The University of Liverpool
The Management School

A framework for the development of reconfigurable simulation models in manufacturing

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Abstract

Simulation Modelling has long been used in the manufacturing environment to enhance design, planning and decision-making process. The strategic importance of delivery accuracy, short delivery times and production flexibility is increasing against a backdrop of increasing cost of raw material, the highly fluctuating demand and short product life cycles of end product. As a result new approaches have been developed to integrate tools such as simulation modelling at an operational level. To achieve this, manufacturing systems and their simulation need to be categorised with a unified formalisation, which makes it possible to describe a wide class of manufacturing systems' components, processes, relationships and conditions.

This research proposes a framework to configure the manufacturing system via a front end system with the unified framework structure before starting simulation modelling. The use of object-oriented approach increases the clarity and ease of manufacturing system description for simulation. The simulation model components are designed in modular continuing the object-oriented approach. The framework will not only hold static data but all the dynamic variables that might need changing frequently for the simulation model to be an operational tool instead of just a planning or design tool.

Four industrial case studies are applied to validate the proposed framework. The use of object-oriented UML diagrams to describe the manufacturing systems into classes has made the framework usable, reusable, reconfigurable and scalable with a short response time. The proposed design system uses a library of classes defined by the conceptual model to construct the design specifications based on the use cases model in similar manufacturing environment. An integrated framework is proposed at the end of the research as future work to enhance the performance of the simulation modelling applications.

Acknowledgements

First of all, I am indebted to my supervisor Dr. H.S. Ismail for his patient and guidance throughout this research. I am grateful for the advice, criticism, and suggestions given.

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Finally I like to thanks my family for supporting me through the long years of research especially my mother, whom had unconditionally encouraged and supported my education. Besides my mother, I would take this opportunity to thank my father and my husband for their kind words and understanding.

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Chapter 1 Introduction

Manufacturers are finding it more difficult to cope with the current volatile environment with the increased prices of raw material and the greater demand for quality and customisation at a lower price. As a result, certain characteristics or qualities are necessary for manufacturing companies to face these challenges and grow. These qualities are being agile, flexible, and scalable thus tuning operations and strategy to market needs. The response to customer demand and market performance is important. In addition to the turbulent environment from a market demand, manufacturing companies now faced many other challenges like globalisation, social responsibility, environmental responsibility, rapid development of new technologies and knowledge management.

In any organisation there are always opportunities for restructuring and improvement to operations. This is more so needed when the business environment is constantly changing and opportunities arise. Restructuring covers a wide range of activities and could happen in any intermediate steps in between starting from market research to final product launched. However there are always risks associating with restructuring in any company especially when it involves physical changes for example restructuring the layout of a factory. Restructuring the factory is costly and sometimes high penalties are attached to the changes and movements of machinery. Hence process design and analysis is critical before any work is carried out. As the systems get larger, the number of possible changes increases, making the ideal solution less obvious. As a result a number of techniques and tools are needed to analyse the possible impact of any change on the system. Key amongst these is modelling techniques.

There are mainly two types of modelling techniques and tools. The first type is techniques and tools that map out the existing system and how the elements of a system interact and the second type is for identifying the behaviour of the system under different conditions. The first type is a static representation and more focused on the nature of the relationship between elements while the second is more concern with the dynamic behaviour of the system. Simulation modelling approach can be categorised in both types of tools depending on the applications.

Simulation modelling approach emerge as a suitable tool to represent a manufacturing system for analysis and used as a decision support tool. This is more so as computing speed has become sufficiently high to analyse more detailed systems within a practical time frame. Therefore, the risks and investment involved for testing the configurations of solutions can be minimised using the simulation models. However, vast amount of data are required to input to the simulation model, and the results generated is not the solution to the problems, and most of the time is a validation for decision policies.

A survey of the literature (Baldwin et al., 2000) has shown that there is still low usage of simulation modelling tool in manufacturing industries. Factors like lack of understanding and expertise in simulation modelling are some of the reasons. A higher level of manufacturing system representation prior to simulation modelling is needed for the expert of a manufacturing system to describe and process model the manufacturing system. There is lack of suitable modelling tools in manufacturing environment (Weston, 1999). The difficulties of capturing and reusing semi structured information and design of system limit the applications of simulation modelling. The process description approach should be easy to understand, simple to use and could contain and represent all the requirements for analysing the system more thoroughly. Besides that the reconfigurability and extendability of the approach in a common platform are important for the approach to advance and be accepted.

1.1 The aim of this research

The aim of this research is to provide a framework for clear, well structured and usable representation of manufacturing entities for process improvement using a simulation model in a manufacturing environment. The research provides both theoretical recommendation through researching into other relevant work and practical application of the proposed methods in industrial cases.

Most specifically, this research aims to propose an approach that covers:

- Define the process of data collection in complex manufacturing system analysis
- Simplify the representation of complex manufacturing systems with object-oriented classification
- Standardise the presentation of common manufacturing system behaviour using Object-Oriented UML diagrams
- Provide a dynamic modular approach in generating results using simulation modelling techniques
- Functional applications in the real world with industrial case studies
- Propose a framework incorporating new advance in technology utilising web based approaches.

1.2 Contribution knowledge

These are the key areas in which this research aimed to add to existing knowledge and provide fresh insights.

- Review the current status of simulation modelling projects.
- Identify the current gap and issues in pursuing simulation modelling projects in manufacturing environment

- Understand the tools and techniques which can enhance manufacturing system analysis and simulation modelling projects.
- Demonstrate how UML can be used to represent the manufacturing system in terms of physical processes and information flow.
- Explore the proposed UML approach in industrial case studies.
- Demonstrate the new modular approach in simulation modelling with actual real system.
- Provide the range of data required in a manufacturing system study and propose a data collection approach.
- Propose a framework to integrate the needs in a simulation modelling project and fill the gap with current technology.
- Validate that the proposed representation and design can be applied in real system.

1.3 Research Methodologies

A research methodology defines what the activity of research is, how to proceed, how to measure progress, and what constitutes success. In this chapter, a few general research methodologies are reviewed, the methodology adopted and the directions of the research are illustrated. Research Methodologies are applied from planning the research and developing the hypotheses to carrying out the fieldwork and analysing the findings. In this research, the case research approach in operation management is applied.

1.3.1 Case Research in Operation Management

The methodology applied in this research is a case based research approach. Case research is the method that uses case studies as its basis for different types of research purposes such as exploration, theory building, theory testing and theory extension/refinement.

A case study is a history of a past or current phenomenon, drawn from multiple sources of evidence. It can include data from direct observation and systematic interviewing as well as from public and private archives. In fact, any fact relevant to the stream of events describing the phenomenon is a potential datum in a case study, since context is important (Leonard Barton, 1990).

Voss et al. (2002) commented that a case study is a unit of analysis in case research. It is possible to use different cases from the same firm to study different issues, or to research the same issue in a variety of contexts in the same firm. Operations management is a very dynamic field in which new practices are continually emerging. Case research provides an excellent means of studying emerging practices and theories. A case research approach can be applied in many research structures like experiment, in-depth case study, quasi-experiment, large scale sample of population and much more. Areas in which case research methods cover (Voss et al., 2002) are:

- **Exploration.** In the early stages of many research programmes, exploration is needed to develop research ideas and questions. Many doctoral theses begin with one or more case studies in order to generate a list of research questions that are worth pursuing further (Frohlich, 1998).
- **Theory Building.** Theory can be considered as being made up of four components: definitions of terms or variables, a domain-the exact setting in which the theory can be applied, a set of relationships and specific predictions (Wacker, 1998). The purpose of theory building is to identify or describe the key variables, identify linkages between variables, and identify why these relationships exist.
- **Theory Testing.** Despite its limited use for theory testing, the case study research has been used in the operations management field in order to test complicated issues such as strategy implementation (Pagell and Krause, 1999).The purpose of theory testing is

to test the theories developed in the previous stages and predict future outcome. When case study research is used for theory testing, it is typically used in conjunction with survey-based research in order to achieve triangulation, to avoid sharing weakness (Frohlich and Tsikriktsis, 2002).

- **Theory Extension/Refinement.** Case studies can also be used as a follow-up to survey based research or another previous research in an attempt to examine more deeply and validate previous empirical results. The purpose is to better structure the theories in light of the observed results.

1.4 Research Area

1.4.1 Simulation Study Project

A simulation study is a system analysis activity that requires careful and structured planning to obtain the best results in a short span of time. Over the years a number of approaches to developing simulation models had been proposed in (Banks et al., 1995; Carson, 2003; Law, 2003). Banks et al. (1995) proposed a structured step-by-step approach to conduct or manage a discrete event system simulation project as shown in Figure 1.1. The first section begins the simulation study with problem formulation, setting objectives and overall project plan, model conceptualisation and data collection. Similarly, Law (2003) proposed a seven step approach (Figure 1.2) beginning with formulating the problem and collecting the information and data before any design work on the simulation modelling should commence. These preparation steps at the start of a simulation study are crucial to ensure the validity of the model created. Although Carson (2003) did not create a step-by-step flowchart, data collection, cleansing and analysis is mentioned for a sound simulation study.

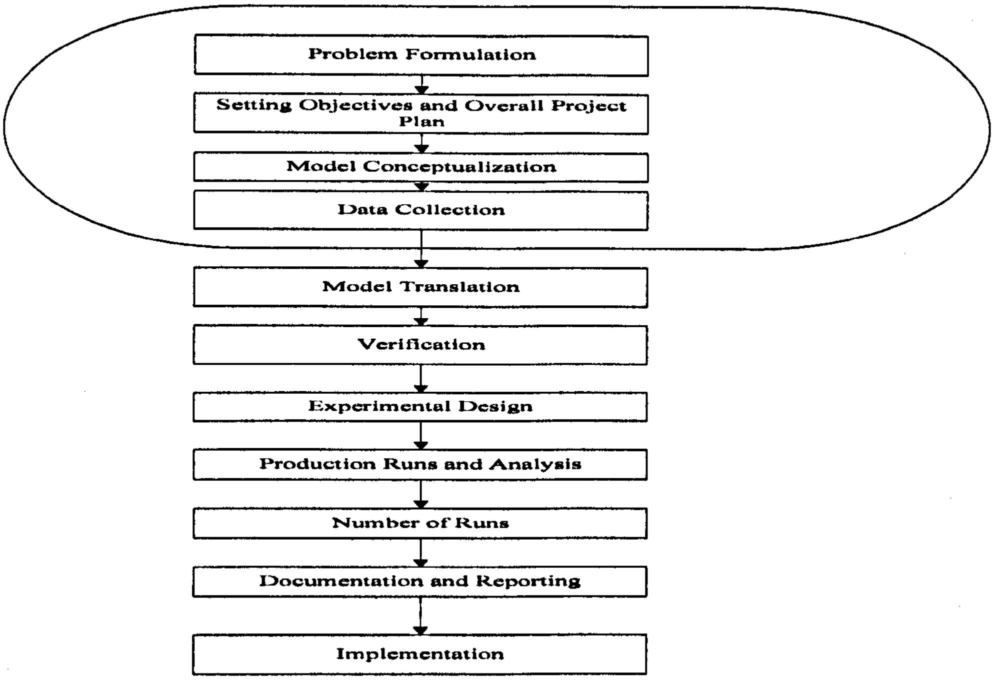


Figure 1.1 The Approaches Adopted by Banks et al. (1995)

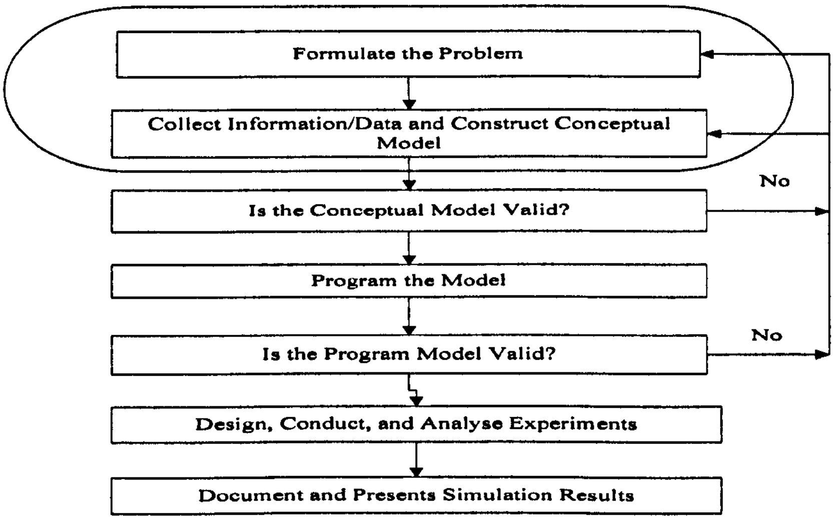


Figure 1.2 The Seven Steps Approach for Conducting Successful Simulation Study by Law (2003)

Data sources for model development include databases, manual records, automatic data collection systems, sampling studies and time studies. It is stated from practice that it is seldom that all or even much of the needed data is readily available or when available is of the desired quality. In such circumstances, much effort and resources are required to collect the data or extract it from the existing information systems. Law (2003) stated that a simulation analyst requires a minimum, knowledge of simulation methodology (model validation, selecting the correct probability distributions for events, design and analysis of simulation experiments, etc), probability theory, statistics, project management, as well as the detailed operations of the system being studied.

The model development is further complicated by the fact that several scenarios would need to be generated to address possible changes and improvement to the system being modelled. This is initially due to the difficulty in predicting all possible scenarios that would emerge as the model is used. Consequently this has an impact on the model structure in terms of flexibility and adaptability to future changes. A conclusion that can be derived from the above sources and the literature review in Chapter 2 suggested that an extra layer is required for creating a modelling approach that address the issues if constructing flexible models that are not simulation software dependent.

An IDEF approach has been adopted for simulation model development. IDEF is a tool that provides detail analyses of the system with all the requirements like input, output, control and mechanism (Wu, 1992). In this research, IDEF diagrams are generated to show in more detail the steps described in Banks et al. (1994). The development stages of a simulation modelling project with a step by step procedure proposed by many experts to create a successful simulation project is illustrated in Figure 1.3.

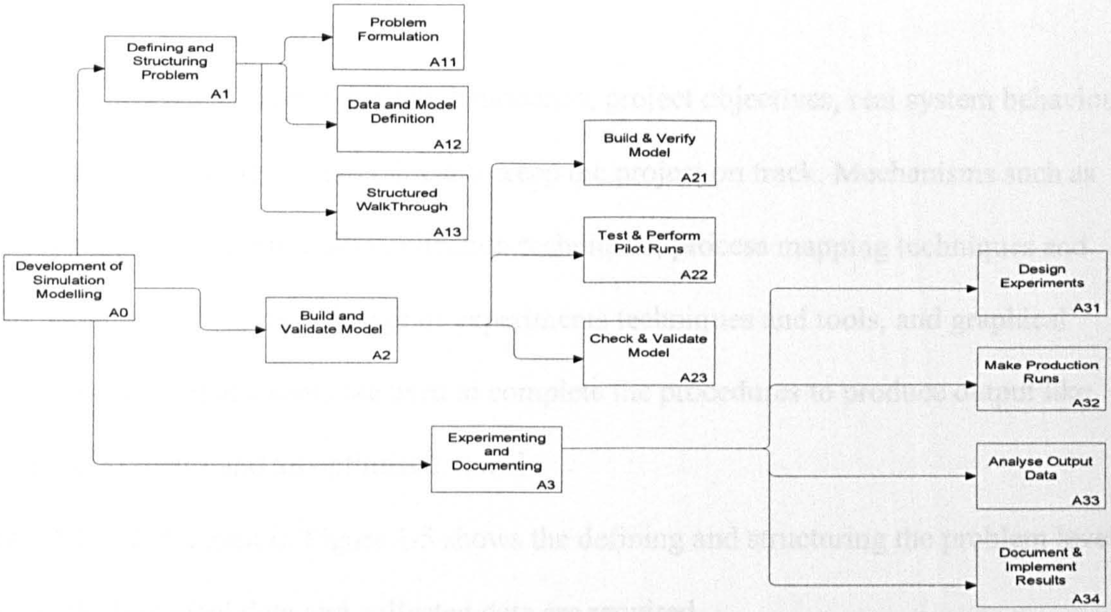


Figure 1.3 Tree Structure View for the IDEF Diagram of Simulation Models

The top layer AO- IDEF diagram illustrated the process of developing a simulation model (Figure 1.4). Inputs such as historical data, collected data, and modelling and analysis knowledge are required to start the simulation project with the proposed method.

