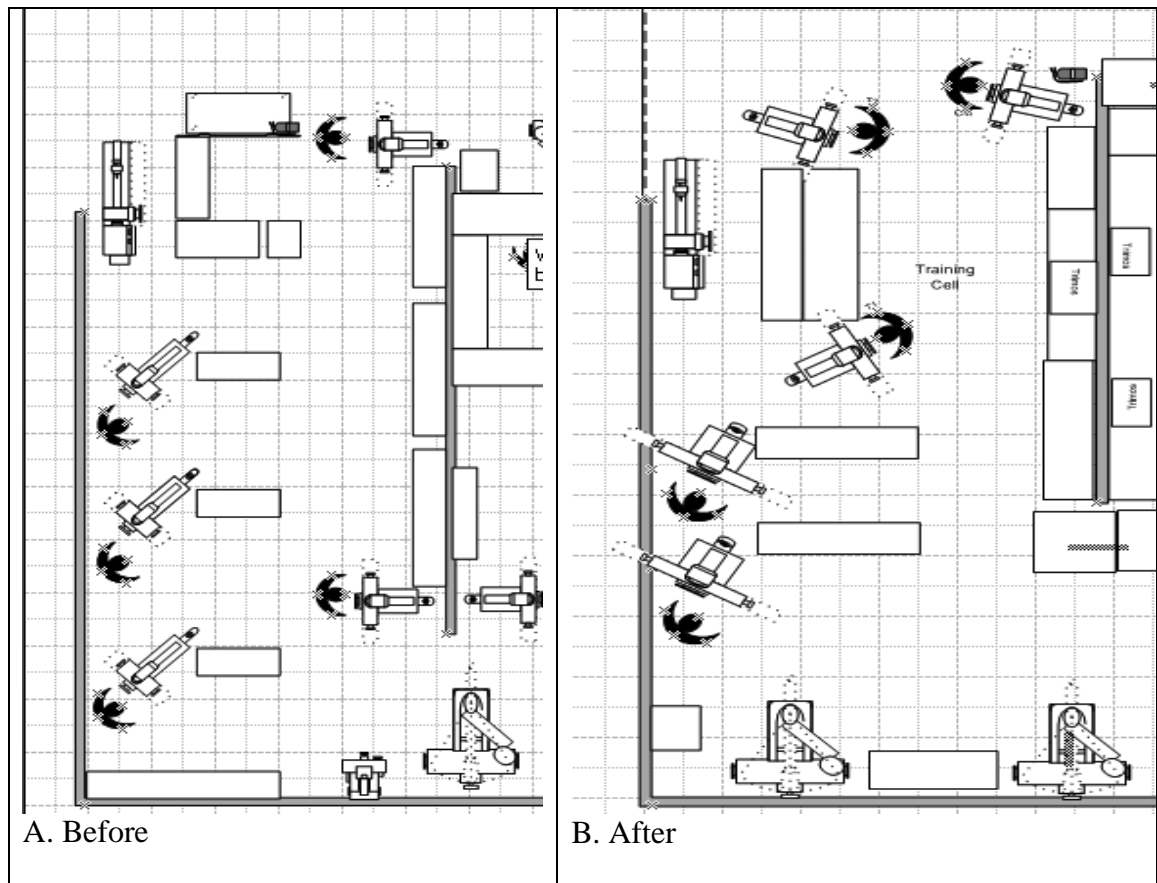


Figure 7.13 a&b: Rotary milling training centre

Key changes in creating the training centre include relocating the “spares” shelves to a more centrally located area for all rotary milling operators, relocating the drilling machine to a more group based environment, creating a workbench for trainee and location of 2 milling machines for trainees, improving overhead lighting from single florescent to double fluorescents to create better lighting in work areas. Re-location of the “spares” shelves afforded creation of the training centre by creating more space and also afforded implementation of a labelling strategy and tagging system for the “spares” shelves and its content. In **Figure 7.14 a&b**, efforts is made to depict a before and after of the “spares” location and labelling strategy.



Figure 7.14a: “Spares” shelves location before improvement

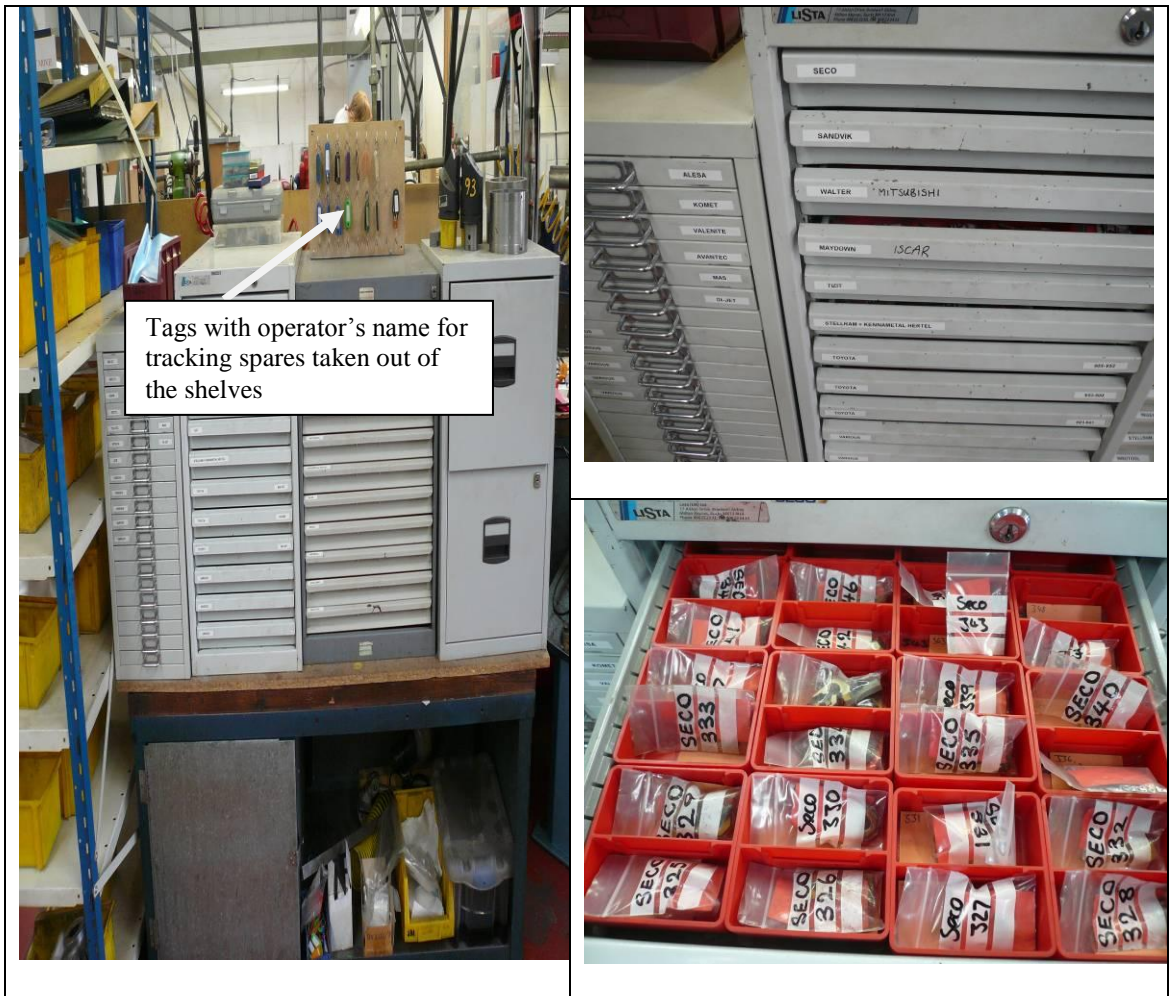


Figure 7.14b: “Spares” shelves location after improvement with labelling strategy

Further to creation of the training centre, a wider shop floor workplace organisation was initiated to improve productivity. A typical implementation of this initiative was within the in-line inspection section. **Figure 7.15 a&b**, shows a before and after improvement within the section, basis changes within the section include improved lighting, relocation of the measurement equipment to allow more room for the operation, labelling of all fixtures and tools used for inspection, location of the shadow graph within the section and re-painting work benches to improve visual appeal.