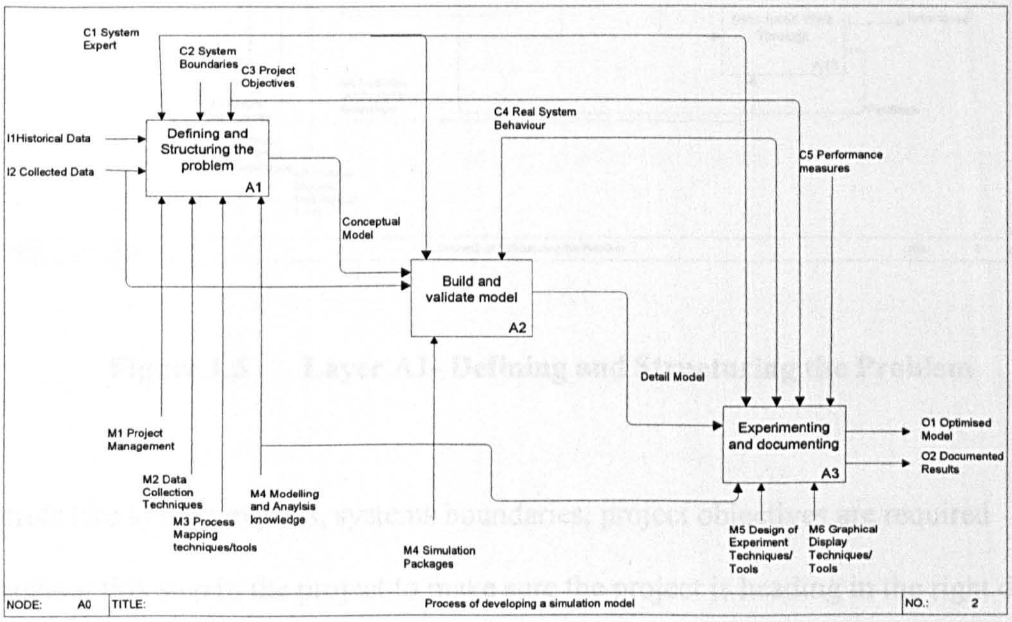


Figure 1.4 Layer A0- Process of Developing a Simulation Model

Controls like system experts, system boundaries, project objectives, real system behaviour, and performance measures are critical to keep the project on track. Mechanisms such as project management skills, data collection techniques, process mapping techniques and tools, simulation packages, design of experiments techniques and tools, and graphical display techniques and tools are used to complete the procedures to produce output like documented report and an optimised model.

The A1-IDEF diagram in Figure 1.5 shows the defining and structuring the problem level. Inputs like historical data and collected data are required.

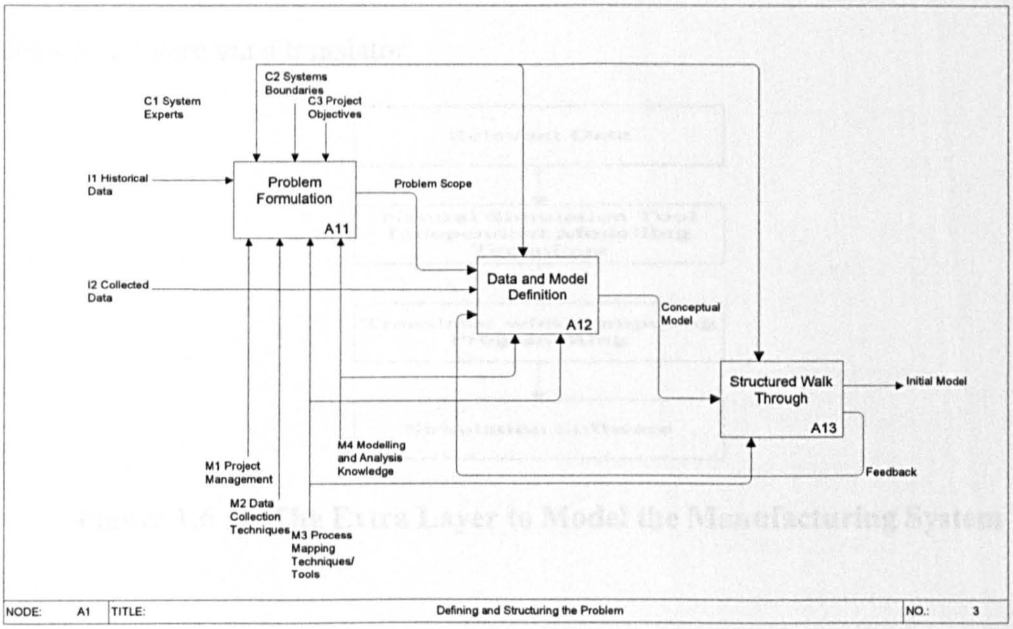


Figure 1.5 Layer A1- Defining and Structuring the Problem

Controls like system experts, systems boundaries, project objectives are required throughout this step in the project to make sure the project is heading in the right direction. The supporting mechanisms are project management skills, data collection techniques and process mapping techniques and tools, the data collection and problem formulation steps.

The authors (Banks et al., 1995; Carson, 2003; Law, 2003) stressed the importance of a structured manner of conducting and managing the simulation study with problem formulation and data collection to begin with. The steps highlighted with the circle in Figure 1.1 and Figure 1.2 provides the basic steps to enable the collection of all the relevant data including system description and model requirement. The relevant data contributes to the neutral simulation tool independent modelling technique which is the primary focus in the research. The main focus of this research is to address how it is possible to provide a structural approach to data and model formulation (A12 in the IDEF diagram in Figure 1.5) that is robust and flexible. In Figure 1.6, the neutral simulation tool independent modelling technique describing the manufacturing system is send to the simulation software via a translator.

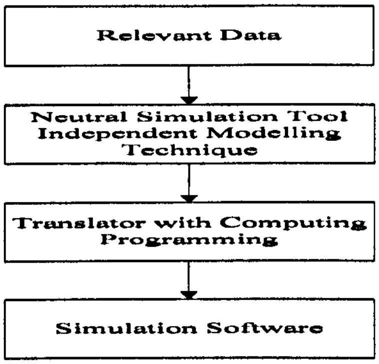


Figure 1.6 **The Extra Layer to Model the Manufacturing System**

In the Winter Simulation Conference (2002, 2003, 2004, and 2005), a number of issues were raised as important features for future simulation software packages development:

- Interactivity when the model runs to change parameters;
- Reusability to increase productivity and consistency of design;
- Scalability to be able to model large complex model;
- Visual Transparency for better and easier control;
- Connectivity and Plugs in to other software like Visio and Excel;

- Extendibility as an open source for integrated environment;
- Browser-based simulation to be shared across internet network;
- Customer Support and future upgrades made available easily;

Some of the issues suggested above have provided the basis for this research and are incorporated in the proposed framework. One of the problems identified in simulation modelling projects is the difficulty in maintaining the project consistent with the current status of the system. This can be solved with a rapid reconfiguration approach as proposed by N.K. Khoo (2003) who provided a system structure, which comprises of product configurator, cell configurator, simulator and evaluator shown in Figure 1.7. The system focuses on product clustering and using fuzzy logic as a module for optimisation in the evaluator.

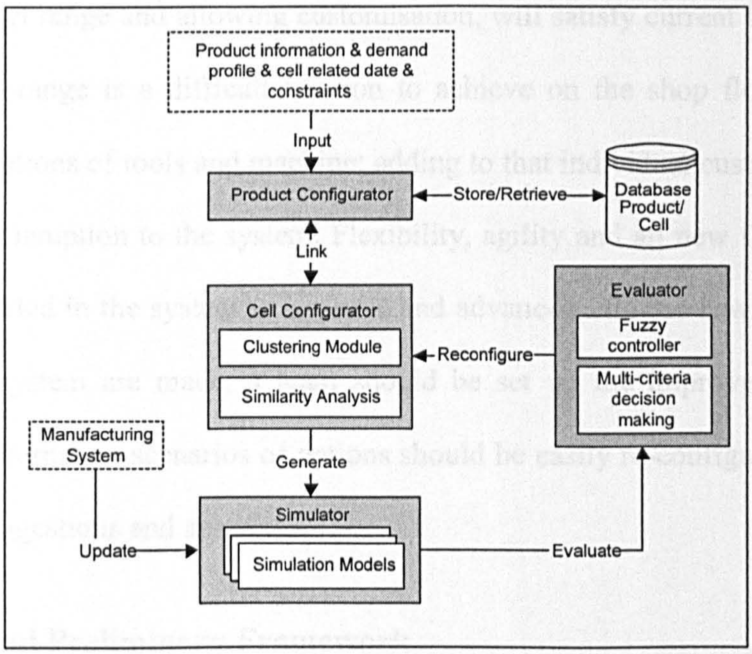


Figure 1.7 System Architecture by N.K. Khoo (2003)

This study had emphasis on a lower level the detailed coding required to integrate the various system components. Object-oriented approaches are used in the system developing process to define cellular manufacturing system, products, processes, and the simulation model components. The system architecture does not provide a higher layer description of the generic manufacturing environment. Auxiliary activities of a manufacturing system like changeover and maintenance have also not been covered by the system. The focus of the configurator is rather specific to the problem area and not the entire system, which might be the first modelling approach to locate the bottleneck section. This research builds on the effort by Khoo to propose a higher level framework to describe manufacturing systems. Theory extension/refinement to better structure the work of Khoo in light of the observed trend is also carried out.

An organisation can only be successful if it makes the products that customers want. With today's media and technologies, the knowledge, needs and expectations of the customers are beyond imagination. Only continuous improvement of quality and services, ever expanding product range and allowing customisation, will satisfy current buyers. A highly scalable product range is a difficult mission to achieve on the shop floor, all different process configurations of tools and machine; adding to that individual customisation create considerable of disruption to the system. Flexibility, agility and all new found techniques should be embedded in the system to improve and advanced into the new era. Before any changes to the system are made, a team should be set up the improvement plans and strategies. The alternative scenarios or options should be easily re-configured to provide a wide range of suggestions and answers.

1.4.2 Front End Preliminary Framework

The extra layer that is required in the simulation study process has set the scene for the preliminary front end framework (Figure 1.8) proposed in this research. The proposed framework starts with the relevant data which include the model requirements and system descriptions to model manufacturing system with the neutral simulation tool independent modelling technique. Model requirements data is required to describe the scenarios for the project. This data are send to a translator which might be an expert translating it manually or in future an automatic translator engine. More interpretation of the system parameters are sent to the scenario translator. The system description is used to build the simulation model. The experimentation model created is subject to various scenarios for experimenting and generating results. Results are evaluated and new scenarios are experiment in the scenario model.

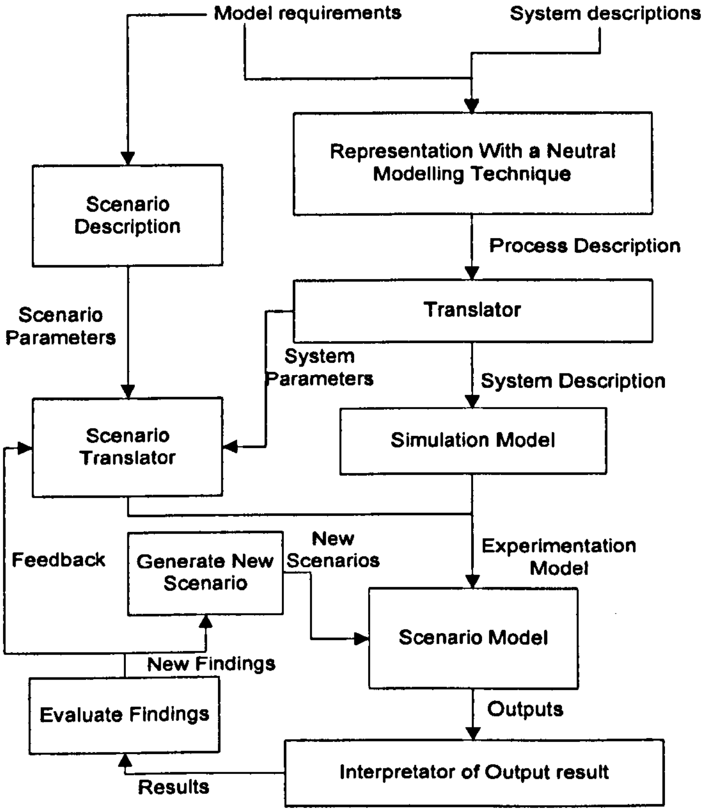


Figure 1.8 Proposed Preliminary Front End Framework

Interpretation of the output results is done by an expert or maybe an optimising programme. The findings are evaluated and send to the scenario translator as a feedback to the user. New findings prompt to generate new scenarios to be tested in the scenario model.

1.5 Research Issues

1.5.1 The following are some of the characteristics of the proposed framework

- *Logical Natural Mapping* – Develop an UML based Object-oriented simulation framework (OOS) with a logical neutral mapping to physical manufacturing objects to represent the interactions between parts and processes in a manufacturing system.
- *Customisability* - Develop an OOS modelling environment that permits programming –free model creation and problem solving approaches in a single base model.
- *Reusability* - Develop a reusable library of classes to support modelling of complex manufacturing system
- *Efficiency*- Develop simulation models that produce output in less time and more experimentation options.
- *Ease of maintenance* – Construct a class library that is more reusable and easily comprehensive, and simplify the description of complex systems.
- *Generalising* – Create templates of various manufacturing system architecture

1.5.2 Research Objectives:

- To investigate the present status of process mapping approaches for manufacturing simulation models and identifies a structured and reusable framework for such applications.
- Using the object-oriented approach to directly map manufacturing systems to simulation modelling.
- Create a generic system component and best practice templates libraries.

- To review the studies and projects carried out in academic institutions, government-sponsored centres, university and private consultancy manipulating optimisation for practical applications.
- The integration of the simulation modelling with an automated user interface for scenario generation on standard software.
- Propose advanced development tools to integrate the entire system and building blocks for a middleware environment for distributed simulation and visualisation in manufacturing using a common platform.

1.5.3 Research Issues:

- Manufacturing systems require more dynamic simulation solutions that can handle complexity, velocity and scalability.
- An Integrated simulation framework will provide less technical but more accurate decision making support.
- This approach enables the rapid development and analysis of scenarios to respond an increasingly turbulent manufacturing environment.
- User friendly interface to create better customized software to customer needs.

1.5.4 Major Tools Used

- Microsoft Office Package with Words for documentation, Excel for spreadsheet, and Access for database.
- Witness Simulation Package (discrete simulation modelling package) creating simulation model for all case studies in this research.
- Microsoft Visio (Microsoft diagramming software) for mapping manufacturing system with UML approach.

- UML diagrams (object-oriented methodology) methods to describe the manufacturing system.

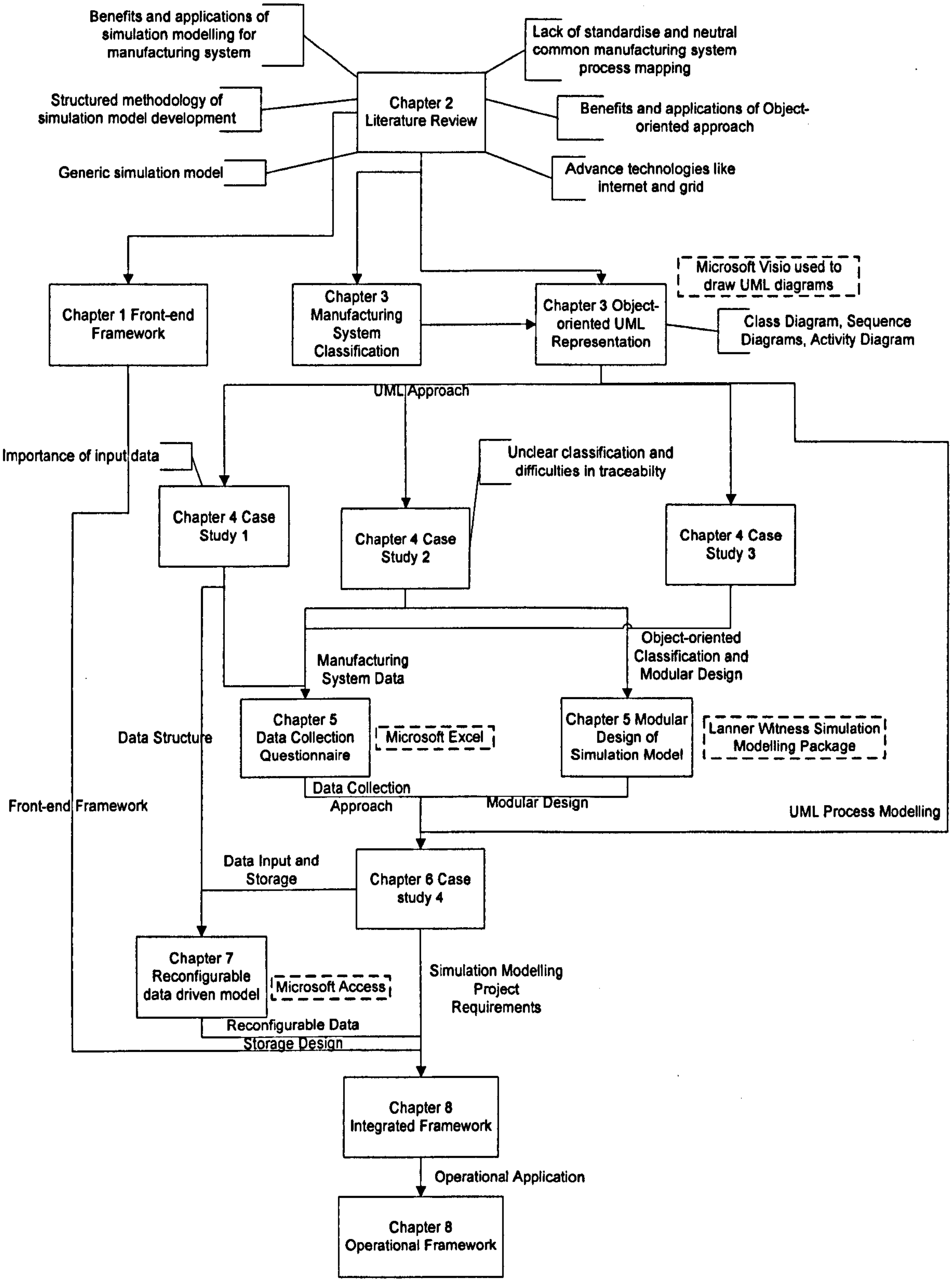


Figure 1.9 Research Methodologies

1.6 Summary of Key Chapters

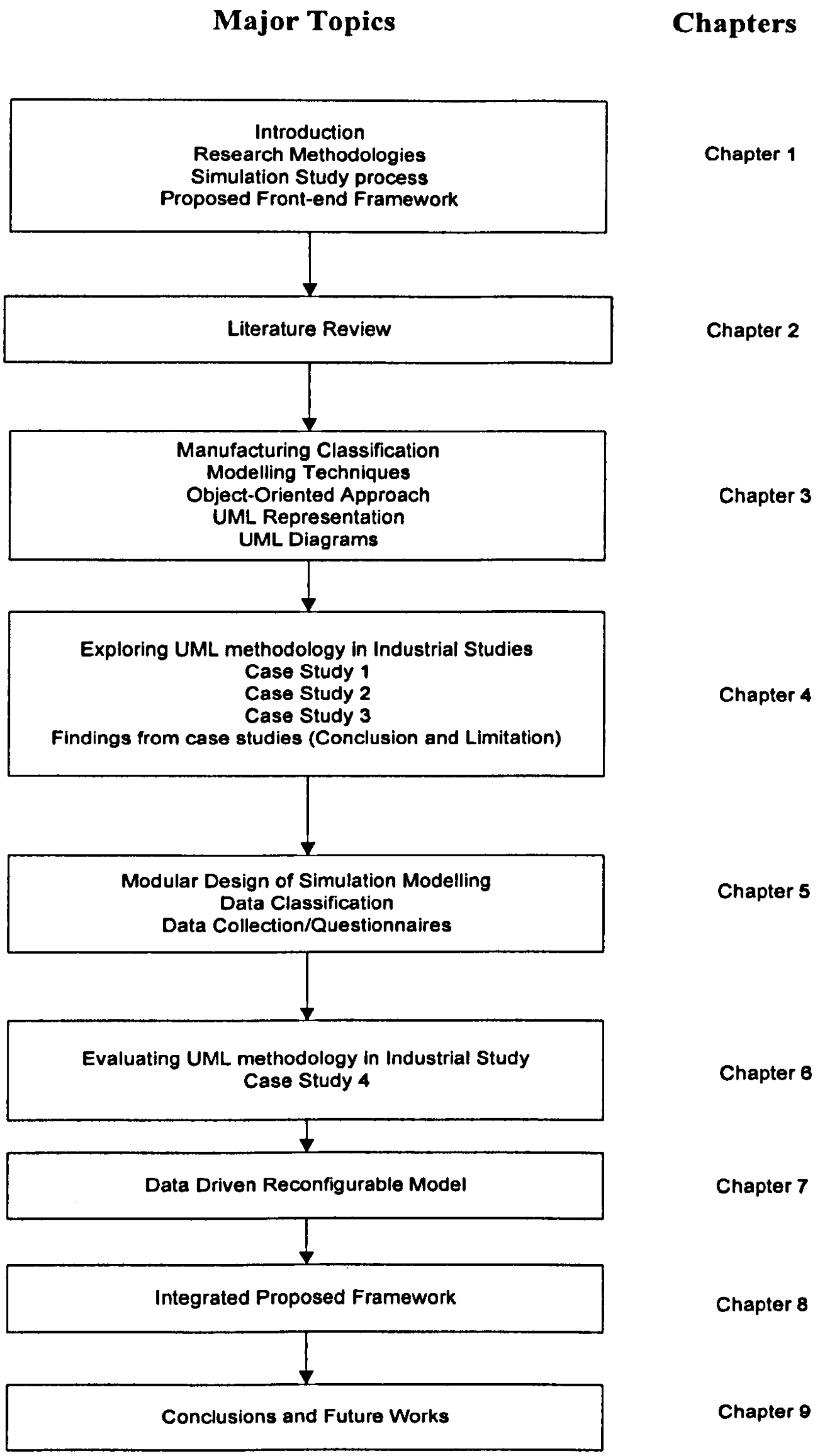


Figure 1.10 Summary of Key Chapters

1.6.1 Chapter 3 Manufacturing Classification with Object Oriented Representation

This chapter starts with classification of the manufacturing environment. The philosophies and different type of manufacturing systems are investigated. The lack of classification and standardisation in process modelling of manufacturing systems in simulation modelling project has prompted the further research in this area. The classification of manufacturing systems is described. Important techniques of process mapping and modelling are explored and discussed. In this chapter, object-oriented process mapping techniques are also presented. The object-oriented approach to modelling a manufacturing system is explained and illustrated. Elements of manufacturing systems are separated into their respective classes and are described. The first section introduces the importance and contribution of UML diagrams. The second section explains design patterns. The third section presents the modelling concept involving a manufacturing system. The objectives of this chapter is to explicitly represent factory control systems by encapsulating decision making in objects as part of the architecture, providing scenario generation utilising the existing best practice models.

1.6.2 Chapter 4 Exploring UML methodology in Industrial Case Studies

A number of company case studies are provided to support and validate the proposed process mapping techniques. The UML method is explored with different manufacturing systems. Case study 1 is a beverage manufacturer with product ranges from canned and bottled beverages to a mixture of powder for vending machines. This project started with the integration of a simulation model with an Excel Spreadsheet for input and output generation. The problem studied in this case study is specific to a line with blending and packaging machine for powdered products. The changeover required a substantial amount of time; hence the product mix is important. And it was necessary to identify the best production mix to reduce down times. UML diagrams are used to represent the simple manufacturing cell. This case study has demonstrated the benefits of integrating simulation model with other software as user interface for data input and output results display, and the importance of having reasonable amount of quality input data.

Case study 2 is a foam manufacturer. This is a specialised manufacturing environment with a process type layout. The optimum number of runs and combination of tools and products are critical. The complex control system is represented with UML class and sequence diagrams. Simulation model has precisely provided the desired results for process improvements. The traditional approach of simulation model design in this case study shown the unclear definition of manufacturing elements.

Case study 3 is an office stationery manufacturer. The studied area is carried out on a single product semi-automated line. The synchronisation of the line and the assignment of labour are critical in this project. The operations are process mapped with the proposed UML tools. The limitation of UML diagrams to represent the simulation models created with traditional approach is discussed and prompted the modular design of manufacturing elements in simulation model.

1.6.3 Chapter 5 Modular Simulation Modelling and Data Collection

In this chapter, modular design of manufacturing system components for a simulation modelling project is presented. The primary reason for building manufacturing simulation models is to provide support tools that aid the manufacturing decision-making process. Simulation models are typically a part of a case study commissioned to address a particular set of problems. The objectives of the case study determine the types of simulation models, input data, and output data that are required. General model libraries and interface data standards could simplify the simulation analyst's job and significantly improve the simulation case study process. The object-oriented representation of manufacturing system in earlier chapters triggered the modular design of elements in the simulation models. The modular design encourages reusability and is easily extended to customise each system. From various case studies on different manufacturing companies, the characteristic and attributes are summarised to form a list of questionnaires to enable a more complete data collection process that can be carried for manufacturing studies or simulation projects.

1.6.4 Chapter 6 Evaluating UML methodology in Industrial Case Study-Case Study 4

This case study began applying the proposed methodologies. Case study 4 is an automotive part manufacturer. The highly competitive and challenging automotive market have driven the manufacturer to re-design the production with high technology automated machines to cope with high capacity demand and reduce overhead costs in the long run. The large quantity and wide range of manufacturing components in this case study provides a good example to validate the process mapping technique and a modular design of simulation element proposed in this research. The outcome of this project had validated the benefits and feasibility of the proposed approaches.

1.6.5 Chapter 7 Data Driven Reconfigurable Model

A reconfigurable database is created for case study 4 in Chapter 6. The design and concepts continues the Object-Oriented approach in classifying data. This chapter illustrated the details of the user interface, forms, tables, queries and macro created for this database. The benefits of the reconfigurable modular database are explained.

1.6.6 Chapter 8 Integrated Proposed Framework

With the benefits and limitation of the front end proposed framework in Chapter 1, an integrated framework with front end process mapping techniques and back end elements of optimisation are proposed for future work. The proposed integrated framework facilitates the complete cycle for better simulation modelling projects. This chapter illustrates the integrated proposed framework for an operational simulation model instead of a one-off design and planning tool.

1.7 Summary

Reconfiguration is important for a company as it attempts to respond to ever changing needs of the current market. Following on from the topic of Object-oriented techniques, libraries can be developed for reuse or exchange. This can provide a way of sharing the burden of developing simulation objects. An Object-oriented approach allows the system model to be re-configurable as well as scalable. Time and effort are cut down tremendously. Using UML as a vehicle, libraries of simulation models or simulation functionality (e.g. a different type of process machine) could be developed representing a wide range of functionality.

The literature review provided a basis for this research proposing a framework for the study of manufacturing systems. The research objectives and tools required are identified. The focus of this research is on the front end of the simulation modelling project. The overview of the system is described. Each of the following chapters explain the approach proposed in the framework like object-oriented UML representation of manufacturing systems, modular design of simulation modelling elements, the structured manner of data collection for manufacturing environment, the data driven reconfigurable model and the industrial case studies applied in this research.

Chapter 2 Literature Review

This research focuses on the use of reconfigurable simulation techniques in supporting manufacturing system design and improvements. A general overview of manufacturing system issues is reviewed. Development study to enhance the manufacturing systems with simulation modelling is of great interest. This study now encompass the object-oriented approach with reconfiguration, optimisation and modularity criteria to rapidly assist the decision making process. Process Mapping techniques are important to a manufacturing system study. The vast selections, applications, strengths and weaknesses are reviewed. Computing technologies of modern age have enabled many proposed ideas to be realised. This chapter also explored the possibilities of current technologies and development work to benefit the research.

Certain sections are not directly used in this research; they are, however, included to provide a better understanding of the current technologies and techniques.

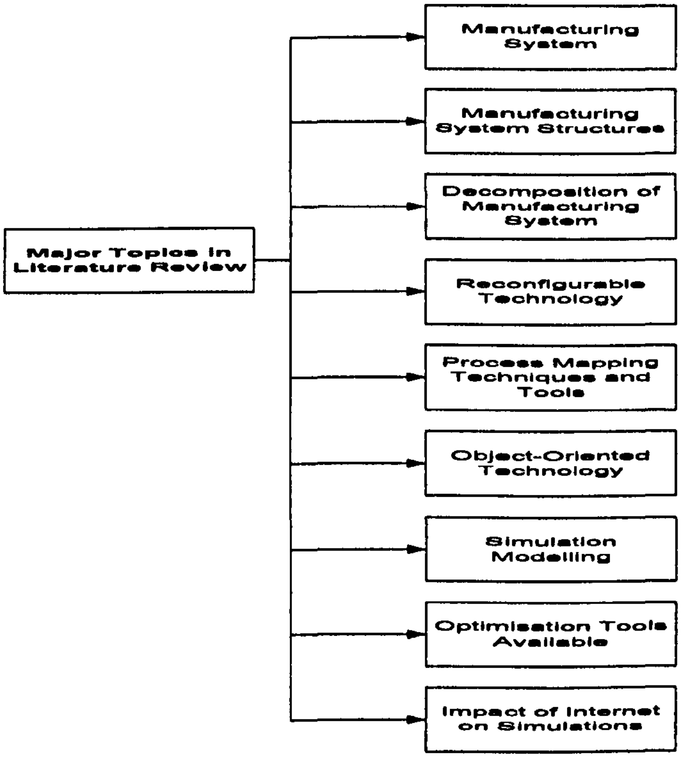


Figure 2.1 Overview of Literature Review

2.1 Manufacturing Systems

This chapter starts with understanding of the manufacturing system, the elements, concepts and philosophies in the manufacturing environment. A manufacturing system usually employs a series of value-adding manufacturing processes to convert the raw materials into more useful forms and eventually into the finished products shown in Figure 2.2. In proposing a framework for modelling manufacturing systems, it is crucial to have an understanding of the behaviours, problems and the current best practice philosophies and tools. This will enable to provide a more complete design and planning decision.

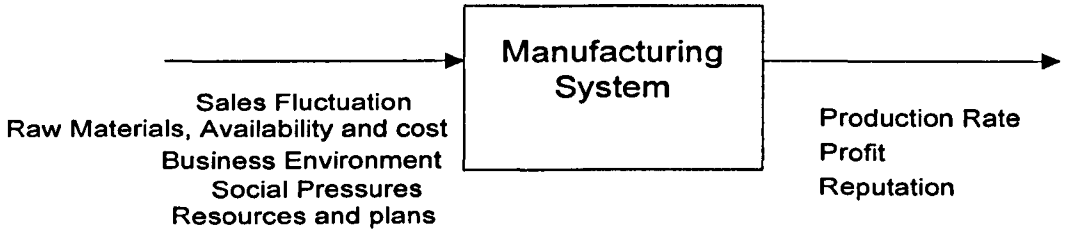


Figure 2.2 Overall View of manufacturing system (Parnaby, 1979)

Over recent years a number of excellent publications have emerged which examine the manufacturing system from academic and theoretical perspective. These have made an important contribution to the development of thinking on the subject.

The strategic importance of delivery accuracy, short delivery times and production flexibility is increasing with the highly fluctuating demand and short product life cycles of end product putting greater pressure on manufacturing system to improve. In the following section, the characteristics and trends of the new philosophies in manufacturing environment are introduced and reviewed.

The traditional approach to managing a factory is delivering the goods to the customer in time and in good quality. Production planning and scheduling, and quality management are used to deliver those goals. As the industry developed, and the ever-changing demands of the market, manufacturers have to deliver a vast diversity of goods and services in order to satisfy the needs and requirements. Improvements on the manufacturing shop floor are expanding to address more issues to enhance the performance of the manufacturer to compete in the market. Factories used 5S and layout design like cellular organisation to optimise the work place. Other approaches like Lean and Agility are deployed to increase competitive advantage. Just in Time (JIT) and Kanban are evolving control approach in the manufacturing shop floor to minimise waste and increase efficiencies.

2.1.1 Toyota Production System (TPS)

Various manufacturing systems structures are reviewed to solve problems emerging from facility shortage or disorganisation. Toyota Production System (TPS) have been introduced to manufacturers worldwide (Sugimori et al., 1977). The idea of waste and what is waste had been redefined and classified by Taiichi Ohno (Ohno, 1988). He had also introduced JIT and Lean operations in Toyota Production System (TPS). The seven wastes are identified are

1. Overproducing: Too early, too much, just-in-case.
2. Waiting: Materials queuing, not moving, people not productively employed, expediting.
3. Transporting: all materials movement, double handling.
4. Inappropriate processing: Too fast, too big, too many variables, one big machine instead of several smaller ones.
5. Unnecessary inventory: Stores, buffers, batch sizes and their control systems.
6. Unnecessary motions: Reaching, bending, exertion, excess walking, excessive turns to loosen, unpack.

7. Defects: Rework, rejects, unnecessary inspection, consequences of not doing it right the first time.

But Bicheno (2000) states that there are also seven other new wastes in addition to seven mentioned above and they are:

1. The waste of untapped human potential.
2. The waste of inappropriate systems.
3. Wasted energy and water.
4. Wasted materials.
5. Service and office waste.
6. Waste of customers' time.
7. Waste of defecting customers.

After clearly identifying and successfully eliminating the waste in the manufacturing system, JIT control is put in place for system synchronisation reducing redundancies and extra stock in the system. Many people have regarded the Kanban system as a JIT system. It is however, not totally true. JIT is a management philosophy rather than a physical system. Kanban is only a controlling activity that is governed by the JIT philosophy. The definition of JIT, originated by Ohno (1988), is defined as "the basis of Toyota production system on which the right parts are needed in an assembly line at the time they are needed and only in the right amount" to achieve "the absolute elimination of waste". The JIT philosophy encompasses not only Kanban but also involves continuous improvement, people involvement, set-up reduction etc, see Figure 2.3

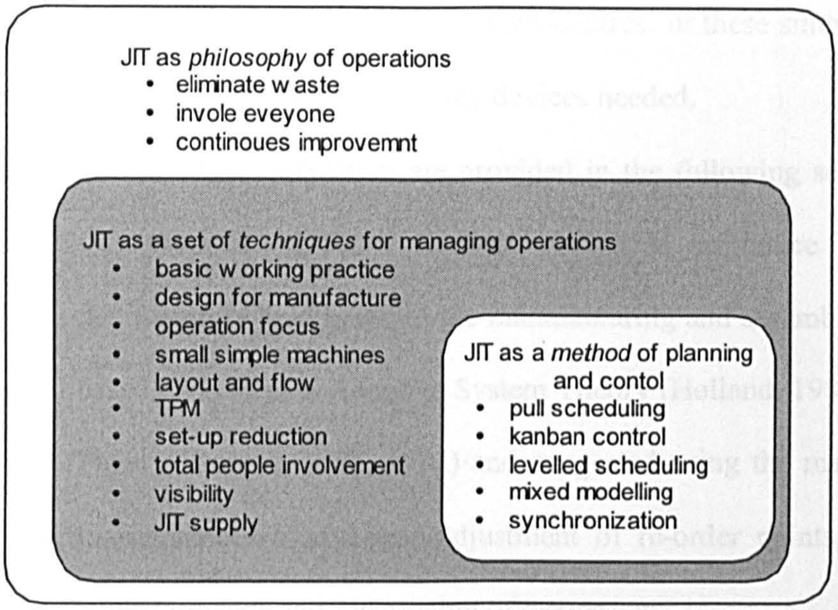


Figure 2.3 JIT philosophy

The successful implementation of the Kanban system has greatly reduced both inventory levels and lead times. However, Hall (1981) points out that "*Kanban is intrinsically a system for repetitive manufacturing. It will not work in a shop controlled by job orders*". It appears to be most suitable for repetitive manufacturing environment (Monden, 1983). For this reason, a new pull-based production system called constant work-in-progress (CONWIP) is suggested (Spearman, 1990). Its main justification is to extend the scope of JIT manufacturing to systems where Kanban is inadequate. Kanban is not useful in an environment where expensive items are rarely ordered, since it would require at least one of each kind of item to be in inventory at all times. CONWIP instead limits the total inventory of all part types in the system and allows part type mix and inventory locations to vary as appropriate.