Figure 7.15a: In-inspection before workplace organisation implementation

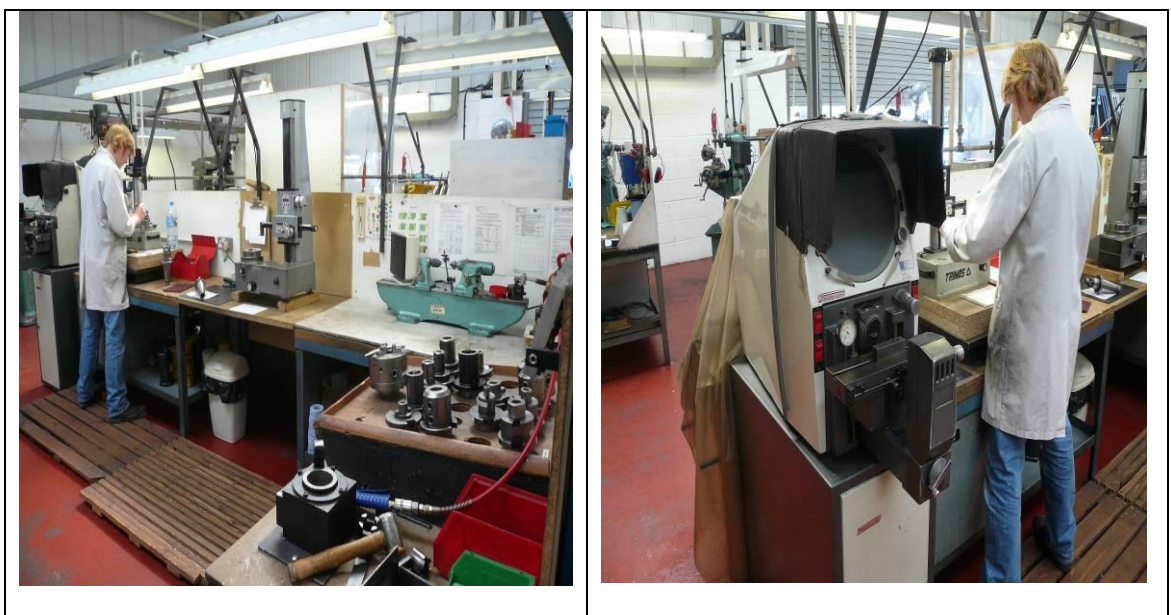


Figure 7.15b: In-inspection after workplace organisation

For sustenance of the workplace organisation initiative a 5S audit framework is deployed. The 5S audit system enable utilisation of rating system to quantify adherence to standard operation as defined with a set of guidelines. **Table 7.11** shows a typical 5S audit check sheet. Check points include sort, set-in-order, shine, standardise and sustain. Each of the check point then has sub-categories, each of which are rated during the audit exercise based on the rating criteria which ranges from 1—4, where, 1= Not good and 4=Very good. After each sub-category has been rated a total contribution% is then calculated. This gives a guideline on direction for improvement, that is, if a higher contribution% of 1 then immediate action is required within each affected sub-category. A good score is achieve if the contribution% is low (<10%) within levels 1-2 in particular and a high contribution% in level 4 (>60%) is considered to be an ideal system. Each work area team leader and the production manager will be responsible for auditing the manufacturing system and making sure improvements are affected with defined time lines.

NTR ^{LTD}		5S Workplace Check sheet		Date:25/02/2008			
Workstation/Area: Rotary Milling		Audited by: Adedeji Esan					
Level 4	Very Good	Waste is anything other than the minimum amount of operator, equipment, materials, parts, space, and operator's time which are absolutely essential to add value to the product.	Very good=No action required				
Level 3	Good		Not good =immediate action required				
Level 2	OK		Good &OK=Improvement required				
Level 1	Not good						
Category	Description	Level					
		1	2	3	4		
Sort out	Sort out what is needed						
When in doubt,	Excess/unwanted equipment, tools are in area		1				
Sort it out	Unwanted/Outdated items on walls, notice board, W/O Items are present on aisle ways, understairs, lockers e.t.c Safety hazards (signs, chemical) in area	1		1			
		1					
Set In Order	Organise and Label, set boundaries and limits						
A place for everything, and everything in its place!	Correct places for items are not clearly marked. Workplaces, Spares, parts to work on, equipment locations not clearly marked Items are not put away immediately after use. Quantity limits are not clearly marked.	1					
		1		1			
		1					
Shine	Clean everything						
Inspection through Cleaning!	Floors, walls, storage area and surfaces are dirty. Lines, signs, labels are dirty, broken or hard to see Appropriate cleaning materials not available. Equipment not properly maintained or other cleaning problems				1		
			1				
				1			
Standardise	Keep check sheet and standards to maintain 3S (Sort, Set-In-Order, Shine)						
Everything in a state of readiness	Standards are not visible in the area and to stakeholders Standards to maintain Sort and Set in Order do not exist. Items needed to do job can't be located in 20 seconds. Quantities/ limits can not easily be seen. Checklist for employee responsibility not visible	1		1			
				1			
		1			1		
Sustain	Maintain discipline and a supportive culture						
Training, reinforcement and measurement	5S Checklist/ Standards are not available or outdated. Daily 5S was not done this week. Daily 5S audit have not been done in the last 2 weeks. Workers in area have not been trained sufficiently on current task Productivity and Quality index Workers in area are not multi-skilled enough for future prospects No Continuous improvement team action ongoing	1					
			1				
				1			
				1			
				1			
				1			
Total		8	3	10	3		
%Contribution		33%	13%	42%	13%		

Table 7.11: Typical 5S workplace organisation check sheet

7.4 Case Five: CAD/CAM integration at NTR Ltd

This case study uses a descriptive approach to present issues relating to CAD/CAM integration at NTR Ltd. The case highlights road blocks and solution procedure and gains from CAD/CAM implementation at NTR Ltd. In **Figure 7.16** key drivers for CAD/CAM integration at the case company is presented.

Figure 7.16 identifies that the CAD/CAM strategy was necessary at NTR Ltd because of changes in cutting tool technology (configuration and complexity) hence limitations in the current manufacturing capability which is vastly manual based (about 80% of machining is done manually). Moreover, part of the company's business strategy was to migrate from its predominantly manual based operation with high labour intensity (direct overhead cost) to a more automated manufacturing system whilst being able to seamlessly manage and transfer knowledge within the organisation.

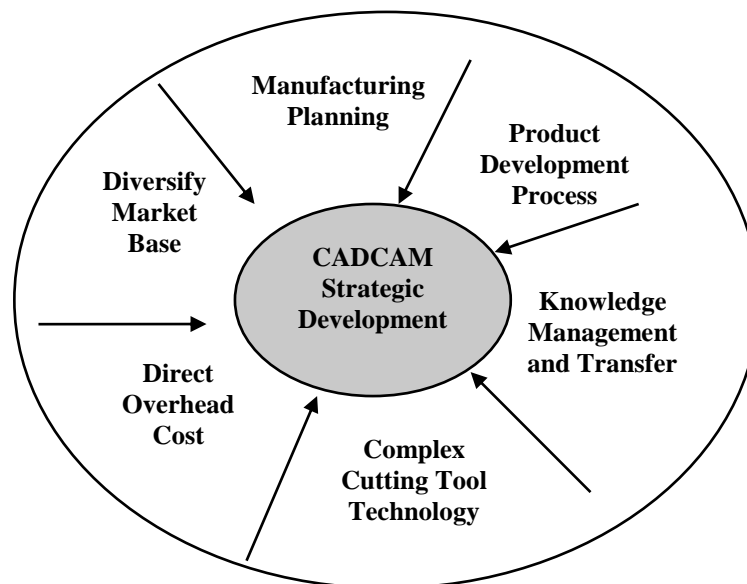


Figure 7.16: Key CAD/CAM Strategic Development issue

7.4.1 Automated Machining Vs Manual Machining at NTR LTD

The manual machining process at NTR Ltd is highly skill dependent and reproducibility and repeatability of machined parts are limited. The goal for CNC/CADCAM integration at NTR Ltd is not to completely alienate manual operation as sizable chunk of work are more attuned and cost effective to machine manually. More so, this will aid incremental change from manual to automated and more importantly enable flexibility in machining parts that are extremely light to medium damage and requiring the lightest “skim”, hence achieving an integration into a lean environment that advocate optimum combination between MAN, MATERIAL and MACHINE.

Although there are arguments for manual production (milling in particular) due to its flexibility and “feel” as these are decidedly required in the tooling reclamation industry where profits margin is based on the ability to swiftly convert input to output in relation to the Original Tooling Manufacturer’s production rate and the competitive environment, however a host of other negatives still applies. Detailed in **Table 7.12** is a force field analysis of the CNC/CADCAM integration strategy at NTR Ltd.

For (Driving Forces)	Against (Restraining Forces)
High Product Quality	Measurement System & Machine tool
Lower Manufacturing Cost	Investment Cost, Payback
Rapid Knowledge Transfer	Product Characteristic Documentation
Complex Tooling Geometry	Measurement System and Machine tool configuration
Lower Throughput Time	Machine tool: CNC machine & Rotary Table
Competitive Advantage	Investment Cost, Payback
New Markets	Marketing, and Sales Strategy
Manufacturing/Business Strategy	Investment Cost, Payback, Marketing/Sales Plan
Reduce Operating Cost	Product characteristics, High Skill Requirement: Milling Knowledge

Table 7.12: CNC/CADCAM Integration force field analysis

The CADCAM integration as seen from **Table 7.12** shows that the company want to be able to quickly (existing manual machining takes about two (2) years to become proficient), and seamlessly transfer, manage and document the organisation's knowledge base hence enabling a concurrent engineering and product data management manufacturing system, increase productivity, improve product quality, diversify market base and achieve lower manufacturing cost whilst forces restraining the deployment of the CADCAM strategy include the extent of investment required in achieving a truly automated CIM environment: cost are not just limited to CADCAM acquisition but also requirements for machine tool technology that permits multi-axis machining and the need for an integrated measurement system.

7.4.2 Wider CADCAM implementation issues at NTR Ltd

Further to understanding the need for CADCAM integration strategy at the case company, the organisation needed to recognise various stakeholders' expectation, risks involved, investment scenario, and expected returns on investment incorporating a

production plan with cost estimates for the wider deployment of the strategy. Through a team based continuous improvement framework the following activities detailed in **Tables 7.13, 7.14, 7.15** and **Figure 7.17** were carried out. **Table 7.13** and **Figure 7.17**, illustrates a Return On Investment (ROI) calculator and an incremental investment strategy developed as part of the CAD/CAM integration at the case company.

Transaction Costs	Average minutes	Loaded Hourly Rate	Activity Cost	Total Customer Cost	Total Business Cost	Assumptions	
OP1	5.0	£50	£4.17		£4.17		
OP2	5.0	£50	£4.17		£4.17		
OP3	15.0	£50	£12.50		£12.50		
OP4	55.0	£50	£45.83		£45.83		
OP5	5.0	£50	£4.17		£4.17		
OP6	10.0	£50	£8.33		£8.33		
OP7	5.0	£50	£4.17		£4.17		
OP8	8.0	£50	£6.67		£6.67		
OP9	5.0	£50	£4.17		£4.17		
Cost Per Transaction				£0.00	£94.17		
Transactions Per day				8	8		
Transaction Cost Per Day				£0	£753		
Rework and Scrap Costs	10.0	£50	£8.33		£8.33		
Transactions reworked /day				0.08	0.08	1.0 %	Error Rate
Rework /Scrap Costs Per Day				£0.00	£0.67		
Annual Transaction Cost				£0	£275,210	365	Days /year

Table 7.13: Process Plan—Production Routings

Table 7.13 shows a production plan with expected annual transaction rate of about £275,000 and a gross systems output of 8 parts per day with investment limited to existing machine tool. This shows a drastic increase in parts produced over the manual operation with output of just 3 parts per day on parts needing total refurbishment. However with incremental investment in advanced machine tool technology and other ancillaries **Figure 7.17** shows an exponential increase in outputs.