Kanban is the Japanese term for card or signal; it is a simple controlling device that is used to authorise the release of materials in pull control systems such as those used in JIT. It is important to note that with stable and level production schedules, priority decisions (which governs how orders are released each day, when orders are released, and the sequence of orders) are routine; thus, the shop floor planning and control are reduced to planning and controlling the movement of the orders between work-centres. In these simple scheduling situations, visual signals and Kanbans are the only devices needed.

Some proven cases of Kanban application are provided in the following section. Haslett and Osborne (2000) proposed using a Kanban system to introduce stability and predictability into the inventory held between the manufacturing and assembly operations. They investigated based on Complex Adaptive System Theory (Holland, 1989; Kauffman, 1989) and Chaos Theory (Lorenz, 1972, 1993) and suggested using the manager's local rule, through the consequences of dynamic adjustment of re-order points, resulting in improvements to the performance and functioning of the system.

The 5S housekeeping approach is the basic housekeeping discipline for lean, quality and safety. Before any improvement plans are introduced, the arrangement of the workplace needs to be addressed with 5S to see the full benefit. Bicheno (2000) has provided a cause and effect figure for 5S implementation (Figure 2.4).

Lean Thinking is introduced as a philosophy, not a system or a technique. It is about simplicity, flow, visibility, partnership and value.

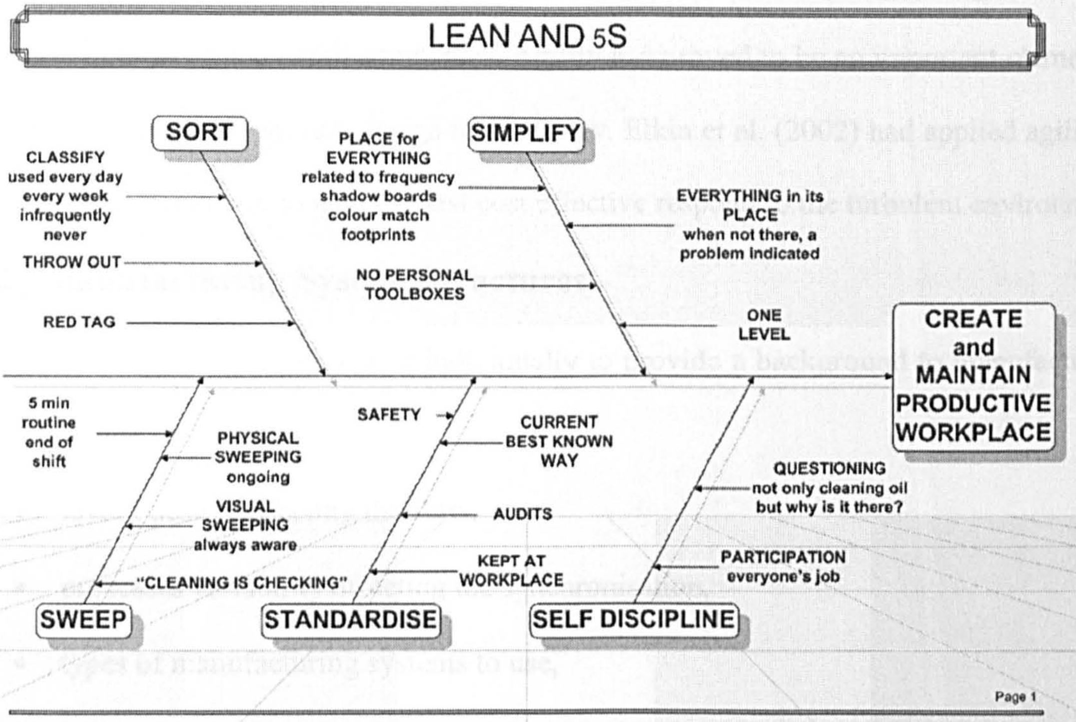


Figure 2.4 Cause and effect diagram of 5S implementation. (Adapted from The Lean Toolbox by John Bicheno)

2.1.2 Agility

One of the major criteria for manufacturer nowadays is to be agile in their operation. A quick view of agile manufacturing is that flexibility has been added to the cost, quality and delivery objectives of lean. But from a wider perspective, "Agility" involves bringing together core skills and competencies from several organisations, according to Bicheno (2000), in order to achieve convenience, flexibility, cost and service. The strategy for agile manufacturing should be focused on faster response to high variability customer demand patterns, shorter design and manufacturing lead times, better utilisation of resources, flexibility to cope with wider range of batch sizes and products and so on (Kidd, 1994).

Ismail et al. (2002a, 2002b) had proposed a strategic framework for agile implementation aimed at both large and small companies. Agility has proved to be an important element in current manufacturing system design and strategy. Elkin et al. (2002) had applied agility in the automotive industry to gain the fast cost effective respond to the turbulent environment.

2.2 Manufacturing System Structures

The following issues are reviewed individually to provide a background to manufacturing system issues:

- layout design affecting the flow,
- processes variability affecting the synchronisation,
- types of manufacturing systems to use,
- the scheduling approach used for the unpredictable demands and setting the best control approach to synchronise the processes in the shop floor

2.2.1 Layout

Layout is one of the key decisions that determine the long-term efficiency of operation. Layout has numerous strategic implications because it establishes an organisation's competitive priorities with regards to capacity, processes, flexibility, and cost, as well as quality of work like, customer contact and image. An effective layout can help an organisation achieve a strategy that supports differentiation, low cost and response. The simulation modelling tools are able to analyse the travel time and distance of the layout whether this could be optimised.

2.2.2 Cellular Organisation

A cell layout which also sometimes is referred to as cellular organisation is one where transformed resources entering the operation are pre-selected to move to one part of the operation (or cell) in which all the transforming resources, to meet their immediate processing needs, are located. The cell itself may be arranged in either a process or product layout. After being processed in the cell, the transformed resources may go to another cell. In effect, cell layout is an attempt to bring some order to the complexity of flow which characterises process layout.

Many operations either design themselves hybrid layouts which combine elements of some or all the basic layout types, or use pure basic layout types in different parts of the operations. The importance of the flow to an operation will depend on its volume and variety characteristics.

2.2.3 Types of manufacturing system

A manufacturing system is a diverse and complicated system. Different researchers have different classification and definition of the manufacturing entities. McCarthy (1995) grouped the existing methods of manufacturing systems classification into five general headings, as shown below:

- operational characteristics (job, batch, mass, project, intermittent, continuous, etc.);
- operational objectives (make to stock, make to order, etc.);
- operational flow structures (flowlines, group technology, etc.);
- a detailed sub-classification of one of the above (batch, flowline);
- a combination of one of the above.

The types of models categorised by (Sule, 1996) to differentiate different system in the manufacturing environment from a scheduling viewpoint as follow:

1. Single machine. There is only one machine (server) available and arriving jobs (work) require services from this machine. Jobs are processed by the machine one at a time. Each job has a processing time and a due date and may have other characteristics such as priority.

2. Flow shop. Jobs are processed on multiple machines in an identical sequence. However, the processing time of each job on each machine may be different. The objective maybe to minimise the time required for completion of all jobs, called the makespan.
3. Parallel machines. A number of identical machines are available, and jobs can be processed on any one of them. Jobs may have dependency, meaning that the next job in the sequence may not start until the previous job has been completely processed.
4. Job Shop. This is one of the most widely used generalised production systems. There are different machines in the shop, and a job may require some or all the machines in some specific sequence.
5. Open Shop. An open shop is similar to a job shop except that a job may be processed on the machines in any sequence the job needs. In other words, there is no operationally dependent sequence that a job must follow.
6. Dependent shop. A job shop environment in which the processing order of one or more jobs depends on the processing of other jobs is called a dependent shop.
7. Batch processing. Jobs are processed in batches, each batch requiring certain processing time, and there may be a capacity limitation on how many jobs can be processed at one time. A baking oven with limited volume is one example of batch processing.
8. Assembly line. The job goes through a certain sequence of operations, and the objective is to define workstations and assign tasks to these stations to achieve a certain production level and efficiency.
9. Mixed-mode assembly lines. The job is processed on an assembly line built to produce similar (not identical) products with different task requirements and task times.

Scheduling methods are tools that allow production and other systems to run efficiently. Scheduling efficiency can be measured by various formulas, and indexes. Two of the most popular are minimisation of time required to complete all jobs (makespan) and minimisation of penalty for completing jobs early or after the due dates according to Sule (1996). Heuristic rules (e.g. Earliest Due Date (EDD) Rule, First In First Out (FIFO) rule, Shortest Processing Time (SPT) rule, etc.) play an important feature in the decision making on the scheduling of the order to enhance the performance of the manufacturing system. For details on how each rule is applied see Sule (1996). No one particular scheduling is better than another; it is more a choice or a combination that fits the organisation's demand and the products. There are hundreds of scheduling methods and approaches, only those used in this research are mentioned.

2.2.4 Synchronisation

Synchronisation of operations in a manufacturing system is critical. The aim is to solve manufacturing problems arising from bottleneck processes. Rodrigues and Mackness (1998) highlighted the importance of manufacturing synchronisation for gaining competitive advantage. Hu and Wang (2001) reinforced the importance of synchronisation by stating that all information, procedures and objects in the model or systems must be balanced. And Diallo et al. (2001) proposed that the design of manufacturing cells include two problems, the constitution of the cells of machines and the assignment of the process plans to be used by the parts. Flexible routings allow the machine usage factor and the throughput time to be improved. This could contribute to better synchronisation of the system

2.2.5 Manufacturing System Improvement

These improvements approach had been proposed and applied in various area like automation of the system, improving human function in the system, optimising operational issues and managements of product (i.e. existing and new). For example, Van Der Zee Durk-Jouke (2001) proposed batching for avoidance of setups/ changeover delays and facilitation of material handling. This approach aimed to improve operational activities in the shop floor. Kenne and Boukas (2003) proposed using hierarchical control of production and maintenance rates to find optimal control policies and again to improve operational activities in the manufacturing systems. Kenne and Gharbi (2004) stated that the availability of machines can be improved through corrective maintenance strategy. Whereas Zulch et al. (2004) commented that in manufacturing system, human resources are the most expensive, but also the most flexible factors. Therefore, the optimal utilisation of human resources is an important success factors contributing to long-term competitiveness.

2.3 Decomposition of manufacturing system

Manufacturing systems are complex systems consisting of many types of input activities, processing activities and also output generation activities. There are many proposals and methodologies out there used to represent one or more parts of such a complex system. To propose and create a general and complete representation and dissection of a manufacturing system is therefore a challenge. Many researchers have attempted a detailed and comprehensive representation to deal with certain aspect of a manufacturing system such as decision making support, flexibility, product configuration and so on.

Shewchuk and Moodie (1998) proposed a detailed and comprehensive definition and classification of manufacturing flexibility types and measuring indexes. This is only useful to measure the flexibility not to define or assess the manufacturing system itself.

Rao and Gu (1997) presented a new design methodology and integrated approach for the design of manufacturing systems in Figure 2.5. A design methodology of manufacturing systems can be defined as a set of procedures that analyses and divides a complex manufacturing system objects into simpler manageable smaller section while still maintaining their links and interdependencies.

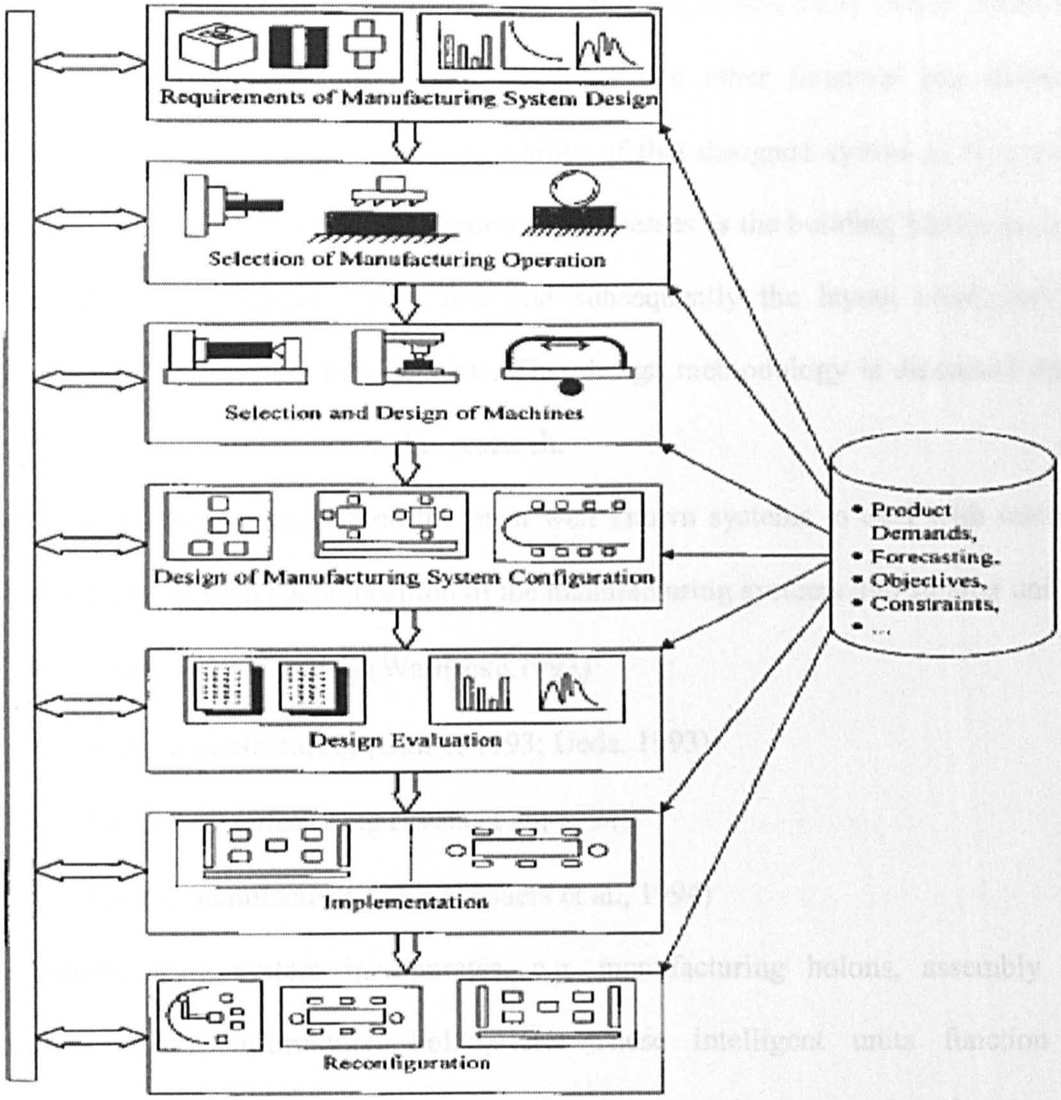


Figure 2.5 Design Methodology (Rao and Gu, 1997)

The following steps had been developed as a guideline by Rao and Gu (1997):

Step1: Requirements of manufacturing system design

Step2: Selection of manufacturing operations

Step3: Selection and design of machines

Step4: Design of manufacturing system configuration

Step5: Design evaluation

Step6: Implementation

Step7: Reconfiguration

The integrated design approach reflects the ability to concurrently tackle issues such as product demand fluctuations, system flexibility and other financial and technological constraints at the design stage, and the ability of that designed system to be sensitive to changes. The approach uses the operations or processes as the building blocks for evolving, the machine requirement design first and subsequently the layout configuration and material handling system requirements. This design methodology is discussed further in chapter 6 in and its relevance to this research.

Kadar et al. (1998) summarised the most well known systems to deal with internal and external changes with decomposition of the manufacturing systems into smaller units are:

- Fractal manufacturing (Warnecke,1993)
- Bionic manufacturing (Okino, 1993; Ueda, 1993)
- Random manufacturing (Iwata et al., 1994);
- Holonic manufacturing (Valckenaers et al., 1994)

A manufacturing system incorporates, e.g. manufacturing holons, assembly holons, transport holon, information holon, etc. These intelligent units function nearly independently; they have their own knowledge representation, processing, decision making and communication capabilities. In some ways, these concepts are similar to the object-oriented approach to holding individual self-contained data. The proposed concepts by Kadar et al. (1998) are hard to understand let alone to practice daily in the shop floor. The disseminations of the manufacturing elements are rather complicated.

Some researches had looked into decomposing the manufacturing system into smaller parts, some had decided to distribute the decision making component from the centralised system viewpoint; and some decided to decompose the focused problem only. For example, Matta et al. (2001) proposed an integrated approach to decompose automated manufacturing system based on hierarchical decomposition of the problem into different sub-problems, each one defined by its level of detail.

Borenstein (1998) developed a new methodology of analysis and evaluation of Flexible Manufacturing System (FMS) design configuration. It examines the use of an integrated, systematic, global and user oriented approach for the complex problem of selecting among several configuration alternatives the most suitable for a specific case. Performance measurements techniques and method applied to FMS design used by Borenstein (1998) were:

- Mathematical Programming (Afentakis, 1992, Stecke, 1991)
- Queueing Networks (Solberg, 1980, Suri, 1981)
- Simulation (Carrie, 1988, Haddock, 1988)
- Petri nets (Narahari and Viswanadham, 1985, Valavanis, 1990)
- Flexibility Measuring Techniques (Barad, 1992, Kochikar and Narendran, 1992, Mandelbaum and Brill, 1989)

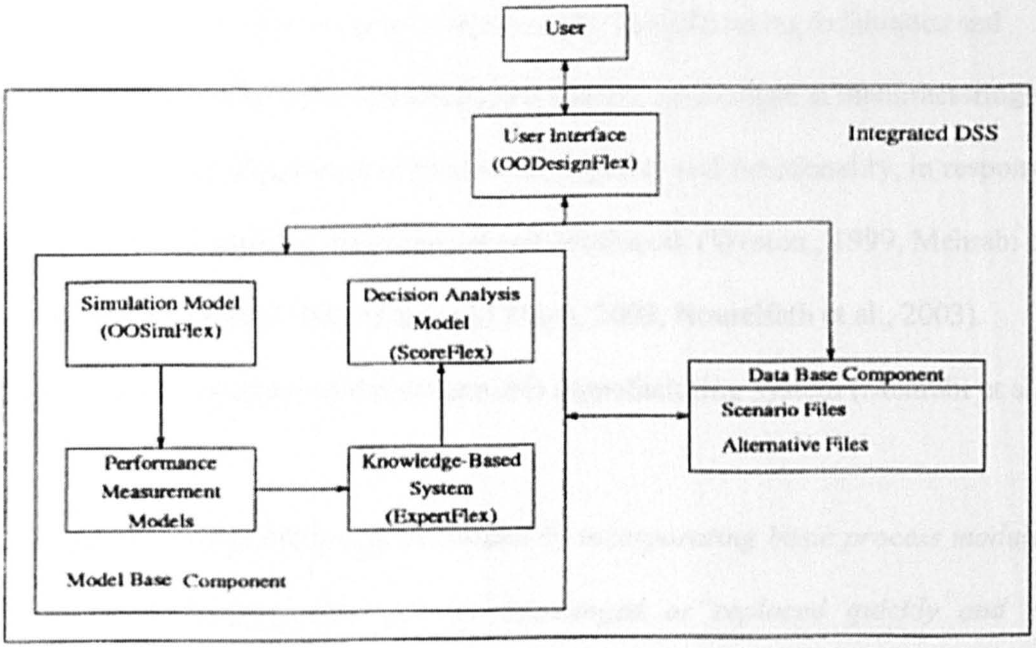


Figure 2.6 IDSSFLEX architecture. (Borenstein 2000)

The framework proposed by Borenstein (2000), shown in Figure 2.6, was a detailed and complete study of a manufacturing system deploying various techniques and decision analysis model (IDSSFLEX architecture) although it focused on FMS only. This provided a good example of the current techniques and methods that could benefit the manufacturing system improvement projects. Different approaches have different applicability to different problems depending on the available input and the desired output result.

The above was a general overview of the issues related to manufacturing system designs and operations. The scope of this field is wide and therefore this review is limited to a listing of some of the key publications that impact on this research.

2.4 Reconfigurable Technology

Globalisation and improvements in communication has allowed customers to know more and want more. Manufacturers have to change constantly and evolve to retain and attract customers. Existing manufacturing infrastructure and systems need to be able to reconfigure rapidly to follow the market demands. Manufacturing techniques and introduction of reconfigurable manufacturing system, a paradigm in manufacturing which is designed for rapid adjustment of production capacity and functionality, in response to changing market conditions are proposed and developed. (Weston , 1999, Mehrabi et al., 2000, Heilala and Voho, 2001, Odrey and Mejia, 2003, Nourelfath et al., 2003).

Definitions and Objectives of Reconfigurable manufacturing system (Mehrabi et al., 2000) are:

"A machining system, which can be created by incorporating basic process modules- both hardware and software- that can be rearranged or replaced quickly and reliably. Reconfiguration will allow adding, removing, or modifying specific process capabilities, controls, software, or machine structure to adjust production capacity in response to

changing market demands or technologies. This type of system will provide customised flexibility for a particular part family, and will be open-ended, so that it can be improved, upgraded, and reconfigured, rather than replaced."

The position of a reconfigurable manufacturing system in a capacity-functionality diagram is shown in Figure 2.7.

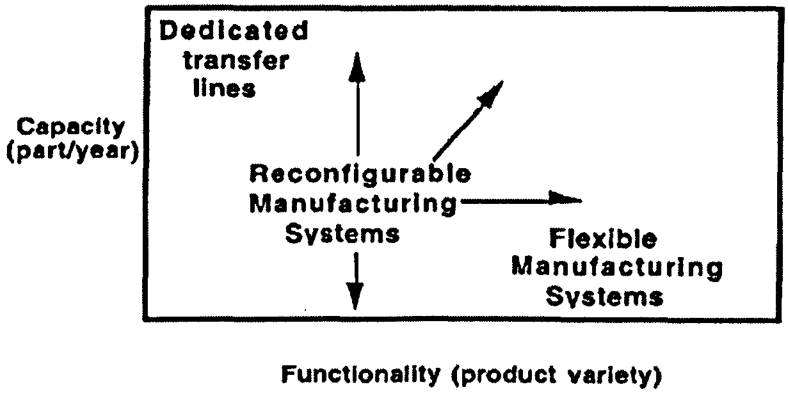


Figure 2.7 Mapping several types of manufacturing systems in capacity-functionality coordinates. (Mehrabi et al, 2000)

Critical criteria to be considered for reconfiguring the system should also include the lead time to steady stage of production after the changes are introduced to the system and the scalability of the system. Manufacturing physical entities and control components should be catalogued and stored for reuse, and new modules added to the catalogue as they are created for reconfiguration of the system.

Heilala and Voho (2001) proposed that for reconfigurability and agility the best solution is the modular semi-automatic approach by combining flexible automation and human skills in assembly lines. Modular system structure makes it possible to change the system. Approaches suggested by Heilala and Voho are focusing on manufacturing physical entities than the manufacturing system design. For example the capacity can be increased using step by step automation and manual work can be replaced by a robotic cell. This offers effective solutions in the development of the systems for a high-mix, low volume dynamic production environment.

Weston (1999) showed process oriented capture of manufacturing system requirements. From this research, according to ISO 14258 process models can be used to define:

- What activity flows (concerned with conceptualising enterprise goals and requirement);
- How activity flows (concerned with determining how enterprise requirements can be met); and
- Do activity flows (needed to achieve product realisation and service provision within the context of enterprise requirements and goals).

Modular systems can be developed at much greater pace, following the availability of object-oriented system design techniques and advances in distributed systems technology according to Weston (1999). A system classification with respect to W, H, and D activities are proposed in this research shown in Figure 2.8.

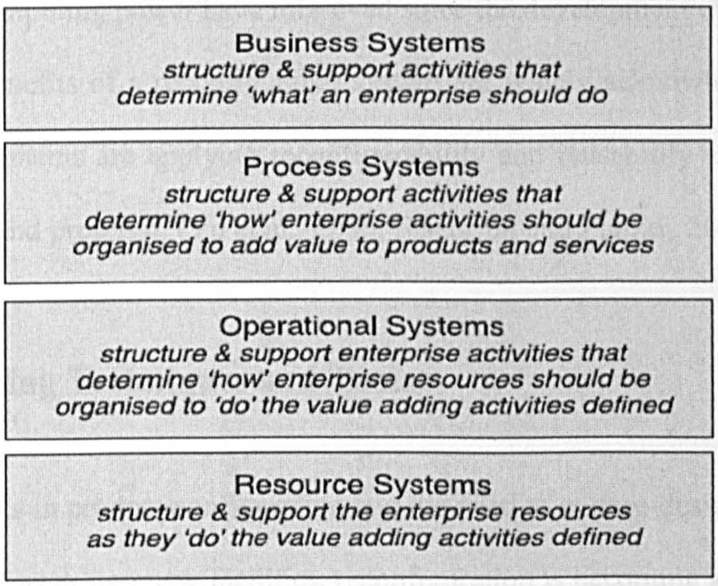


Figure 2.8 System classification with respect to W, H, and D activities (Weston, 1999)

The study above provides only the general requirements, general assumptions and conceptual design requirements of a component-based approach to reconfiguring manufacturing systems. Weston (1999) also discussed about the current constraint as:

- Having access to explicit models of functional, interactional and behavioural capabilities of system components before wide-scale, reconfigurable manufacturing systems can be generally deployed.
- Lack of suitable modelling tools and engineering environment
- Lack of well-defined, multi-vendor interoperable system components
- Difficulties of capturing and reusing semi-structured information has been found to limit the application of domains in which very significant lead-time and cost benefits can be achieved
- Importance of agreeing and establishing a meta framework of system engineering concepts that target system development on the configuration of component-based system

Modelling tools and computing power have improved since the development of the Weston model in 1999. The benefits of a reconfigurable system are widely acknowledged. More researches and developments are applying reconfigurability and reusability as one of the criteria in their design and proposal. (Yu et al., 2000, Eisenring and Platzer, 2002, Paul and Taylor, 2002).

2.5 Process Mapping Techniques and Tools

Due to the rapid changes in product configuration and the need to ever re-design or modify existing process as well as design new facilities, reconfiguration is becoming a strategy for competitive advantages. As a result, these organisations will need not only manufacturing information systems to plan and control the operations of their existing structures, but also methodologies and computer-aided tools to help, possibly frequently, restructure and re-engineer their organisation arrangement (either strategically, functionally or physically). An object-oriented approach has provided the new paradigm to a reusable and reconfigurable system. Traditional tools are mostly suitable for infrequent or one-off design projects. There are many modelling tools and techniques in the market, Michalski (1998) has listed over more 40 for implementing improvement activities. Some are common and traditional tools, i.e. checklist, control charts, Pareto charts, flowcharts and time study chart; and there are more advanced and complicated tools for example Potential Problem Analysis (PPA), workflow analysis (WFA), Activity Network diagram and Failure Mode Effect Analysis (FMEA). Bal (1998) compared and classified process modelling techniques shown in Figure 2.9 .

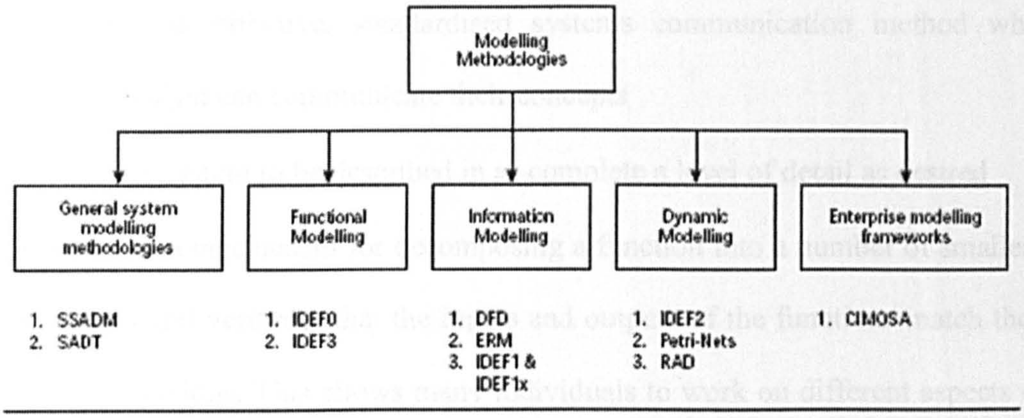


Figure 2.9 Classification of Modelling Techniques (Bal,1998)

Congram and Epelman (1995) proposed using Structured Analysis and Design Techniques (SADT) in the service industries to encourage communication for reaching organisational consensus. SADT deals with the representation of a system's structure, not its behaviour over time. SADT is a static modelling paradigm, not a simulation tool, but it can help to prepare for a simulation exercise.

Another modelling technique derived from SADT, Integrated Computer Aided Manufacturing Definition (IDEF) developed by US Air Force in 1981 for analyzing and communicating the functional perspective of a system. IDEF 0 is a method designed to model the decisions, actions, and activities of an organization or system (http://www.idef.com/IDEF0.html). There is a need for a system definition for the system analysis and specification of coordination intensive manufacturing systems and mainly easy to use for manufacturing engineers. Although IDEF provide a rather structured framework to start the process specification but the scalability of the framework is limited. The strength and limitation of IDEF to describe the manufacturing system is addressed in detail in Chapter 3.

The main advantages of IDEF:

- It allows an effective, standardised systems communication method whereby system analyst can communicate their concepts
- It allows a system to be described in as complete a level of detail as desired
- It provides a mechanism for decomposing a function into a number of smaller sub-functions and verifying that the inputs and outputs of the functions match those of its sub-functions. This allows many individuals to work on different aspects of the total system and yet to be consistent in terms of final system integration.
- It has the potential to be used as an industry standard for manufacturing system design. In December, 1993, the Computer Systems Laboratory of the National Institute of Standards and Technology (NIST) released IDEF 0 as a standard for Function Modelling in FIPS Publication 183.

Perera and Liyanage (2001) proposed an IDEF based methodology for rapid data collection. A functional module library and a reference data model developed using IDEF. Yu et al. (2003) proposed using Knowledge-based Timed Coloured Object-oriented Petri Net

(KTCOPN), which is combining object-oriented methods with PetriNets, to ease the reconfiguration of control software. Sargent (2001) proposed using Histogram, Box Plots and Behaviour Diagram for operational validation. A figure of real world and simulation world relationships with verification and validation were showed. Hierarchical and Object-oriented Manufacturing Systems Analysis and Definition (HOOMA) by B.Wu (1995), aims to bridge the divide between the function-based approach and pure O-O approaches (Figure 2.10).

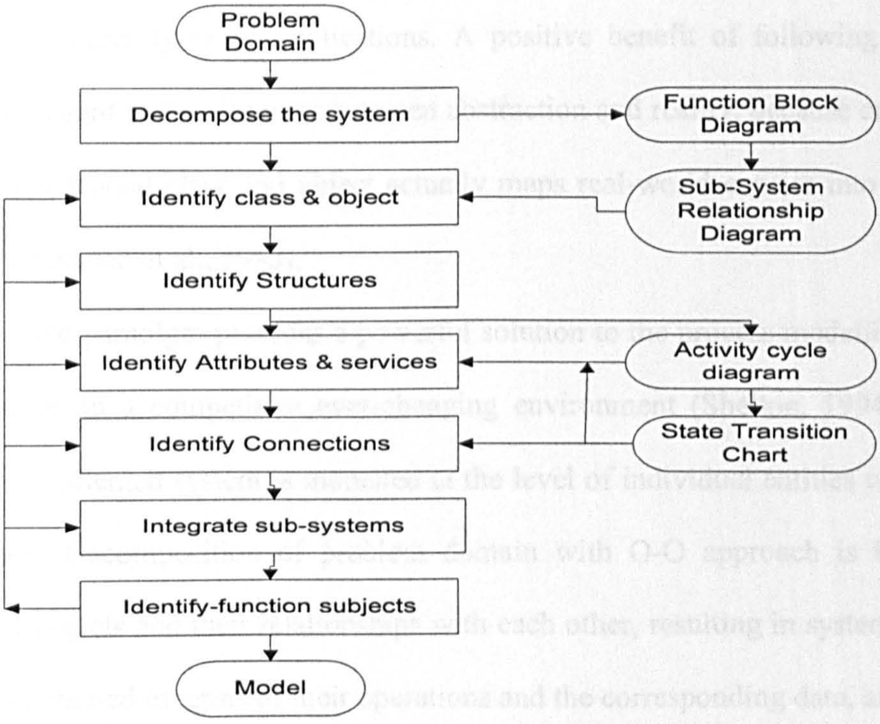


Figure 2.10 Summary of HOOMA Procedure (B.Wu, 1995)

The work by Wu had greatly influenced this research with its analysing and structured decomposition of the manufacturing system. The details of this development are discussed with the proposed methodology developed in this research in a later chapter (Chapter 3).