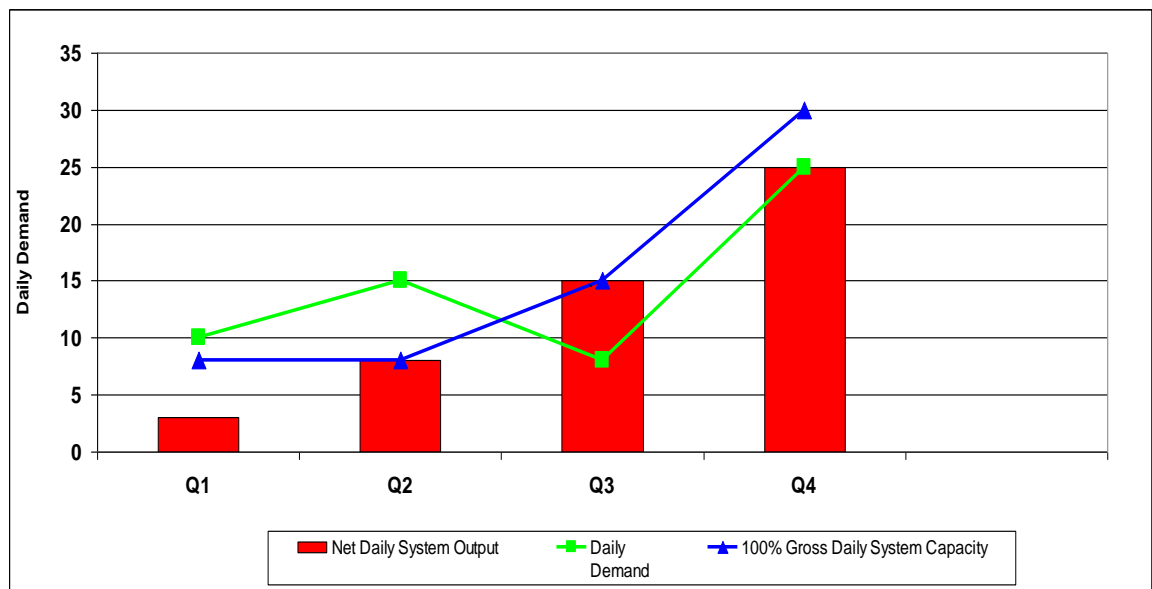


Figure: 7.17: Incremental investment capacity

Furthermore, in order to successfully manage and realise these projections the case company carried out a stakeholder analysis. **Table 7.14** shows a stakeholder assessment carried out at NTR Ltd. The table uses a matrix structure to identify key stakeholders and the level of their commitment to CAD/CAM integration at the case company. The matrix shows that the management of the company is helpful whilst the production staff are indifferent about the need for such strategy as it is perceived as an avenue to “de-skilling” their jobs.

Level of Commitment	People or Group			
	Sales	Management	Production	Customer
Enthusiastic		O	O	
Helpful	O	X		OX
Compliant				
Hesitant	X			
Indifferent			X	
Uncooperative				
Opposed				
Hostile				

(Key: O - Level Necessary for success, X-Current level)

Table 7.14: CAD/CAM Integration Stakeholders analysis

Some other perception of the production staff with regards to CAD/CAM integration include the understanding of how the integration would be achieved with the current CNC milling machines and more importantly what are the benefits over the existing conversational based CNC programming and manual milling methods. These concerns along with other risks involved are presented in Table 7.15.

Table 7.15 uses a risk assessment framework that briefly describes the nature of the risk, a business impact and probability of occurrence rating, hence providing the organisation with a decision making opportunity. Detail approach exploited in mitigating some of the risks identified in **Table 7.15** is presented in section 7.4.3—CAD/CAM change management at NTR Ltd and section 7.4.4—Benefits of CAD/CAM at NTR Ltd.

Risk Description	Business Impact	Probability of Occurrence	Priority
	(1, 3, 5)	(1, 3, 5)	
Poor CTQ definition	5	3	15
Extended product development time	5	3	15
Access to investment finance	3	1	3
Barrier to Entry: Marketing & Sales Strategy	5	5	25
Software and Computer Integration	5	1	5
Hardware: Machine Tools, Measurement System	5	5	25
Production Staff: Communication Plan & Buy-in	5	5	25
Learning Organisation (Time-to-Train, knowledge Mgt& IP)	5	1	5
Highly Skilled Staff Retention	5	1	5
Continuous flow of work to process centre	5	5	25

Table 7.15: Risk Assessment CNC/CAD/CAM integration (1=Low, 5=High)

7.4.3 CAD/CAM Integration at NTR Ltd: Change Management

In order to gain support for CAD/CAM integration and perhaps with any change in organisational culture staff buy-in is always a pre-requisite. Another point of reckoning is the ability to source for a reliable vendor for the CAD/CAM system. Reliability in this instance is directed at provision of on-going support for the client and continuous product quality updates. **Figure 7.18** illustrates the approach taken in managing the change process in the case company.

The framework involves the establishment of a CAD/CAM integration continuous improvement team centred on production staffs, and education, training and creating awareness of the benefits of CAD/CAM (detailed explanation provided in the following section) to the production staffs. The focus of the training was on how to use the CAD/CAM system and ways of developing Product Data Management structure that allows collaborative design for manufacture using serve based technology.

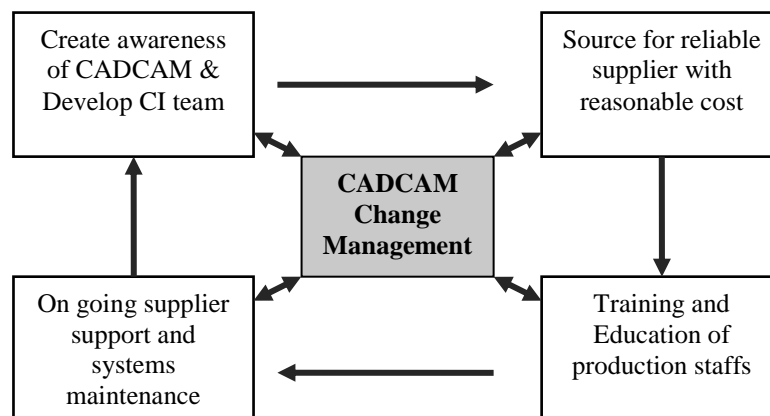


Figure 7.18: CAD/CAM Change Management at NTR Ltd

Furthermore, for the training process to be effective, relevant an on-site training method was utilised with a combination of practical (hands on machine based training) and software based training. This type of training method afforded the production staffs the opportunity to witness first hand the advantages of the system over current methods and more importantly it provided an avenue to share their concern over the deployment of the strategy. Other change approach utilised in deploying CAD/CAM at the case company involved supplier or vendor partnership. The vendor was not just involved in the sales of the product but rather actively involved in training, and product development. A typical collaborative product development approach utilised in the supplier integration include the concept of remote team working.

This method involves working in conjunction with the supplier using web enable technology to manage both product development and systems maintenance. The technology allows the supplier to remotely take absolute control of the manufacturing/design engineer's PC thereby facilitating knowledge transfer and rapid product development.

7.4.4 Benefits of CAD/CAM integration at NTR Ltd

Figure 7.19a & b show how the CAD/CAM systems implemented at NTR offer valuable advantages over traditional design/manufacturing methods, the **Figure 7.19a**, illustrates the current manual data transfer methods. The process begins with generation of a 2D CAD model that includes manual calculation of relevant "pattern location" using trigonometry. The application of this trigonometry calculation is especially limited in calculating compound "pattern locations".

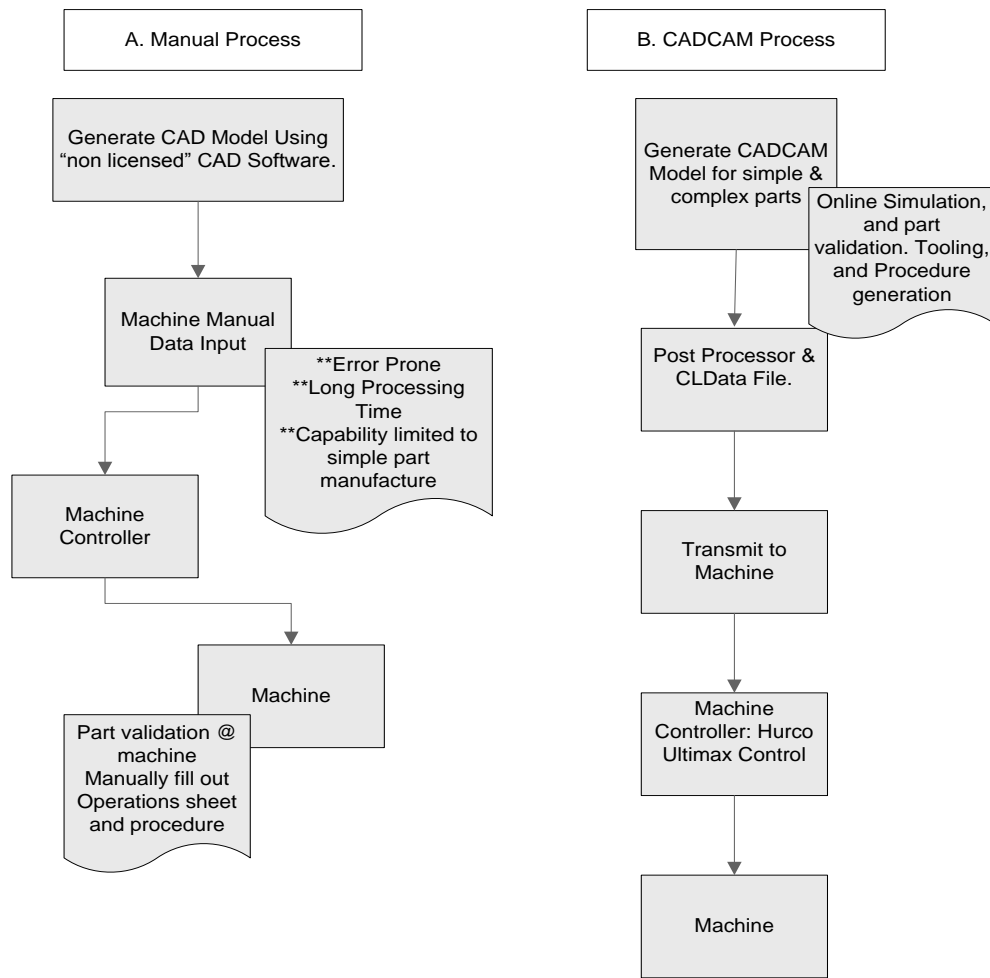


Figure 7.19a & b: Manual process Vs CAD/CAM process

Furthermore, on generation and extraction of relevant geometries from the CAD model the details are then manually transferred into the machine using the conversational part programming interface. This particular process is often long and lends its self to data input error. Other observations from **Figure 7.19a** are that tool paths validation is always done at the machine hence the need to continuously adjust programmes to fit (over-processing) and on successful validation of programme, the programmer then needs to develop an operations sheet (tooling, procedures, and other instructions) which often takes time.

Another relevant observation is that the current conversational based programming is limited to one single machine tool type/manufacturer hence limiting the company's options in sourcing for other machine tool due to interchange-ability of programmes. However, with the application of CAD/CAM all the highlighted limitations are non applicable. **Figure 7.19b** describes the process route for the CAD/CAM integration. The figure suggests that the CAD/CAM system integrates a suite of collaborative product design software that addresses the complete product development process, from product concept specifications through product-in-service, in a fully integrated and associative manner by allowing parts to be designed, manufacture and validated in a single environment.

The CAD/CAM system allows minimising manufacturing procedures, processes, tooling, and operations through concepts in CAD/CAM such as parametric and feature-based modelling. The concepts of part and flexible management of tools stored in file-based tool libraries or in external tool databases, solid modelling techniques and application of crystal reports makes it possible for the case study company to drive designs toward and from a manufacturing viewpoint.

The key to the use of this technology is in the concept of CAD/CAM part libraries and that of parametrically driven feature libraries, associativity with design parts for efficient change management and ability to quickly reuse and modify existing design for manufacturing using machining logic into a template or library that can be instantly applied to vast array of other parts hence facilitate lean operations. **Figure 7.20** shows the operating levels of the CAD/CAM system sourced for NTR Ltd whilst **Figure 7.21** shows the operating type of the CAD/CAM system.

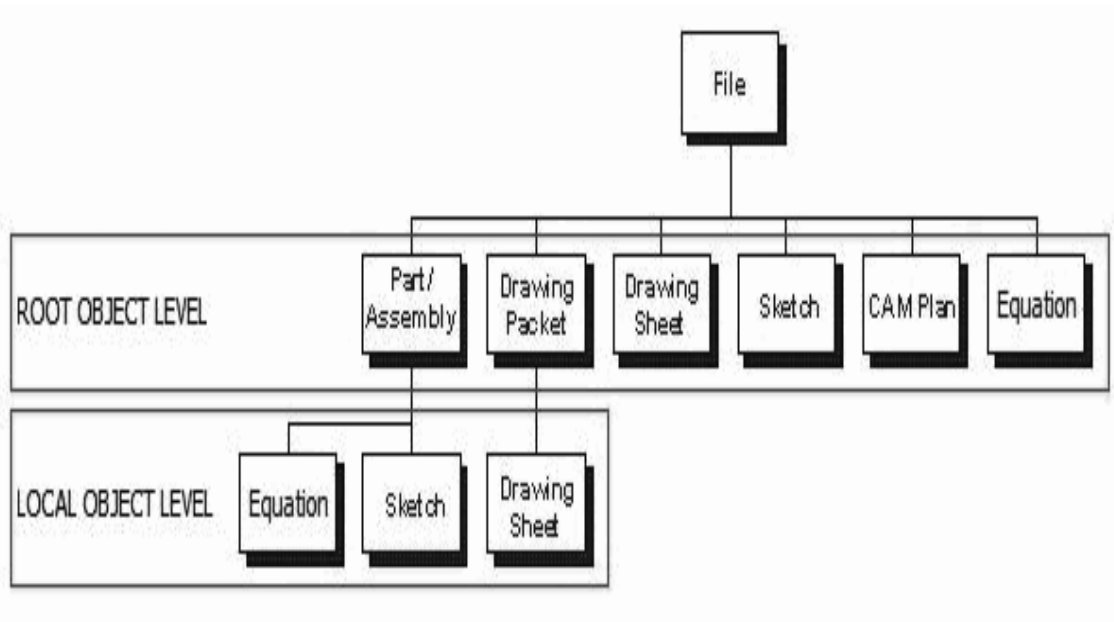


Figure 7.20: NTR Ltd's CAD/CAM system operating levels

Furthermore, the CAD/CAM concept permits the case company to speed their responses to market needs and frees users to focus on creativity and innovation and production at minimum possible cost through facilitating true collaborative engineering across the multidisciplinary extended enterprise, including mechanical design, fixturing and systems engineering, machining analysis, simulation and tool path verification by material removal simulation, collision checking and analysis of the in-process part.

The system allows for accurate tool path definition through a full set of milling operations from 2.5-axis up to 5-axis (it is worth noting that the current conversational based programming can not handle 5-axis machining) and axial machining operations with high level of automation and standardisation by capturing and reusing proven manufacturing know-how thereby enabling faster development, and a reduction in time-to-market, gives:

- a competitive advantage over competitors who take longer to respond to market changes, customer needs, new technologies; or ...
- premium prices before competitors offer customers a choice;
- a faster return on the development investment and therefore a lower financial risk;
- a longer life cycle for the product;
- a higher return on the total investment.

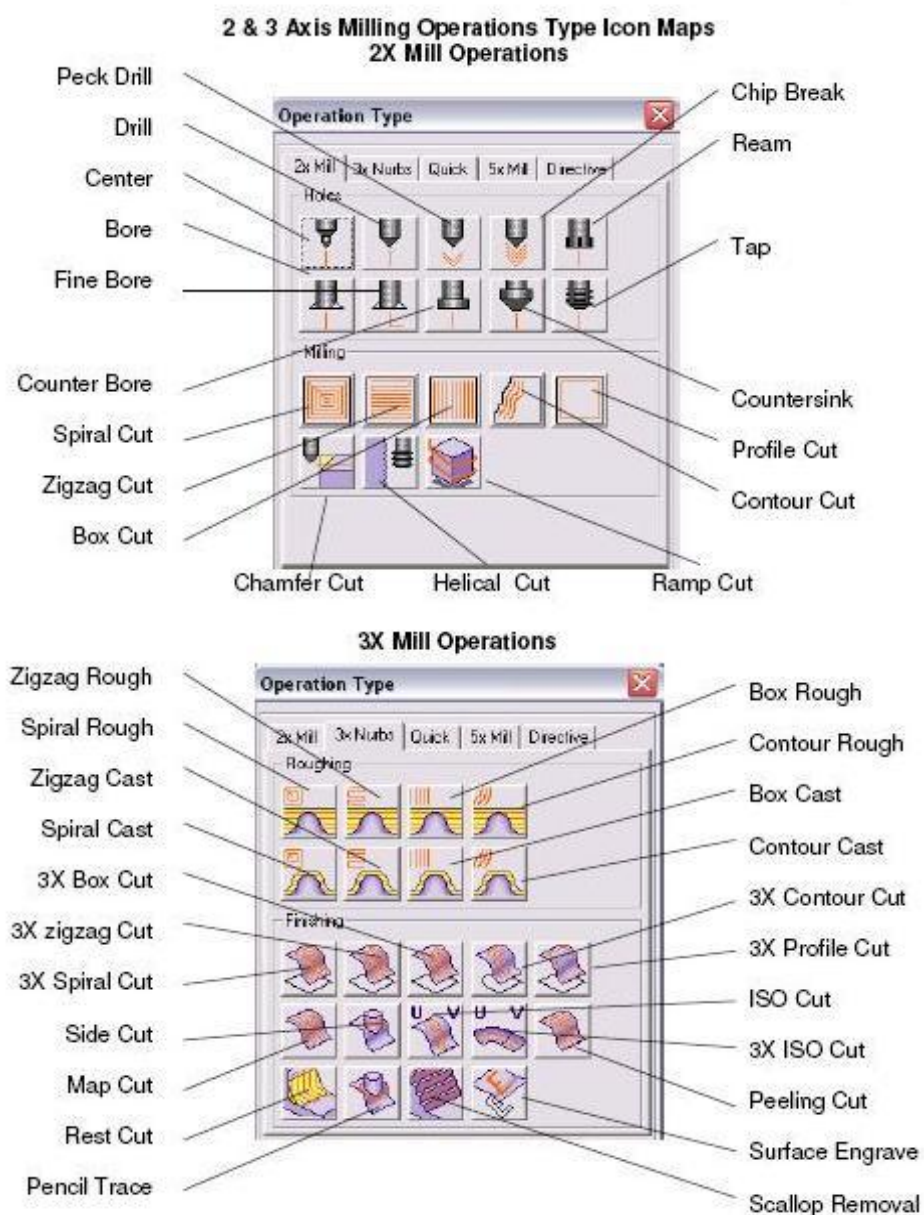


Figure 7.21: Operation type of the CAD/CAM system

Additionally, the CAD/CAM assembly design technology, for tool body, to “insert” utilise an object-oriented databases and object-oriented programming techniques, that actually allow an “insert”, used in multiple locations in an assembly (tool body), to be designed interactively as a single model while simultaneously being displayed in its parent assembly at various locations. The CAD/CAM system allows users to apply their own operating procedures and intelligence to machining unlike the current conversational based machining that is highly prescriptive and the manual machining methods that the knowledge is encrypted in people’s head.