Weyland and Engiles (2003) listed the five major business process definition languages currently being developed in the market by various vendors and institutions:

- BPML (Business Process Modelling Language)
- BPEL4WS (Business Process Execution Language for Web Services)
- EDOC (Enterprise Distributed Object Computing)

- XPDL (XML Process Definition Language)
- UML 2.0 (Unified Modelling Language)

The above developments suggested that a standard process definition or describing language or notation is important to move ahead no matter its in business process modelling, enterprise modelling or manufacturing system modelling.

2.6 Object-Oriented Approach and Representation

To date the object-oriented concepts have not only been used in the software industries but are also found in other types of applications. A positive benefit of following an O-O approach in this regard is the closeness between abstraction and reality, because organising a required system around class and object actually maps real-world entities into required components (Narayanan et al., 1998).

The object-oriented paradigm provides a powerful solution to the process modelling needs of an organization in a competitive ever-changing environment (Shelton, 1994; Taylor 1994). An Object-oriented system is modelled at the level of individual entities within the problem domain. Decomposition of problem domain with O-O approach is based on classification of objects and their relationships with each other, resulting in system entities which are self-contained in terms of their operations and the corresponding data, and which communicate explicitly to each other. The fundamental characteristics of an object-oriented approach that provides capabilities that could greatly improve the quality of modelling. The following section identified the major object-oriented representation of manufacturing systems and their applications currently being developed or in application.

In an overview, Narayanan et al. (1998) identified six large-scale, persistent object-oriented simulation methodologies:

- BLOCS/M developed by University of California, Berkeley and is a manufacturing specific object-oriented simulation framework primarily for semiconductor fabrication.
- DEVS is developed by University of Arizona as a methodology and software implementation with applications to autonomous system modelling.
- Laval is developed by Laval University focuses on different levels of factory design which include simulation modelling.
- OOSIM is developed by Georgia Institute of Technology which integrate automated operation and human supervisory control in discrete manufacturing system.
- OSU-CIM is developed by Oklahoma State University to separate the modelling process from problem solving activities in modelling and simulation of discrete manufacturing systems, and
- SmartSim/SmarterSim is developed by University of Michigan Dearborn for simulation program generation for manufacturing.

Object-oriented Programming (OOP) provides natural mappings, modular design, and software reusability. The study showed the importance of domain analysis as a process of developing abstractions to represent manufacturing systems and software design in the implementation of those abstractions to realise the benefits of OOP. Amongst the methodologies identified by Narayanan et al. (1998), three methodologies: Laval, OSU-CIM and OOSIM allow explicit representations of the decision-making process. A more elaborate description of the methodologies, including several references, can be found in the paper by Narayanan et al. (1998).

All approaches mentioned recognise the need for separating activities associated with decision making from other activities related to physical transformations or data processing.

Differences are found in the choice of basic classes for modelling manufacturing entities and their relationships. Also the level of detail with which classes and class hierarchies are defined differ. In this research, the modelling of physical structures and information flow are considered. Laval, OSU-CIM and OOSIM allow for specifying *decision logic* in terms of control rules for driving activities within a certain domain. Also the need for modelling control concepts like hierarchy and coordination is recognized. The lack of attention for *decision logistics*, i.e., the timing of control activities is missing in the approaches. Clearly, the timing of decisions may have a large impact on manufacturing performance. Dynamics in simulation models is mainly related to physical transformations and not to decision-making activities. The limitation is addressed in this research and will be covered using UML Sequence diagram in Chapter 3.

Basnet et al. (1990) had proposed an object-oriented modelling environment for manufacturing system shown in Figure 2.11. The framework used object-oriented approach to separate the physical entities and information control in model specification language which is not graphical and difficult to understand.

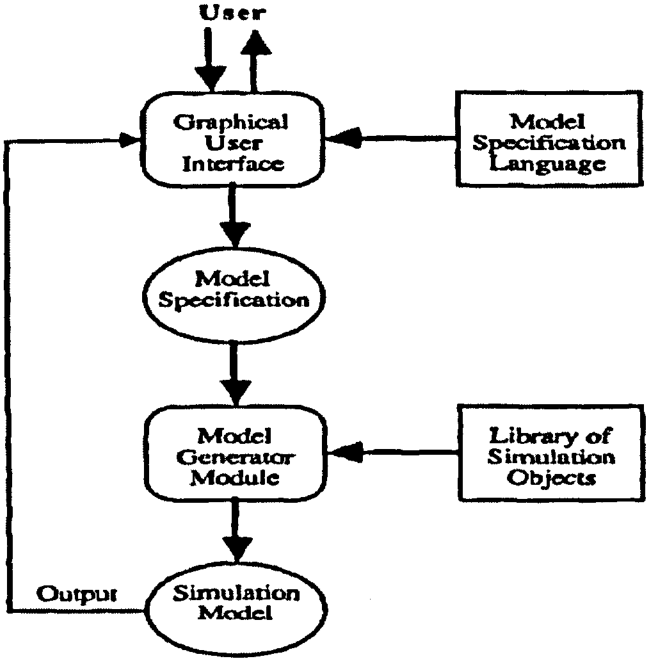


Figure 2.11 Modelling Environment Architecture (Basnet et al, 1990)

Kang et al. (1998) presents an integrated modelling framework for manufacturing system (IMF-M) consisting of a three layer model describing process, activity and objects in Figure 2.12.

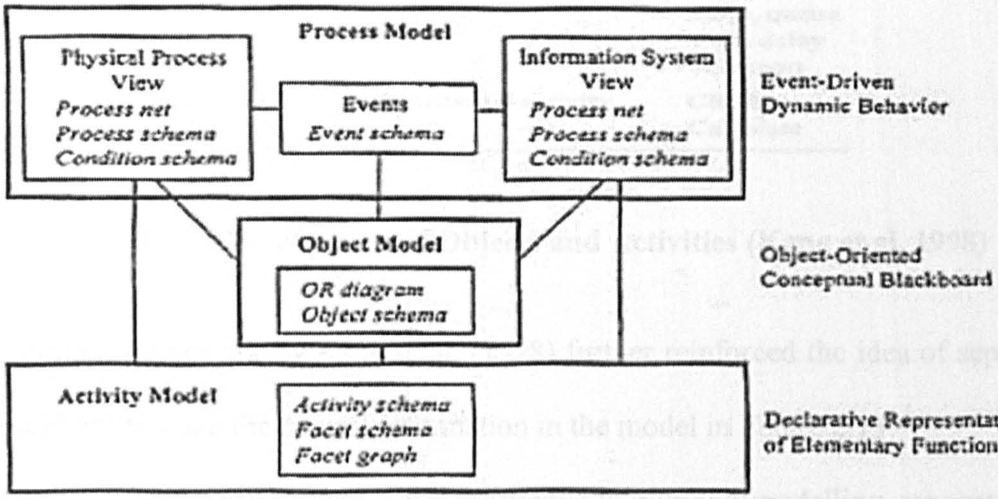
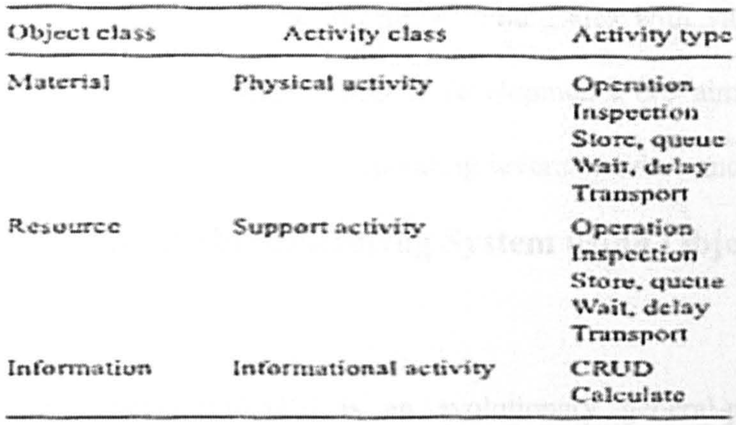


Figure 2.12 IMF-M Modelling Framework (Kang et al, 1998)

The modelling framework proposed in their design to provide the following advantages:

- The conceptual modelling of physical material flow is supported by a graphical representation facilitates improvement of operations in manufacturing environments.
- A declarative and executable representation of control information systems helps to improve information management by managing a variety of information models with improved readability and reusability.
- A unified representation of the physical process and information system provides a common modelling environment in which efforts can be coordinated among several groups working in different domains of scheduling, shop floor and logistic control, and information system.



Object class	Activity class	Activity type
Material	Physical activity	Operation Inspection Store, queue Wait, delay Transport
Resource	Support activity	Operation Inspection Store, queue Wait, delay Transport
Information	Informational activity	CRUD Calculate

Figure 2.13 Classification of Objects and Activities (Kang et al, 1998)

This modelling framework by Kang et al. (1998) further reinforced the idea of separating the physical entities and the control information in the model in Figure 2.13.

Ho and Ranky (1995) established a generic methodology and modelling concepts using object-oriented approach, extending the CIM-OSA concept, for open, modular and flexible material handling systems. The suggestion of moving from structured-type methods of process modelling to object orientation is made in the 4th Industrial Engineering Research conference by Barnett et al. (1996) and it is stated that the transaction required more than alterations in technique or modelling syntax but the change of the design concept. Bodner et al. (1995) proposed a control modelling approach, Operator Function Model (OFM), which integrates human operators and the computerised controller (in OOSIM) of manufacturing system. This approach is based on a reference model for manufacturing control which provides the framework having a consistent basis for both human operator control and computerised control. It is also based on domain analysis, which provides the basis for the reference model, and a task analysis, which provides the basis for the content and structure of the modelling tools in use. OOSIM contains a reference model for automated manufacturing control system in its representation of controllers and their interactions with one another and with the rest of the factory. A controller object has knowledge about other entities in the system, communicates with various entities, and makes decisions in real time. All the above developments are aimed at large scale information and manufacturing system incorporating several vendors and players.

2.6.1 Representation of Manufacturing System using Object-oriented methodologies

Unified Modelling Language (UML) is an evolutionary general-purpose, industry-standardised modelling language for specifying and visualising software systems. The language is applicable to different types of systems (software or non-software). UML is object oriented and component based and enables capturing and communicating of system knowledge.

Alhir (1998) proposed using the use case modelling with UML tools to depict the functionality of a system. McLean and Leong (2002) provided a comprehensive list of use cases for simulation modelling the manufacturing issues. This is discussed in detail in Chapter 5.

Borenstein (2000) had proposed an object-oriented tool for simulation modelling of the flexible manufacturing system to study the flexibility of systems. Simulation objects are separated into entity, relationship and domain as shown in Figure 2.14. Possible events are developed as sub-classes under the super classes. The relationship between the main objects in the simulation model are categorised to separate the functionality shown in Figure 2.15. The proposed modelling approach does not show the interaction of the objects.

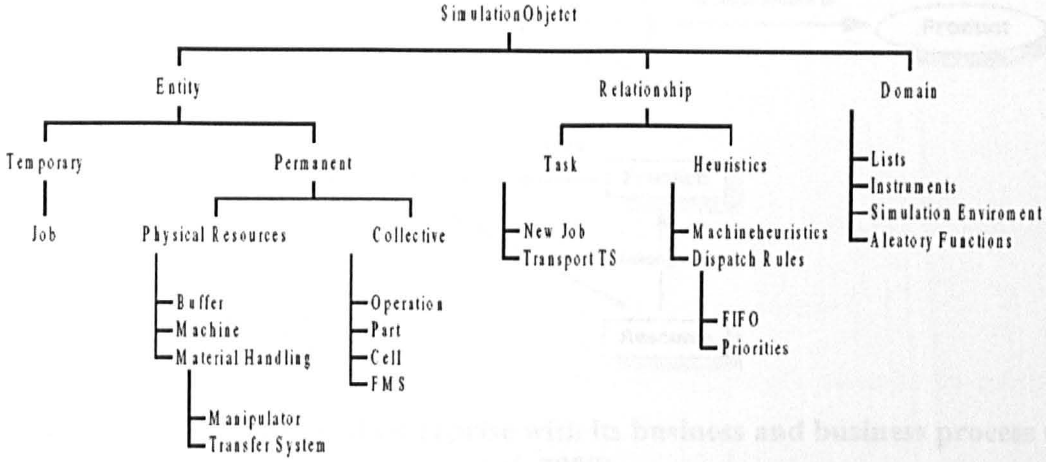


Figure 2.14 Classes defined in the simulation model (Borenstein 2000)

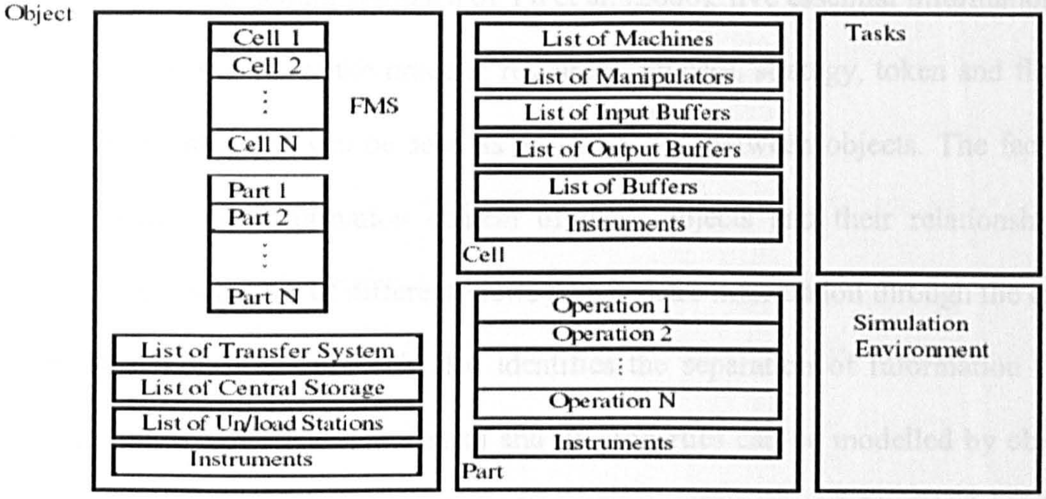


Figure 2.15 The relationships between the main objects in the simulation model. (Borenstein 2000)

Another research by Yu et al. (2000) although not focussing on manufacturing systems but enterprise modelling has influenced this research with its classification of objects. The modelling concepts had used the Object-oriented approach. The enterprise environment and its objects are shown in Figure 2.16.

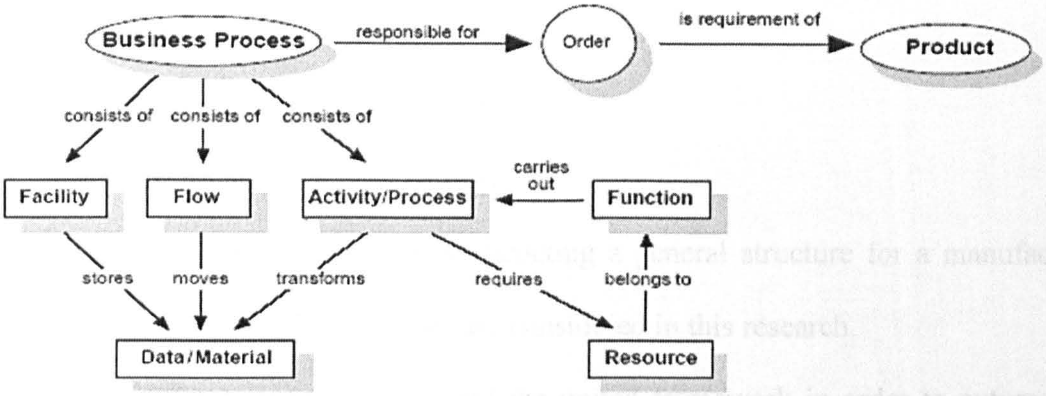


Figure 2.16 Description of enterprise with its business and business process (Yu et al, 2000)

In the Enterprise modelling approach of Yu et al. (2000), five essential information classes had been defined to cover the process: resources, process, strategy, token and flow. Each activity in an enterprise can be seen as an interaction between objects. The factory data model captures the information content of these objects and their relationships. This facilitates the integration of different views which share information through the enterprise model. This modelling approach also identifies the separation of information flow and physical entities flow. The real system and its properties can be modelled by objects and their relationships with other objects as follow:

- Objects are defined by the attributes holding descriptive data, functions and relationships between objects.
- The object oriented class structures and the class hierarchies inheritances the similarities between object characteristic.
- Attributes of object are assigned values at instantiation.
- A message is passed between objects to trigger an event or changes.

Dewhurst et al. (2002) were also focussing on constructing a General Enterprise Model identified five key design issues:

- Level of Detail
- Model Division and Integration

- User viewpoint
- Flow Entity Creation and Routing
- Relationship between flow entities

The design issues are similar when constructing a general structure for a manufacturing system model. Hence the design issues are considered in this research.

Lau and Mak (2001) proposed to extend the united framework in order to automate the process of system design for automated manufacturing systems. With reference to the unified system development framework, a frame-based representation method is applied to capture the semantic operation of the objects that are identified in the design specification of the united framework. The design specification is expressed in an expert system shell frame, a specially developed expert shell is then used to prototype the specification, and therefore automating the verification process between system analysis and design. Object Oriented Design (OOD) addresses system design, whereas 'use case method' emphasis the system requirement analysis. However, the drawback of adopting different approaches to cover the entire system development lifecycle is the difficulty in integrating the various approaches. The expert system shell frames approach is similar to having object-oriented class approach which has reconfigurable and reusable units (i.e. class, or frames).