This is possible because the CAD/CAM system takes a unique, whole part approach to machining. The user establishes “rules of engagement” to control and contain tool path. The system even automates small changes to individual machining operations; for example, changing a tool size automatically adjusts the XY step over in a roughing operation. This rules-based approach is extremely effective in rest milling operations where the machinist simply wants to remove the material that the previous operation didn’t remove. The automation comes from machinists storing their logic and intelligence in a template of operations.

Other benefits in the CAD/CAM system are roughing and advanced finishing operations that provides optimum tool loading, extremely efficient material removal, and high quality finish to reduce machine wear and tear which improves machine tool utilisation and reduces polishing time. The technology increases tool life and reduces machine wear by keeping the cutter in the material, dramatically reducing rapid moves, and by maintaining a constant chip load.

All cutting motions are smooth; corners and tight areas are cleared without taking full width cuts which prevents tool overload for both roughing and finishing operations. This is critical for unattended machining and key to extending tool life and reducing wear and tear on the mill. The system takes scan data to the next level, integrating scans into product and tool designs using a full-featured, fully-integrated CAD/CAM system with complete solid and surface modelling; shape morphing, reverse engineering, detailing, assembly, and milling tools.

7.5 Product characteristics definition for CNC/CAD/CAM integration at NTR

As shown in **Table 7.12**, accuracy of defining the characteristics of NTR Ltd's product for use with the CAD/CAM system is paramount to achieving high product quality and critical to knowledge transfer. The knowledge transfer interface refers to the opportunity to use defined products CTQ to create new and existing product's CAD models, NC programmes, and CAM plan. **Figure 7.22a & b** shows a Coordinate Measuring Machine (CMM) for extracting the characteristics of NTR Ltd products, a typical high value product –24MM 390COROMILL END MILL is depicted in the **Figure 7.22b**.

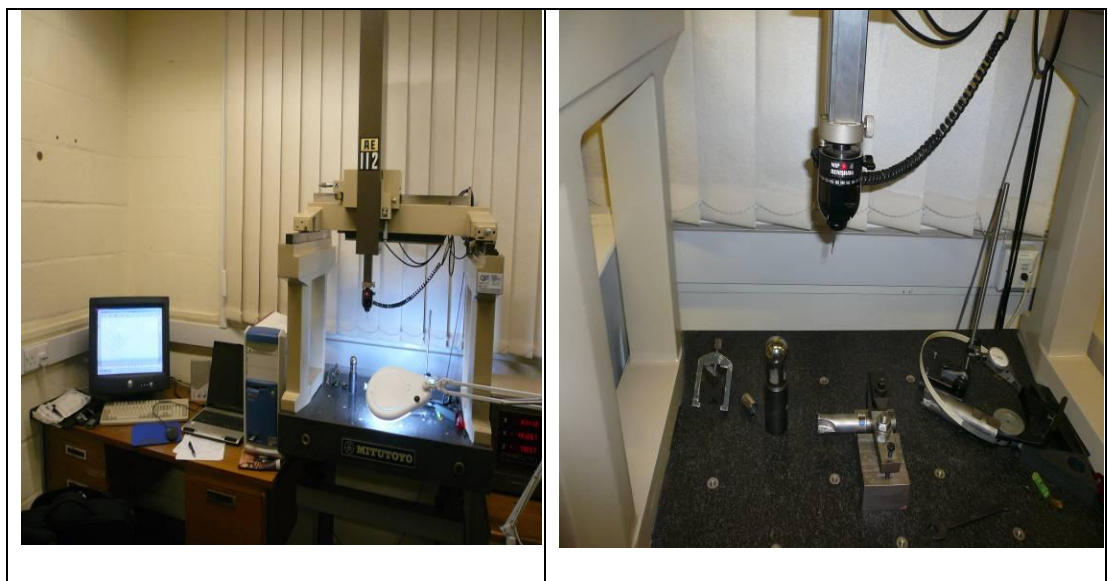


Figure 7.22: CMM for NTR Ltd product characteristic extraction

Output from the CMM extraction of the 24MM Endmill characteristics is represented in **Figure 7.23** below. The extraction method uses series of planes, lines, arcs and prismatic shapes to create a 3D geometry of the part. The output from the CMM then forms an input into the CAD/CAM software sourced for NTR Ltd. In the CAD interface, surfaces are created, whilst the CAM plan generates the CNC inputs.

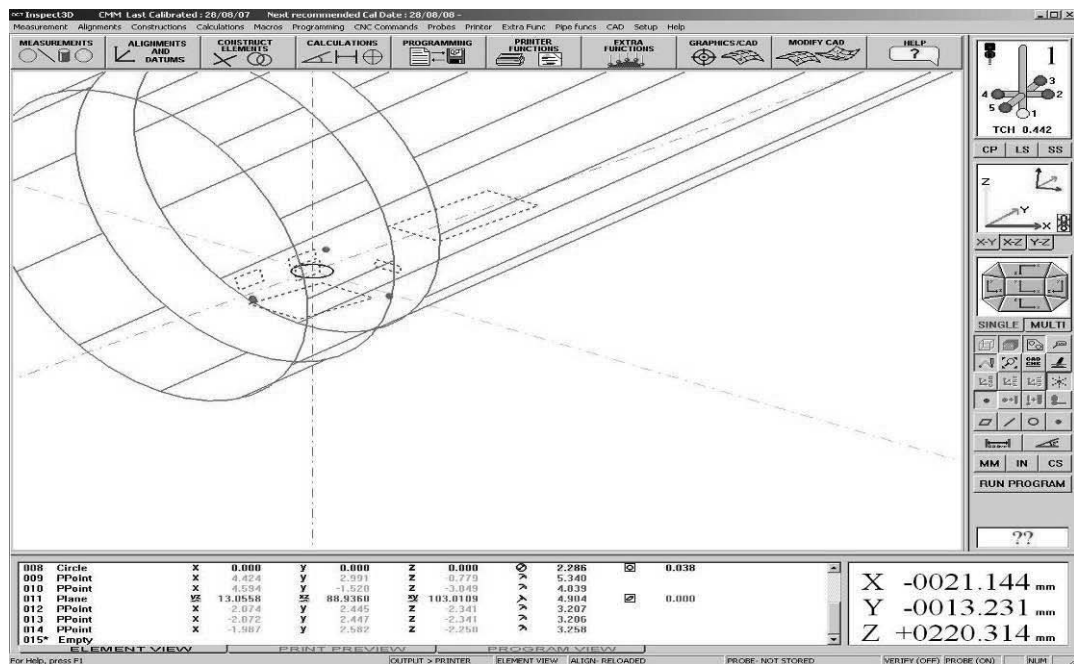


Figure 7.23: CMM output for the 24MM Endmill

The limitations of the software used in **Figure 7.23** were that there was a few data loses and the CMM used a probe system only as against having a probe system and scanned (vision system) data as well. Proposed solution to the limitation is briefly discussed in the future work section of Chapter 8.

Figure 7.24 shows a machined part for the first order won by the company due to its new capability. The main advantage that the CAD/CAM system afforded in winning the order is the ability to use continuous 3-axis (It is worth noting that the current conversational based programming is only limited to 2-axis milling operation) for

machining the radius showed in **Figure 7.24**. The system uses its 3-axis spiral cut milling operation and containment strategy to create the profile. The order's worth was about £50,000 hence representing an immediate pay-off and significant return on investment on the CAD/CAM software and associated training costs (with total cost of about £8,500).

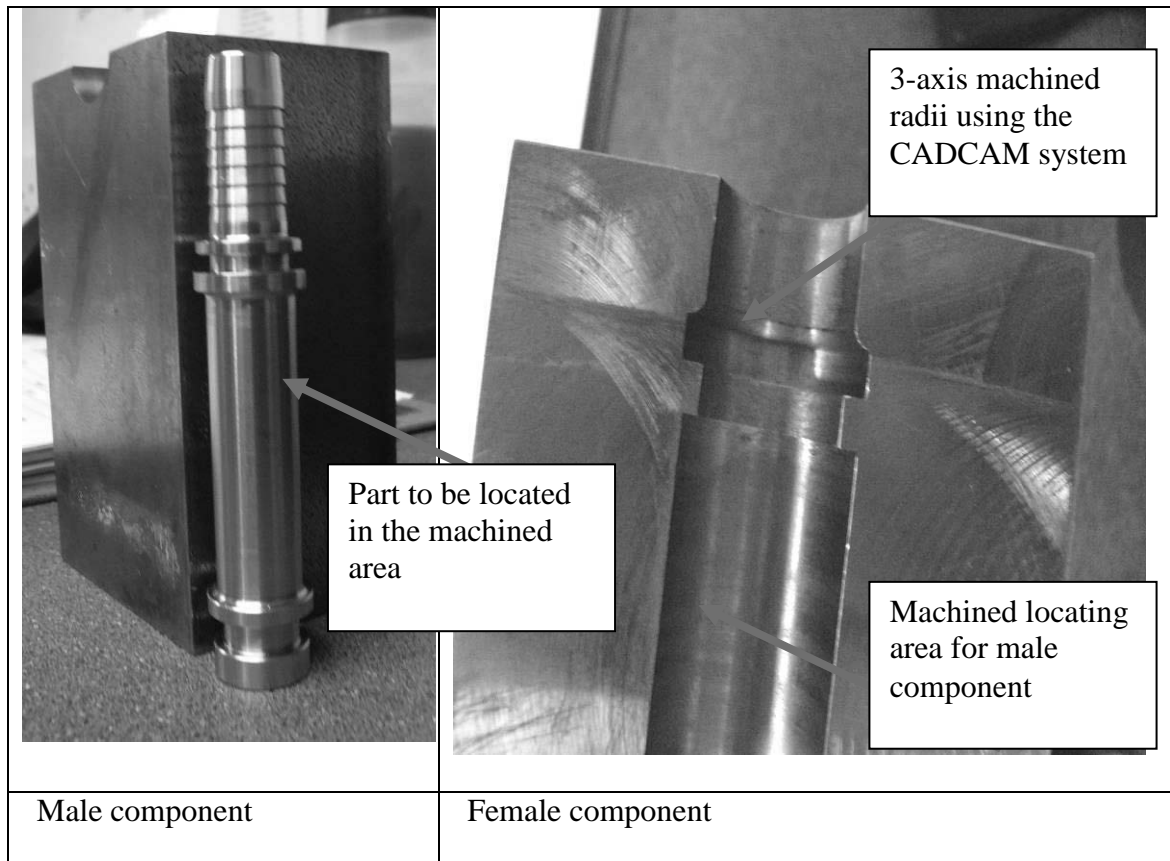


Figure 7.24: Machined component for first order

7.6 Summary

In this chapter a further application of lean manufacturing and continuous improvement has been defined using a DMAIC framework, application of the golden lean check matrix and a descriptive analysis of other improvement initiatives undertaken at NTR Ltd. Three case studies were presented in this chapter to validate the application of this

frameworks in NTR Ltd. Case three, examined the application of the DMAIC methodology in improving delivery rates, whilst cases four and five uses a description analysis for productivity improvement and CAD/CAM integration at NTR Ltd.

Case three—Delivery rate improvement, examined the ship window compliance of NTR Ltd manufacturing system. The base line data presented showed a PPM value of the delivery rate between the first weeks of September 2006 to second week of November 2006. The mean delivery rate over these periods is 186771, which was about 2.4 Sigma. The project goal/objective was the creation of a process that will significantly increase delivery rates to > 90% and also reduce the panic at month-end.

Furthermore, a process map was developed as part of the Define phase, with key process defined, that is, quote handling, goods outwards and booking in. In the Measure phase a C&E matrix was outline and rating developed. Additionally, the highest occurring causes, such as, information transfer, multi-part order, part splitting e.t.c were transferred into the FMEA. Major categories of actions from the FMEA were implementation of a daily productivity information framework, implementation of a maximum wait time for goods-in processing, operator training on the quote release process, implementation of splitting handling system, creation of a new processing centre using available database, and improving the work order's production instruction field. A capability plot was also conducted with a Cpk value of -0.42 and Ppk value of -0.37, which suggests that the current process is not capable.

Following a well structured improvement programme, development of split handing system, and training of quote handling and goods in/outwards operatives, an IMR chart

was set-up as part of the Control phase to measure any out-of-control condition that may affect the big Y-which post improvement, the process sigma for the delivery process improved from 2.5 Sigma to 2.9 Sigma.

Case four— Productivity improvement—the case presents some of the solutions to resolving issues relating to extended queues and poor machine and operator utilisation. Furthermore, the case discussed wider implementation of a 5S programme at NTR Ltd, shop floor re-layout to improve communication within teams, creation of a training centre, development and implementation of training programme for multi-functionality, and other initiatives undertaken to improve NTR Ltd manufacturing system's productivity.

Further to developing the a productivity framework for NTR Ltd's manufacturing system, utilising the information produced by database to drive productivity was paramount. Output from the productivity index suggested that a multifunctional work force was required to improve the overall skill base of NTR Ltd. A skill matrix for NTR Ltd's shop operations was developed; the matrix lists all shop floor operators against operations within the manufacturing system. The current % multi-skilled operation is 47%. In CNC milling operation, the number of WIP inventory was reduced from 8hours to 4hours by providing training for an operator upstream (Finishing) in turning operation.

This was necessary because the VSM showed that WIP inventory accumulates after welding and before CNC milling for the CNC product line. The principal reason for this being that there was limited number of operators skilled in turning that was NOT constrained by other operation. But by training the operator responsible for CNC products finishing (a process after CNC milling) in turning operation (cycle time for

CNC finishing is 8minutes whilst cycle time for CNC milling 55minutes) a 50% reduction in WIP inventory was achieved.

Finally, % multi-functionality was increased by 7% and for sustenance of a wider workplace organisation initiative developed at NTR Ltd; a 5S audit framework was deployed. The 5S audit system enable utilisation of rating system to quantify adherence to standard operation as defined with a set of guideline. A good score is achieve if the contribution% is low (<10%) within levels 1-2 in particular and a high contribution% in level 4 (>60%) is considered to be an ideal system. Each work area team leader and the production manager will be responsible for auditing the manufacturing system and making sure improvements are affected with defined time lines.

Case five— CAD/CAM integration— CAD/CAM strategy was necessary at NTR Ltd because of changes in cutting tool technology (configuration and complexity) hence limitations in the current manufacturing capability which is vastly manual based (about 80% of machining is done manually). The manual machining process at NTR Ltd is highly skill dependent and reproducibility and repeatability of machined parts are limited. The goal for CNC/CAD/CAM integration at NTR Ltd was not to completely alienate manual operation as sizable chunk of work are more attuned and cost effective to machine manually.

Furthermore, a force field analysis, and risk assessment framework that briefly describes the nature of the constraint and risk within the manufacturing system was conducted. Key output from the analysis include seamlessly transfer, management and documentation of the organisation's knowledge base , improve product quality, diversify market base and achieve lower manufacturing cost whilst forces restraining

the deployment of the CAD/CAM strategy include the extent of investment required in achieving a truly automated CIM environment: cost are not just limited to CAD/CAM acquisition but also requirements for machine tool technology that permits multi-axis machining and the need for an integrated measurement system.

In order to gain support for CAD/CAM integration and perhaps with any change in organisational culture staff buy-in was required and the ability to source a reliable vendor for the CAD/CAM system. Reliability in this instance was directed at provision of on-going support for the client and continuous product quality updates. Training and education were conducted on utilising the system and a supplier on-going support system was also developed. A comparison of the CAD/CAM system and current conversational programming was also carried out. Typical cases for the CAD/CAM system include minimising manufacturing procedures, processes, tooling, and operations through concepts in CAD/CAM such as parametric and feature-based modelling as against the conversational programming.

Finally on CAD/CAM integration at NTR Ltd, a discussion of the first order won by the company due to its new capability was carried out. The main advantage that the CAD/CAM system afforded in winning the order was the ability to use continuous 3-axis (It is worth noting that the current conversational based programming is only limited to 2-axis milling operation) for machining. The system used its 3-axis spiral cut milling operation and containment strategy to create the required profile. The order's worth was about £50,000 hence representing an immediate pay-off on software and training cost which is about £8,500 and significant return on investment.

CHAPTER 8

CONCLUSION AND FUTURE WORK

8.1 Introduction

At the onset of this research, four primary objectives were identified. The first was to identify the current and future market potential of the case company so that the current manufacturing strategy and operations can be devised for expected growth. This will necessitate identifying the current and future trends in the business operations of the case company, through the study of home and overseas markets. The second was to design and create an integrated manufacturing knowledge base (scheduling/ capacity planning) system for the case company manufacturing system. The creation of the knowledge base system was to contain process routes and costing for each of the product range.

The third objective was to implement a culture of just in time (JIT, continuous improvement, six sigma process improvement) through the use of a team based approach with emphasis on key elements of lean manufacturing and Six Sigma process improvement methodologies. The fourth and last objective was to design, develop and implement a CIM environment at the case company that will enable it to migrate from manual machining to an automated system. This chapter describes the conclusion on the four objectives, develops an integrated manufacturing strategy framework for SMMEs and also covers the future work recommended to sustain and consolidate the objectives.

8.2 Identify the Current and Future Market Potential of NTR Ltd

In Chapter 3, the need for Lean Manufacturing and the details of the knowledge transfer partnership programme between the case study company and the University of Bradford was defined. Additionally, the current business environment of the case company was established using an industry specific and process specific analysis framework. The industry analysis used Porter's five force analysis and the PESTLE external factor analysis frameworks. Key outputs from the Porter's five force analysis were: barriers to new entrants and that the case company have little power to dictate to suppliers their needs. A typical scenario is that Original Product Manufacturer (OPM) might achieve lower product cost (e.g. through flexible manufacturing techniques) to the extent that the cost of reclaim to cost of new is not significant enough to warrant product reclamation. This sort of behaviour further buttressed the need for lean manufacturing strategy deployment in the case company, as lean can significantly lower manufacturing cost, hence achieving competitive advantage and sustainability.

In relation to the competitors interface in the Porter's five force analysis the chapter discussed that with the exception of competitor A and competitor B all other competitors in the UK have emerged out of NTR Ltd over the last 28 years. Competitor B was established at the same time as NTR but has never been able to compete against NTR's quality and service. However, what successive competitors have done is to drive down the value of reclamation by providing an inferior product and service to that offered by NTR. The chapter further investigated the external business environment of the case company through a PESTLE analysis. The PESTLE analysis showed the impact of globalisation on UK manufacturing and the case company in particular and

also demographically implication of changes on the age distribution on the case company.