Object-oriented simulation methodology had been used in a new modelling framework developed by Van Der Zee (2003) to serve as a conceptual basis for extending capabilities of simulation models, tools and libraries in analysing manufacturing system in particular to control problems not the system in general. The framework suggested classes to represent manufacturing entities which Van Der Zee defined as agents shown in Figure 2.17.

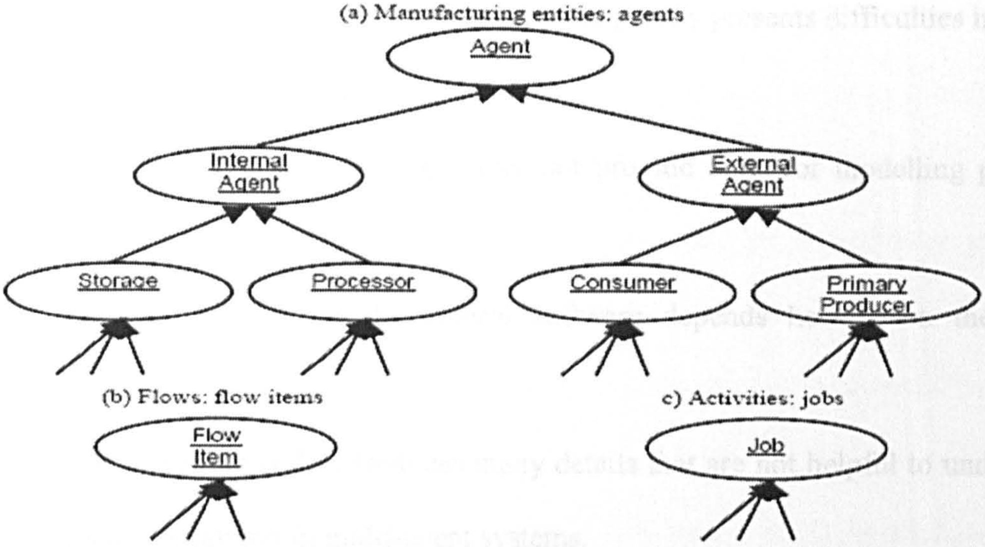


Figure 2.17 Main Classes in Modelling Framework (Van Der Zee 2003)

The Unified Modelling Language (UML) is developed to provide a united environment for system development. In addition, a framework that aims at providing a common language with guidelines and building blocks for domain specific application development has been produced. The process of prototyping facilitates system designers to better visualise the behaviour of the system model, to identify and resolve design inadequacies, and hence to ensure the design's accuracy. Ideally, a system's prototype should be a direct mapping of a system design to reduce discrepancies and the semantic gaps between the prototype and the corresponding design. The conceptual model provides a common reference for the seamless mapping of objects between design specification and prototypes, whereas semantic model extend the use of frames and provides a mean to explicitly specify system behaviour.

Odrey and Mejia (2003) presented the advantages of OOP compared to traditional programming include portability, extendibility and modularity. A major drawback is that object-oriented methods cannot be applied alone towards modelling and optimising the operation of a manufacturing system. The primary reasons as stated by Odrey and Mejia (2003) are:

- OOP lacks a mathematical basis and consequently presents difficulties in predicting the system performance;
- Object-oriented software code does not provide tools for modelling parallel and concurrent processes;
- The interpretation of the control software depends heavily on the computer language;
- OOP computer code introduces many details that are not helpful to understand the agent's behaviour in multi-agent systems.

Although this research is focusing on the Object-oriented Programming and not in a general design approach and representation but the limitations suggested above are considered in this research.

The literatures reviewed supported applying the Object-oriented approach in designing and classifying the manufacturing entities is suitable and adequate. This research proposed an object-oriented process modelling approach with UML diagrams and this is described in more detail in Chapter 3.

2.7 Simulation Modelling

Simulation models allow managers to test and experiment with the model in order to learn more about the real system. They are tools for supporting managerial decisions. For example, simulation models may be used to draw conclusions about the risks and benefits associated with entering a new market, accepting another customer order, introducing a new product, and changing the current production technology. Beside these, the simulation models can be used to assess how the changes affect the current business model and future profitability; what kind of cost savings might be achieved by changing processes; what kind of return can be obtained from the investment, given certain risk factors, etc.

Simulation is similar to all other types of tools with advantages and limitations depending on the application. A comprehensive review of the benefits of simulation can be found in Banks et al. (1999). These can be summarised as follow:

- It is easy to use. Numerical modelling is too complex and often give misleading result by oversimplifying problems.
- A simulation model can represent the characteristics of a manufacturing system more realistically and dynamically.
- The increase in computing speed coupled with user-friendly interface and graphics give one a better understanding of the system.

Murphy and Perera (2001) stated that simulation modelling is used to design and experiment on numerous scenarios that are refined before being put into physical practice within business environment. The applications of emerging and diverse simulation types can help to enhance and analyse all aspects of design and manufacture of a product.

From identification of design errors earlier in the product life cycle to overall optimisation of facility processes in the full development of products and processes, companies need to have planned in detail their approach to gain full benefits from simulation modelling. Reichenthal (2002) commented that simulation focuses on information creation and analysis. In this context, the primary goal is to provide knowledge, or answers to important questions through experimentation and modelling, which would otherwise be too difficult or expensive to obtain.

The disadvantages however include:

- The data collecting process is too time consuming
- The simulation results may be difficult to interpret
- Model building requires special training

Baldwin et al. (2000) presented a survey on the use of simulation software and further improvement. It concluded that current simulation packages are easy to use, visual-effective and interactive but limited for complex and non-standard problems and further more are slow.

2.7.1 Current Simulation Packages

Simulation is widely used to design manufacturing systems. Although simulation can be used to evaluate relatively simple operational procedures such as production scheduling, quality control, and policies for raw materials inventory level and product logistics, it is difficult to represent and evaluate significantly large MS/OR models and heuristic operational procedures (Park, Kim, and Kang, 1996). A list of commercially available Simulation Modelling Packages (COTS) is compiled by Ryde and Taylor in March, 2003 includes:

- Arena (Rockwell Software)
- AUTOMOD (Brooks Automation AutoSimulations Division)
- Awe Sim (Frontstep,Inc)
- EXTEND (Imagine That,Inc)
- GPSS/H/Proof Animation/SLX (Wolverine Software Corporation)
- iGraphx Process 2000 (Micrografx,Inc)
- microGPSS/webGPSS (Ingolf Stahl)
- ProModel (Production Modelling Corporation)
- QUEST(DELMIA Corporation)
- SIGMA (Custom Simulation)
- SIMPROCESS/SIMSCRIPT II.5 (CACI products Company)
- SIMUL 8(SIMUL 8 Corporation)
- Taylor Enterprise Dynamics (F&H Simulations)

- Visual Simulation Environment (Orca Computer, Inc.)
- Witness (Lanner Group, Inc)

In the 2001 Winter Simulation Conference, a panel of simulation expert (Kachitvichyanukul et al., 2001) had compared a future predication of the simulation environment done in the late 80's and now. Integration simulation modelling is becoming the centre of focus. Barton et al. (2003) summarised the current simulation industry needs and predicting the future in terms of requirements and technology. A summary of the improvements needed are identified:

- Ease of Use
- Reusability
- Scalability
- Interoperability/ 'Plug-In' Support
- Productivity
- Promotion/Support of Collaborative Modelling
- Supporting Component-Based Modelling
- Building Libraries of 'Canned' Model
- Integrating Simulation Software with the following:
  - Database Tools
  - Supply Chain Software
  - ERP Software
  - Browsers and other widely used tools

The above criteria for the future of simulation modelling, point to the future trend in the development of modelling package functions. One of the key difficulties for new entrants to the use of a simulation tool is the selection of the correct package for their needs. Lyons et al. (2000) simulated a small enterprise using Witness, SIMNET II, a network simulation language and queuing modelling using Operations Management Expert. Each approach was found to accurately model the company operations, provide a consistent indication of operational performance in terms of throughput and resource utilisation. Whereas other experts had decided to focus on one particular simulation modelling package to assess its applications and benefits. For examples, Harrell and Price (2003) presented the ProModel simulation package; Williams and Gunal (2003) showed how to use SimFlex as a supply chain modelling tool; Bapat and Sturrock (2003) reviewed the Arena product family and the integrations; and Fujimoto (2003) presented FlexSim simulation packages' environment and application.

2.7.2 Generic Simulation Model

Traditionally, the topology and structure, as well as the component description of the system are fixed in the simulation model. That means that these data are linked to the model by the simulation language of the simulator. This makes building and maintaining of larger and more complex simulation models difficult. A better solution is to create a simulation model at run-time out of a database, in which all necessary data can be stored and easily updated (Richter and Marz, 2001, Randell and Bolmsjo, 2001). Such kind of simulation models is also called generic simulation models, with the main distinguishing feature being that both the description of the system structure and the system load parameter are stored in a database. The data is only read and interpreted when the individual simulation model is generated. Graupner et al. (2002) stated that components must be designed as modules that are part of a building block system and is necessary to have an extensive component library (including machines, queues, conveyor systems, etc.) available. This components library consists of a collection of defined, documented and coordinated manufacturing processes and standard objects. During the configuration process, the components are dimensioned, selected and parameterised, and material flows are defined. By joining the elementary components, an abstract model of the manufacturing system is produced.

2.7.3 Applications of Simulation Modelling

Kang et al. (1998) proposed a rather complete modelling perspective illustrating the directions or goals for a simulation project. The following is list of cases of simulation modelling being applied in the manufacturing environment:

- Ingemansson and Bolmsjo (2004) stated that different disturbances can be categorised into downtime losses, speed losses, and quality losses and proved with case studies that discrete event simulation combined with the knowledge of disturbance reduction will make optimum results possible by testing different alternatives;
- Grewal et al. (2002) described the validation of cycle times in factory simulation modelling;
- Ferrin and Muthler. (2002) recommended using simulation to support six sigma improvement projects in manufacturing system;
- Tsai (2002) studied the use of Taguchi's Experiment Design in simulation to solve decision-making problems in integrated manufacturing systems.
- Saraph (2001) had gone beyond basic what-if analysis and estimates of measure of performance to offer better predictability for operations planning in a Biotech industry with simulation modelling;
- Korhonen et al. (2001) used the simulation model to compare the effect of scheduling, queuing rules, buffer policies, and lot sizes on customer service and cost efficiency in Printed Wiring Board Manufacturing;

- Gunn and Nahavandi (2000) used discrete event simulation modelling on an existing factory to control the levels of WIP on the shop floor, through the control of the buffer levels with a specific algorithm in the bottleneck machines;
- Farahmand Kambiz (2000) proposed using simulation to support implementation of a flexible manufacturing cell;
- Silva et al. (2000) showed another successful case study using simulation for manufacturing process re-engineering;
- Al-Aomar Raid (2000) shown carrying product-mix analysis with discrete-event simulation;
- Fields et al. (2000) presented a case study using simulation to assist in the development and integration of the assembly and test processes with a focus on capacity, material flow optimisation, and equipment layout;
- Dahl and Jacob (2000) presented an example of embedding decision making in simulation modelling in a cereal manufacturing company to improved throughput;
- Chan and Jiang (1999) created a SIMFACTORY model for production cell and assembly cell in an automotive company to enabled analysis of different design alternatives and system performance, hence to obtain the optimum operating conditions in cost-effective manner;
- Polajnar et al. (1995) presented a case study of simulating different transport solutions in the flexible manufacturing cell using analysis on flow line and cost to justify;

2.7.4 Simulation Model Building Approaches

Simulation models of a manufacturing system can be made using different simulation technologies. This research is focused on discrete event simulation technologies, mainly used for material flow analysis. There are two basic approaches to build such a model, either to use a simulation language or a simulation package. The two basic approaches can be categorised as given by (Randell 1999):

- **Languages** e.g. SLAM, GPSS/H, SIMAN. These are high-level languages that offer the programmer more flexibility and a more powerful language than the simulation packages can give. However this approach is much more time consuming than using a simulation package.
- **Simulators** e.g. Witness, ProModel, TaylorII. These are data driven systems with little or no programming required. This approach is fast and easy but more limited in application.

There is a third approach that is derived from these two:

- **Hybrid systems** e.g. Arena and QUEST, Witness also uses a programming language which combines the flexibility of a simulation language i.e. SIMAN and SCL respectively, with the user-friendliness of a data driven system. The aim is to exploit the speed of the simulator package and still have the flexibility of the simulation language.

Beside the stated three approaches by Randell, there is an addition of languages like Java and C++ which is have the most flexibility in creating but the most time consuming and difficult to use. Notation is another important factor for simulation modelling. From literature (Eklund, Mellin and Brimark, 1998, NIST, 1993) and experiences in industrial application from Oscarsson and Moris (2002), a number of criterions to be fulfilled by using notations have been identified.

- **Neutral notation**. The need for a neutral notation, not limited to any specific languages, software or systems. The main reason for this is that there is no language or software that is a standard in simulation engineering. Due to this, the notation(s) should be able to support the development in e.g. UML, Visual Basic, Witness or a simulation language. A neutral notation offers a possibility to first document models in one system and at the same time translate that documentation into another system for the purpose of re-use.

- **Generic notation.** The need for a generic notation that can describe different systems of various purposes, complexity and scope. A generic notation would support the standardisation in documentation procedures.
- **A recognised notation.** The importance of using a known and well-recognised notation is beneficial. If there are any interpretation difficulties because of the use of an "in-house" solution, the notation may need additional documentation for it to be understood. Using a notation that is a standard and well recognised improves communication and support the model maintenance during its life cycle.
- **User friendly.** Notations help the reader to understand the abstract code level and the natural language (Eklund, Mellin and Brimark, 1998). There is always a balance between the descriptive and intuitive approach and the extendibility of the notation (Sinan, 1998). If the notation is too simple it may lack the possibility to describe the simulation model in detail.
- **Descriptive at several levels.** A notation with the possibility to describe different levels of abstraction gives the user the possibility to study the system from a top-down or bottom-up point of view.
- **An in-house competence.** The documentations are for the clients and the selection of notation should consider how they could use the documentation. Some companies have already standards they use in procedure documentation (e.g. Value Stream Mapping and Flowcharting). A neutral notation should be able to interpret other notations used.

These above six criterions should guide the selection of notation, though they are probably not the only ones, but these are among the most important ones and could serve as a base in future consideration of notations for simulation studies. The sixth criterion, is in house competence, is up to each individual company or organisation to find out their competence. For documentation of discrete event simulation models for manufacturing industry the following recommendations is made (Oscarsson and Moris, 2002):

- For low-level documentation intended for developers for the system, flowcharts and comments in the code are useful. If there is a need to be more precise in the description of the structure and behaviour of the system then UML diagrams are necessary. For conceptual documentation, IDEF0 can be used to describe the flow in the system. A more detailed level can be decompose when it is necessary to describe the system flow more in depth and accurately. The IDEF0 models with Flowcharts can be combined to visualise the physical structure of the system.
- When the details of the system are not of great interest to the viewers, simulation model is a suitable tool. An animation of the simulation, perhaps in 3D with fairly realistic graphics is by far the clearest documentation of system behaviour. It supports communication in a project group, and through the dynamic behaviour illustrates more than many diagrams can do together.

2.7.5 Distributed Simulation Modelling

At the Winter Conference a list of simulation packages are reviewed and concluded that all the simulation modelling packages can provide the dynamic results required for the analysis but each has a different definition structure and have plenty of choices to fit individual functionality. Ryde and Taylor (2003) examined the interoperability of commercial simulation modelling packages focusing on the purposes of distributed simulation. They concluded the benefits of distributed simulation are:

- Model reuse. If components or parts of models can be reused within a larger model then this could save the development time.
- Inter-enterprise simulation. The modelling of global enterprises across geographical boundaries, which could normally be prohibitive because of distance and/ or 'working hours' issues.
- Commercial sensitivity, non-disclosure, protection of intellectual copyrights (IPRs) and privacy. In a supply chain, where confidentiality may have prevented organisations sharing information (since it is likely that model developers would need access each other models and hence potentially sensitive information) the creation of models that work together over a network that are private but share information, could enable the modelling of supply chains where information must be secure.
- Concurrent Development. Models can be built individually thereby enabling concurrent development in the same way that many large software packages are developed. A simulation model can be complex and as time consuming.
- Large model development. Some simulation models are built in parts and 'cutting and pasting' these models together to run in a single environment is sometimes difficult to achieve and sometimes due to the size of the simulation model, to get results from the experimentation may be too long. This is another opportunity for distributed simulation.

Kilgore (2000) also stated the benefits of distributed simulation include:

- Faster execution times of a simulation experiment through distribution of runs and alternatives to banks of available processors
- Geographic distribution of the simulation to allow more convenient collaborations

- Integration of simulations on different hardware devices and operating systems, particularly in training application
- Integration of actual systems and simulated systems for test and evaluation or control

In the 2002 Winter Simulation Conference, Taylor et al. (2002) expressed that interoperable distributed simulation had been use in many cases in the defence industry but not fully exploited in the manufacturing and service industry.