The PESTLE analysis further suggests that NTR Ltd is susceptible to the current trend of globalisation and global economics. This impact is bore out from the fact that the cost of manufacturing (in particular labour cost) in the UK is relatively higher than developing economics hence the potential of the market place been flooded with cheaper tooling alternatives. Although the effective use of machining technology that facilitates lower set-up procedures, lower operator intervention (other loading and unloading parts, several machine to one operator), and high throughput offers potential for sustainable competition with developing economics. Furthermore, the aging population (experience) and the ability to attract young and dynamic individuals to the organisation offers potential for reforms which can substantially improve the organisations competitive position.

In addition, Chapter 3 also examined process specific issues relating to the case study company using a SWOT analysis, change management model and performance measure framework. The SWOT analysis identified typical opportunities for improvement at the case company as need for increased workers cross functionality, improved quality systems, improved work place organisation, production planning and control and so on. Whilst the change management model advocated the practical application of a punctuated equilibrium paradigm of organisational change management utilised in deploying lean manufacturing as a manufacturing strategy, a three (3) stage lean manufacturing change management deployment strategy in the case company was also enunciated with stage one (1) advocating the development of various continuous improvement (CI) projects and teams, stage two (2) of the lean change management

strategy involved shifting focus from internal productivity improvements to customer's enthusiasm and stage three (3) advocated developing control plans and being proactive as against reactive to process issues, that is, innovation and the development of innovative initiative that do not appear yet in the marketplace

Chapter 3 concluded by advocating that performance indicators are key criteria for integrating lean manufacturing policy deployment into the case study company as it explicitly shows the effect of changes taken place. The plant is required to use these KPIs to communicate key manufacturing strategic objectives to all employees and accelerate continuous improvement in their work area. Typical KPI developed in the chapter include: FTQ, HSE, OE%, and ship window compliance. To ensure performance improvements are occurring, the chapter suggested that frequent review of relevant KPIs should be done as part of process/production meeting. The focus is on trend analysis, rather than on month-to-month variation. The chapter concluded with the development of a golden lean check matrix that advocates three key check points for intermediate analysis of lean deployment progress.

8.3 Design and Create an Integrated Knowledge Base System

In Chapter 4, lean manufacturing and strategic planning was defined, with a production planning and manufacturing cost and product cost structure approached established. The production planning framework established the product family matrix (PFM) as a baseline in lean manufacturing policy deployment. PFM aggregated the product cluster of the case company into three (3) distinctive product lines: Standards, Rotary and CNC Tooling product lines. The chapter further created a master production schedule (MPS) for the case company using exponential smoothing forecasting technique and a smoothing constant of 0.8 for determining the MPS. The analysis suggested that the

MPS structure for NTR Ltd follows a Make-To-Order (MTO) aggregate production planning structure, hence no order is scheduled until sales has occurred, thus future demand is usually an order backlog, no finished goods inventories exist and demand forecast always show a close match with actual demand.

The Chapter also examined the manufacturing cost and product cost structure of the case company. The approach taken in developing the manufacturing cost and product cost structure of the case study company is the well known value engineering concepts of multiple-stage manufacturing system accumulating costs between individual stages as well as by transfer/material handling and work-in-process. The details collected also included principal industrial statistics (such as salaries and wages, cost of materials and supplies used, cost of energy and water utility etc.), as well as information about the products produced and consumed. The analysis showed that due to the 'labour intensive' nature of NTR Ltd's manufacturing system; costs are dominated by the costs of labour. Considering the stated cost is a major factor in its manufacturing activities, the organisation is susceptible (staff T/O to Volume ratio) to any fluctuation in salaries and wages.

Chapter 4 concluded by critically investigating the output of the manufacturing cost analysis by constructing a profit/value matrix. The products comparison showed an implicit relationship between price and value across the case company's product families. The analysis revealed that the Rotary product family is highly profitable and high value, whilst the CNC product family is low profit and high value. Although, the Standards product family is practically not profitable and of relative low value, however, the analysis further established that a product: Boring Heads Exchangeable of the standards product family is high profit but low value. Furthermore, the profit/value

matrix was used to determine the relationship between lean manufacturing and strategic planning using a competitive discounting and pricing strategy approach and a product family discontinuation and/or augmentation for effective lean manufacturing strategic deployment.

8.4 Implement a Culture of Continuous Improvement

In Chapter 5 Lean Manufacturing and resource planning was defined using a mapping, audit and analysis framework. The chapter examined the application of a lean assessment system to the case company and returned a **46%** score rating which showed that NTR Ltd has a fair understanding of Lean Manufacturing but guidance is required to reach the next level. The chapter further utilised a current state value stream map to generate a deeper understanding of the case company's manufacturing system. Key outputs from the current state map were: poor resource utilisation, poor FTQ and high level of WIP within the case company product lines. Due to the static nature of value stream maps, the chapter then further validated the current state value stream map through a simulation study (dynamic effects). The chapter concluded from the simulation of the three distinctive product lines within the case company's manufacturing system that constraints were due to lack of continuous flow, poor resource utilisation that then resulted in high levels of WIP inventory.

To resolve all the identified issues from the analysis in Chapters 3, 4 and 5, Chapters 6 and 7 used a continuous improvement approach to resolve some of the issues.

In Chapter 6 the application of Lean Manufacturing and continuous improvement was defined using a DMAIC framework and application of the golden lean check matrix. Two case studies were presented in the chapter to validate the application of this

frameworks in NTR Ltd. Cases one and two, examined the application of the DMAIC methodology in reducing internal defect rate attributed to lack of weld and heat treatment respectively.

Case one—lack of weld, which refers to a part not welded at a Critical-To-Quality (CTQ) feature on that part was estimated to cost the company in terms of Cost of Poor Quality (CTQ) of up-to £30,000 per year. The Define phase of the project focused on a goal statement of creating a process that will significantly reduce internal returns due to lack of weld by 50% within a 90 days' timeline and with every support requirement clearly detailed. Furthermore, a process map was developed as part of the Define phase, with key process defined, that is, welding, and strip down. In the Measure phase a C&E matrix was outline and rating developed. The highest occurring causes, such as, welding operator's skill, welding team leader over-check, pre-inspector skill e.t.c were transferred into the FMEA. The FMEA was then rated and the highest RPN's were action by the team. Key actions from the FMEA include operator training, welding team leader workorder's sign off post strip down and tooling damage recognition. Following a well structured training programme and development a tooling damage recognition flow chart, a IMR chart was set-up as part of the Control phase to measure any out-of-control condition that may affect the big Y-which post training had earned a cost savings of about £25,000/year.

Case two—heat treatment defect reduction—the heat treatment method is flame hardening (Oxy-Acetylene torch). It's used within NTR Ltd's manufacturing system for localised heating of tools 'reclaimed' on the CNC product line. The nature of constraint exhibited by the facility was its inability to guarantee reproducibility and repeatability of tools been heat treated. Parts had to be heat treated thrice (reworked) to achieve the

required hardness level (38-60HRC). The result from the measure phase of case two's gauge R&R that the gauge is acceptable because the total gauge R&R % contribution is 0.42% (<2% acceptance criteria). Furthermore, the gauge system was validated as acceptable because it suggests that the number of distinct category is 21 hence greater than 10 specified in acceptance criteria. Additionally, with a total gauge R&R tolerance of 19%, this further confirmed the acceptability of the measurement system.

Based on the measure phase key affect on the hardness value of the part were identified as the diameter of the part been heat treated, time-to-heat treat, and the torch cone length. In other to understand the relationship between these key inputs that affects the hardness value, an experimental design was setup. The experimental design used a 2 by 3 factorial design. Furthermore, the main effect plot of the experimental design inferred that the hardness property of the part increased with decreasing diameter, whilst an increase in hardness property of the part is directly proportionally to increasing heat treatment time and cone length of the acetylene torch. In the improve phase of the DMAIC methodology, the major output were provision of extensive training for an operator based on the experimental design result, development of a standard operating procedure for heat treating part, and sourcing alternative welding rod with good hardness properties. Post training of a process capability index of 1.13 achieved over an initial index of -0.07 post improvements. Finally, the cost saving attributed to case two was £18,000 per annum.

Further to the continuous improvement initiative Chapter 7 detailed two extra case studies, that is, case three and four. Case three—delivery rate improvement, examined the ship window compliance of NTR Ltd manufacturing system. The base line data presented showed a PPM value of the delivery rate between the first weeks of

September 2006 to second week of November 2006. The mean delivery rate over these periods is 186771, which was about 2.4 Sigma. The project goal/objective was the creation of a process that will significantly increase delivery rates to > 90% and also reduce the panic at month-end.

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Following a well structured improvement programme, development of split handing system, and training of quote handling and goods in/outwards operatives, an IMR chart was set-up as part of the Control phase to measure any out-of-control condition that may affect the big Y-which post improvement, the process sigma for the delivery process improved from 2.5 Sigma to 2.9 Sigma.

Case four—productivity improvement—the case presents some of the solutions to resolving issues relating to extended queues and poor machine and operator utilisation. Furthermore, the case discussed wider implementation of a 5S programme at NTR Ltd,

shop floor re-layout to improve communication within teams, creation of a training centre, development and implementation of training programme for multi-functionality, and other initiatives undertaken to improve NTR Ltd manufacturing system's productivity. Further to developing the a productivity framework for NTR Ltd's manufacturing system, utilising the information produced by database to drive productivity was paramount. Output from the productivity index suggested that a multifunctional work force was required to improve the overall skill base of NTR Ltd. A skill matrix for NTR Ltd's shop operations was developed; the matrix lists all shop floor operators against operations within the manufacturing system. The current % multi-skilled operation is 47%. In CNC milling operation, the number of WIP inventory was reduced from 8 hours to 4 hours by providing training for an operator upstream (Finishing) in turning operation.

This was necessary because the VSM showed that WIP inventory accumulates after welding and before CNC milling for the CNC product line. The principal reason for this being that there was limited number of operators skilled in turning that was NOT constrained by other operation. But by training the operator responsible for CNC products finishing (a process after CNC milling) in turning operation (cycle time for CNC finishing is 8minutes whilst cycle time for CNC milling 55minutes) a 50% reduction in WIP inventory was achieved. Finally, % multi-functionality was increased by 7% and for sustenance of a wider workplace organisation initiative developed at NTR Ltd; a 5S audit framework was deployed. The 5S audit system enable utilisation of rating system to quantify adherence to standard operation as defined with a set of guideline. A good score is achieve if the contribution% is low (<10%) within levels 1-2 in particular and a high contribution% in level 4 (>60%) is considered to be an ideal system. Each work area team leader and the production manager will be responsible for

auditing the manufacturing system and making sure improvements are affected with defined time lines.

8.5 Design, Develop and Implement a CIM Environment at the Case Company

In the last part of Chapter 7, Case five was discussed— CNC/CADCAM integration— CNC/CADCAM strategy was necessary at NTR Ltd because of changes in cutting tool technology (configuration and complexity) hence limitations in the current manufacturing capability which is vastly manual based (about 80% of machining is done manually). The manual machining process at NTR Ltd is highly skill dependent and reproducibility and repeatability of machined parts are limited. The goal for CNC/CADCAM integration at NTR Ltd was not to completely alienate manual operation as sizable chunk of work are more attuned and cost effective to machine manually.

A force field analysis, and risk assessment framework that briefly describes the nature of the constraint and risk within the manufacturing system was conducted. Key output from the analysis includes seamlessly transfer, management and documentation of the organisation's knowledge base , improve product quality, diversify market base and achieve lower manufacturing cost whilst forces restraining the deployment of the CADCAM strategy include the extent of investment required in achieving a truly automated CIM environment: cost are not just limited to CADCAM acquisition but also requirements for machine tool technology that permits multi-axis machining and the need for an integrated measurement system.

In order to gain support for CADCAM integration and perhaps with any change in organisational culture staff buy-in was required and the ability to source a reliable

vendor for the CAD/CAM system. Reliability in this instance was directed at provision of on-going support for the client and continuous product quality updates. Training and education were conducted on utilising the system and a supplier on-going support system was also developed. A comparison of the CAD/CAM system and current conversational programming was also carried out. Typical cases for the CAD/CAM system include minimising manufacturing procedures, processes, tooling, and operations through concepts in CAD/CAM such as parametric and feature-based modelling as against the conversational programming.

Finally on CAD/CAM integration at NTR Ltd, a discussion of the first order won by the company due to its new capability was carried out. The main advantage that the CAD/CAM system afforded in winning the order was the ability to use continuous 3-axis (It is worth noting that the current conversational based programming is only limited to 2-axis milling operation) for machining. The system used its 3-axis spiral cut milling operation and containment strategy to create the required profile. The order's worth was about £50,000 hence representing an immediate pay-off on software and training cost which is about £8,500 and significant return on investment.

8.6 Conclusion

The research question for this thesis was to determine if the integrated manufacturing strategy perspective of Lean—Six Sigma—CIM is applicable to SMME's with job shop type manufacturing systems. In the preceding sections of this chapter the implementation protocols of the integrated manufacturing strategy with financial benefit & organisational changes as been highlighted for the case company. Presented in **Figure 8.1** is an integrated manufacturing strategy framework which summarises the implementation paraphernalia of the Lean—Six Sigma—CIM integrationist perspective

in the case company and also provides a baseline for SMMEs to follow in manufacturing strategy configuration and implementation. From the literature review, it is argued that SMMEs need this framework to enable identification and agreement of an explicit set of objectives for manufacturing as this seems to increase the likelihood of manufacturing strategy formation being more deliberate. Moreover, the framework will also enable SMMEs to understand manufacturing strategy formation routings, influences of incrementalism, culture, and leadership on their business system. The framework's emphasis is on incremental transformation hence it is divided into 4 phases with each phase containing a set of activities.

Integrated Manufacturing Strategy Framework				
	1	2	3	4
Phase	Business Environment	Lean Strategic Planning	Lean Resource Planning	Continuous Improvement
Activities	Establish need for strategy	Establish KPI for IM strategic implementation	Conduct current state value stream map	Develop improvement hopper
	Establish leadership for strategic implementation	Initial education programme on Lean, Six Sigma & CIM strategies	Establish machine and operator capacity and resource baseline	Develop project teams
	Conduct Porter's 5 force analysis and/or PESTAL	Establish production planning modules (BOM, & MPS)	Simulate value stream to establish dynamic state	Conduct extensive training for project teams on Six Sigma framework
	Analysis of the manufacturing system using SWOT	Analysis of manufacturing cost and product cost structure	Develop future state value stream map to eliminate issues from current state value stream maps	Implement individual projects
	Review and GO to Phase 2	Establish profit/value matrix	Review and GO to Phase 4	Look across and lessons learnt
		Establish discounting framework & competitive routing		
		Review and GO to Phase 3		

Figure 8.1: Integrated Manufacturing Strategy Framework

Further to the literature review, it was argued that in developing appropriate manufacturing strategy for a manufacturing system, it is imperative to integrate the manufacturing strategy with the business objectives. Corporate objectives lead to marketing strategy. Marketing identifies appropriate markets, product mix, services and the degree to which an organisation needs to customise and innovate hence enabling the integration of a manufacturing strategy that focuses on critical dimensions typically cost, lead-time, quality, reliability, capacity, production control, product features, design capability, human resources, suppliers and distribution. In phase one (Business Environment) of the integrated manufacturing framework efforts as been made to guide SMMEs in ways to achieve the required level of integration with their business strategy through better understanding of the need for the chosen strategy, establishing leadership for implementation and conducting external and internal analysis of their business system. Subsequent to these activities, SMMEs are required to carry out a review process to ensure a comprehensive understanding of their current state and how they need to proceed to achieve their objectives.

Furthermore, in phase two (Lean Strategy Planning) of the framework, six major activities as been detailed to further guide SMME's in achieving the integrated manufacturing strategy. The first key milestone in phase two is establishment of KPIs which will provide opportunities for standardisation, communication and tracking integration and lean manufacturing initiatives. SMMEs are required to use the KPIs to communicate key manufacturing strategic objectives to all employees and accelerate continuous improvement in their work area. Following the KPIs, an initial education programme of employees on the strategic direction of the organisation should be carried with key elements of lean manufacturing, Six Sigma, MRPII and CIM detailed with their associated benefits to the organisation, and employees involvement protocols.

These activities should be conducted in such a way that allows for support systems that provide the management of process through liberal exchange of knowledge, building of trust and acknowledgement of the heterogeneity in values preferences and interests. Other activities within this phase include developing the organisation's production planning modes, establishing a manufacturing cost and product cost structure which should inform a profit/value matrix and discounting/competitive pricing outline. As with phase one, SMMEs are required to carry out a review process at the end of phase two to ensure a comprehensive understanding of the activities set-out in phase two.

Following the review process of phase two, SMMEs are required to proceed to phase three (lean resource planning) where they are required to carry out detailed steady state current state value stream analysis of their manufacturing systems. This will enable them to understand where non-value adding activities accumulate within the manufacturing system. Further to the initial steady state value stream map, SMMEs are encouraged to conduct dynamic state current state value stream mapping using simulation model to reduce analysis time and potential resource constraints. As there is little spare resource in SMMEs, the dynamic state value stream mapping will further effective strategic deployment. By better understanding of the non-value adding activities, SMMEs are then required to conduct a future state value stream map to mitigate some of the negatives from the current state maps. A review process at the end of this phase is also encouraged to ensure all activities set-out have been achieved.

Finally in phase four, SMMEs are required to establish a continuous improvement environment within their organisation through development of a projects hopper (a central database containing problem statements and potential benefits post implementation) based on non-valuing activities noted from the value stream maps,

business environment analysis in phase one and phase two's discounting structure and manufacturing/product cost structures. For each project in the hopper, SMMEs are required to create project teams centred on those employees within the project's scopes area of responsibilities with an overall project leader (Six Sigma Black Belt) to track, and manage all the projects in the hopper. For those selected/nominated or indicate interest in each of the projects, detailed education and training programme are required to be carried out on lean/six sigma/CIM/MRP II tools and techniques (depending on project scope) pre-project start-up for each team member with project guidance and support from the project leader throughout the project life. On completion of each project, a look across process is encouraged to enable knowledge transfer across the manufacturing system. A review process at the end of this phase is encouraged to ensure all activities set-out have been achieved and an overall review of the integrated manufacturing strategy framework is also required to ensure the organisation is on track.

8.7 Recommendations for Future Work

- Development and implementation of an induction heating system for heat treating products produced at NTR Ltd and the CNC product line in particular. The need for the induction heating and/or alternative hardening system was discussed in Chapter 6. The vision for the induction heating system is to further improve parts hardening consistency. The major challenge however will be development of various Jigs and Fixtures to accommodate the range of products heat treated at NTR Ltd.
- Development and implementation of product characteristics configuration methods to be used with the CAD/CAM software. The configuration should comprise of application of a CMM with digitising and vision systems

capabilities. More importantly, data transfer between the CMM and the CAD/CAM software should be seamless.

- Implementation of a planning and scheduling—MRP II—system. The MRP II system should enable integration of various spreadsheets developed as part of the knowledge-based system (MPS, manufacturing and product cost structure analysis) in Chapter 5.

8.7 Summary

The objectives set for this research project have been successfully achieved. An integrated manufacturing strategy framework was achieved through business environment analysis, lean strategic and resource planning and continuous improvement. Some of the issues from the integrated manufacturing strategy implementation were resolved using a continuous improvement framework that supports lean manufacturing, Six Sigma and CAD/CAM methodologies. The future work and limitations of various strategies have been discussed and recommendations made.

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