Distributed systems offer an architecture that decreases the centralisation and rigidity, and increases the flexibility of the plant. Management of complexity, changes and disturbances is one of the major challenges of production today. Distributed, agent-based structures seem to be a viable alternative to hierarchical systems provided with reactive and proactive capabilities.

2.7.6 Extending Simulation's functionality

Simulation is an experimental technique in which solutions are sought through a finite number of experiments. Hicks and Earl (2001) suggested that triangulation may be used to compare results with complementary studies. Sensitivity analysis may be used to establish the significance of various factors within the simulation. The input-output transformations can be validated using the statistical method. Persson (2002) proved with examples that the credibility of the results generated by simulation modelling depends on the level of detail input into the simulation model. Pulgar-Vidal Fancisco (2002) stated that simulation project should expand their reach beyond the creation of effective simulators but into the tasks of implementing the results created into the real world. It also stated that uncertainty is likely to evolve into a chaotic transition if the organisation embarks in a broad program of changes, where it may launch several improvement projects at once, each with its own goals and duration. These examples suggested the practicality and accuracy of simulation modelling output results are important enhancement to decision making policy of the company.

Schulze et al. (2000) created Management Simulation Models (MSM) to help manufacturers to evaluate the system capacity for new orders, for changes in an operator team and for changes in operating conditions. They help to support management of manufacturing systems for analysis of throughput and detection of bottlenecks. MSM requires a greater level of detail like complex control mechanisms and strategies may have to be implemented and must be initialised with the state of real systems. The flexible simulation languages have to fulfil requirements like management of simulation objects, flexible data structures and effective features for modelling conditions-delays.

Seppanen and Kumar (2002) used Microsoft Visio as a process map tool in the implementation of simulation in a teaching process of using simulation for business process design and improvement. And another application example is Kim et al. (2002) suggested an integrated decision making process embedded in the simulation modelling process in shop floor control with examples of application of programs.

Gahagan and Herrmann (2001) introduced the use of a production control framework that consists of components, queue controller, workstation controller and shop controller that increases the adaptability of simulation models with a wide range of production control policies to a set of simple parameters. This framework differentiates between the flow of material and the flow of information in the system, but uses the same techniques to control both. Beside the application of simulation modelling in manufacturing systems, Ladbrook and Januszezak (2001) showed that the importance of full implementation and changes required for the simulation environment to ensure the maximum benefits was gained from the investment made in simulation. Three key elements (availability, support and right tool for the job) have been identified as essential to maximise efficiency. Exploiting other components to enhance the simulation modelling application can be demonstrated in Son and Wysk (2001) as they presented a structure and architecture for an automatic detail simulation model generation direct address discrete part manufacturing system that operate single part unit loads. The methodology is used to generate an Arena simulation model from a resource mode (MS ACCESS 97) and a message-based part state graph (MPSG) base shop floor control model. There are two essential stages to be automated for automatic simulation model generation: system specification and associated model construction. Four approaches are outlined for defining the simulation model, or problem specification. These approaches are natural language interface, graphical interface, interactive dialogue interface, and the use of the existing resource and process models. A resource model and control model are used for system specification.

Simulation modelling consists of the following elements classification (Son and Wysk, 2001):

- Static information: physical and logical data pertaining to the shop, such as layout and resource information.
- Dynamic (time-varying) information: temporal changes in the system objects in state change in response to interactions with other objects.
- Interaction with external modules: the simulation communicates with an execution system and external databases like Manufacturing Planning Scheduling (MPS) and process plan.
- Default components in simulation: Additional analysis information like simulation duration, number of replicas and project information.
- Animation: displays a graphical representation of the activities taking place and conveys the status.

- Statistics required: Observation statistic and duration statistic for performance measurement and analysis purposes.

Zulch et al. (2004) presented a simulation aided approach for designing organisational structures in manufacturing systems. This approach is based on a detailed modelling and characterisation of forecasted order program, especially elementary processes, activity networks and manufacturing orders. Two software packages have been used: The organisation modelling system FORM, and the simulation tool FEMOS. Seila (2003) presented a list of the capabilities, features and limitation of spreadsheet use for simulation modelling, which summarises the benefit in integrating excel with simulation modelling. The capabilities of spreadsheets are:

- A way to represent mathematical and logical relationships between variables in the form of computations and assignment of values, and algorithms that describe how to do a series of computations
- A way to generate random numbers and use them to sample observations from various distributions.
- A means to repeat a series of computations, thus implementing replications.

Features of Spreadsheet to make the process quick and reliable:

- A large number of functions to do mathematical, statistical, database, date/time, financial and other calculations.
- Database representations and database access.
- Charting and Graphing
- Display and documentation features such as fonts, colours and geometric shapes to improve presentation.
- Automation through scripting languages such as VBA (in Excel).

Limitations of Spreadsheet:

- Only simple data structures are available
- Complex algorithms are difficult to implement
- Spreadsheet are slower than some alternatives
- Data storage is limited and two dimensional

Paul and Serrano (2003) used the insights gained during a UK funded research project, namely ASSESS-IT that aimed to depict the dynamic relationships between Business Process and Information Technology. Although its business process is different from manufacturing systems, but the information gathered indicating the advantages of the information technologies in helping process optimisation tools for design and modelling encourage the development of information technology in a manufacturing optimisation project.

Lendermann et al. (2001) proposed a framework shown in Figure 2.18 that enables integrated optimisation of business processes and operations of an enterprise. It allows an industrial user to actively manage transitions from one business model to another and to analyse the effect of changes.

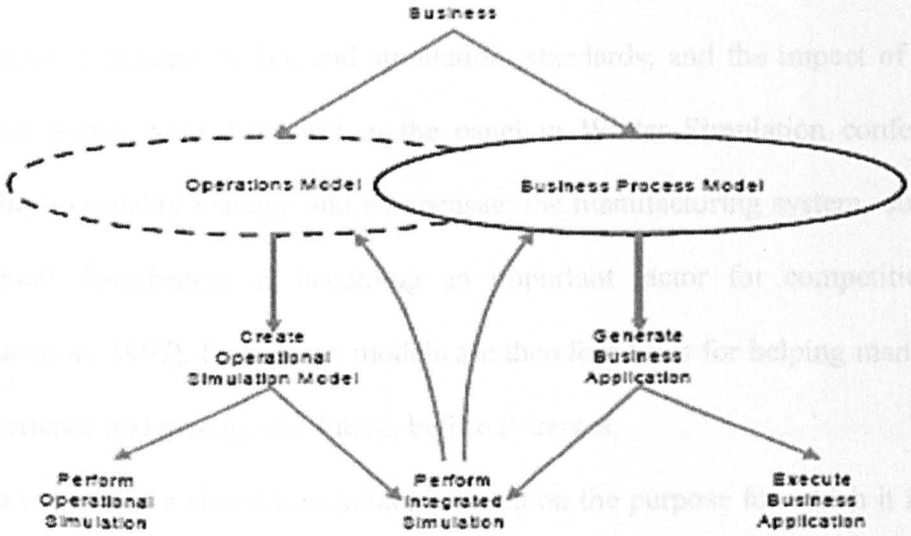


Figure 2.18 Overall framework (Lendermann et al , 2001)

The technology appears to be applicable in environments that are subject to high variability and stochastic uncertainties across the entire supply chain and where a lot of complex operational interdependencies between suppliers and customers bear significant potential for optimisation and therefore foster the search for collaborative performance improvement. The prototype being built consists of:

- A business application encompassing, in minimum, an order management system, a scheduling system, and a job tracking system.
- A simulation model of the production execution system,
- An order arrival simulator, to simulate the arrival of customer orders based on the historical data

Lendermann et al. (2001) concluded that to achieve interoperability, standards for modelling and communications protocols for data exchange between simulations models will have to be further developed.

Future challenges in simulation modelling methodology include modelling problems in business applications; human factors and geographically dispersed networks; rapid model development and maintenance; legacy modelling approaches; markup languages; virtual interactive process design and simulation; standards; and the impact of Grid computing. These issues were discussed in the panel in Winter Simulation conference 2004. The ability to quickly manage and compensate the manufacturing system, due to external and internal disturbances is becoming an important factor for competition (Jackson and Johansson, 1997). Simulation models are therefore tools for helping managers to imagine, experience and manage the future, before it arrives.

The validity of a simulation model is based on the purpose for which it is created and the assumptions that are made. The accuracy of the conclusions made based on a simulation model depends on how well the model represents the real situation or system. The closer the representation the more accurate the conclusions will be. The modellers therefore rely on the availability, accuracy, and reliability of input information to build a good simulation model. The sources of such information include company computerised information systems, written documents, subject matter experts and the mental models (intuitions) of decision makers within the organization. All these information are critical, difficult and time consuming to gather.

Earlier studies on the modelling framework form some of the enterprise integration modelling approaches, which includes GRAI (Doumeingts et al., 1987), CIMOSA (Jorysz et al., 1990; Vernadat, 1994), and TOVE (Gruninger and Fox, 1995). For example, CIMOSA suggests a modelling framework that takes into account the dynamics of control structures in business processes and can produce a process-able model of the CIM system as opposed to IDEF (Goranson, 1992; Jorysz et al., 1990; Kosanke, Mollo, Naccari, and Reyneri, 1994). The process model in CIMOSA, however, does not facilitate a complete material flow. This prevents a modeller from visualising the materials flows of the physical process and limits full development of the conceptual physical process model to identify the opportunities for operations improvement (Devereux and Wood, 1994).

2.8 Available Optimisation Tools

The optimisation of large complex systems involves identifying the correct set of operating parameters from amongst a large set of possible values. To attempt to carry out a brute force search in such a search space is time consuming and not practical.

Optimisation tools and software exist, both approximate and exact for each types of problem to reduce the time required to obtain results. Optimisation tools in the market are researched and reviewed to identify whether it can be incorporated into the framework to minimise the experimentation time to find the optimum results. Below are some examples of optimisation methods proposed by experts for various types of problems, and some are optimisation tools provided by the simulation modelling packages as a plug-in. April et al. (2001) showed several real-world applications that have been developed using an integrated set of methods, including Tabu search, Scatter Search, Mixed Integer Programming and Neural Networks, combined with simulation. Lu (2002) identifies 4 main approaches for optimising simulations:

- Stochastic approximation (gradient-based approaches)
- (Sequential) response surface methodology
- Random Search
- Sample Path optimisation (also known as stochastic counterpart)

Pierreval et al. (2003) presented a detailed study on Evolutionary algorithms, the application and summarises the solution characteristic. Brennan and Norrie (2003) developed two basis classes of performance metrics (manufacturing systems and control systems) that can be used to evaluate the relative performance of alternative control architectures for manufacturing. Danielsson et al. (2003) presented a comprehensive classification of different methods for validation, off-line programming and optimisation of industrial control logic and their respective advantages and disadvantages. The method control system emulation is concluded to be more superior. McAllister (2003) proposed an approach for robust conceptual design optimisation using Monte Carlo techniques within simulation-base design to evaluate both the mean and variance of a response. Chidambaran (2003) found that population size, fitness criteria, and the ability to seed the program with known analytical equations, are important determinants of the efficiency of Genetic Programming. In simulation approaches, April et al. (2003) examined OptFolio, a portfolio optimisation software system that simultaneously addresses financial return goals, catastrophic loss avoidance and performance probability. Lourenco and Pato (2004) stated when flexible manufacturing systems are designed within a group technology approach, numerous decision-taking processes emerge requiring control of multiple characteristics of the system. It comprises a standard genetic heuristic with appropriate operators, improved through a specific local search.

The ability to choose the best optimisation approach for the problems and areas depends on resources and expertise in house. For example, by modelling a manufacturing system using generic principles, the genetic algorithm techniques evolve a possible solution starting from an initial random solution. Depending on the formulation of the fitness function, multiple objectives can be satisfied within specified constraints. This development is rather difficult to grasp for the shop floor engineers who are domain experts and is a time consuming methodology.

Optimisation approaches can only suggest a better population of answers to be tested but not necessary point out the best solutions. A solution to a problem depends on many factors and an optimisation method could only enhance and support the decision making process. Human intervention with expertise and experience is necessary for the best solutions to be adopted.

2.9 Impact of the Internet on Simulations

2.9.1 Web-Based Simulation

The advancement in the information technology especially the internet has greatly impacted the development of simulation modelling packages and its applications. Peng (2002) proposed a framework of an industrial-oriented web-based program, linking resources and databases to User Interface accessed by SMEs. Peng stated that a web-based design and manufacturing support system may need to be supported by design information integration, remote execution of the systems, use of Java programming, client-server architecture, open computing and user interface design, and the human computer interaction. Lau et al. (2002) proposed another web-based simulation portal for

Information sharing being centralised. They highlighted the necessity and significance in sharing information in order to remedy the bullwhip effect and its associated impacts. This action simulates resource allocation, material requirement planning and rescheduling. Reichenthal (2002) did a comparison of the web and simulation in terms of structural, operational and communication to identify the advantages of incorporating web into simulation modelling. Bedrossian et al. (2000) stated that work had been done especially in the United States to construct Web-enabled simulations that have distributed analysis and simulation capability. Draper Laboratory collaborated with Yale University and Stanford University to create eSim software for web-enabled simulation. There are three versions of eSim software, the first version is a general propose simulation software, the second version adds on human factors and the last version for maintaining duplicate subsystem in a distributed simulation problem.

All the research above highlighted the importance and the growing trend to incorporate web into the simulation project to realise its full benefit and potential.

2.9.2 Web services translation and interoperability

'*Web services can be defined loosely coupled, reusable software components that semantically encapsulate discrete functionality and are distributed and programmatically accessible over standard Internet protocols*' (Sleeper, 2002)

Kilgore (2002) listed the three roles one can play in the development of web services

- Service providers, who create, expose and maintain a registry that makes those services available.
- Service brokers who act as liaisons between service providers and service requestors.
- Service requestors, who implement service brokers to discover web services, then invoke those services to create all or part of their applications.

A web service entails a connection between two applications, a remote procedure call (RPC), in which requests and responses are exchanged in Extensible Markup Language (XML) over Hypertext Transport Protocol (HTTP). XML-RPC provides critical layers of abstraction that make it simple to connect different kinds of computing systems without needing to create new standards for every application. Because XML-RPC is built on commonly available HTTP and XML technologies, the costs of implementing it are low.

The latest innovation provided in ASP. Net, the XML Web Service eases and speeds up the development of a XML translator. Web-enabled simulation and modelling is achievable by being able to manipulate XML to describe UML diagrams of the components and system to the simulation packages. XML is rapidly establishing itself as the meta-grammar for inter-organizational communication around the Internet. Daum and Sargent (2002) stated the benefits of XML and the consistent use of XML reconcile formerly disparate data formats.

- Straightforward usability over the internet
- XML documents can be processed by readily available, standardised software
- XML documents can be easily transformed
- XML documents are human-readable

XML's strongest point is its ability to do data interchange. XML makes it easier for two computers to exchange data with each other, because different organisations (or even different parts of the same organisation) rarely standardise on a single set of tools, and it takes a significant amount of work for two groups to communicate. Data is described using tags that describe what each piece of data is. XML is quickly becoming the universal protocol for transferring information from site to site via HTTP. XML doesn't replace HTML, though; they're designed for different purposes. XML is the Web's language for data interchange and HTML is the Web's language for rendering. Whereas, the HTML will continue to be the language for displaying documents on the Internet, the developers are using XML to transmit, exchange, and manipulate data. It is appropriate to use XML when the need is to send self-describing data to another machine or application. XML changes the way data moves across networks. XML encapsulates data inside custom tags that carry semantic information about the data.

General requirements of information and communication architecture are high accessibility, reliability, scalability and openness towards heterogeneous systems.

The question now would be the way XML could be able to translate the UML object – oriented diagrams into the simulation packages as simulation model.

Literatures on how UML can be mapped in XML Schema Mapping Specification stating the procedures and application had been published by Booch et al (1999). To develop the mapping between XML Schema and UML, the UML extension mechanisms (stereotypes and tagged values) are used to create new classes of UML objects to explicitly represent XML artifacts. The alternative approach would have been to specify a general mapping from UML classes to XML Schema. Such a mapping would have been applicable to a range of existing UML models. UML is chosen for the following reasons:

1. The extension approach allows users to directly model XML Schema in UML in an unambiguous way.
2. An explicit mapping makes it easier to write tools to handle only the XML content of a model and to clearly differentiate XML components from other aspects of a model.
3. Given an existing UML model, there are several issues relating to mapping it into XML, including choosing what is required and necessary to map. Having a set of stereotypes specifically for XML Schema allows for a two-pass mapping, with the first pass applying a straightforward mapping, and the second allowing for a user to

edit the results according to Bosch (1999). All elements and data types in XML schema can be mapped into classes annotated with stereotypes. A sequence number of content model elements should be included to indicate ordering in the UML representation. Example can be demonstrated in Mervyn et al. (2003) using XML schema to design the information support in an integrated manufacturing environment.

Lu et al. (2003) stated the potential obstacles of the use of XML as the standard language are:

- Computing System compatibility
- System Security
- Industry user participation
- Software vendor participation
- Wide acceptance of the XML-based simulation standard

Although there are limitations in using XML as the industry standards but the benefits and common applications of XML suggested that XML will continue to be used as a translation language between software.

2.9.3 Standard language platform with .Net Technologies

A standard platform where most software in similar industries can communicate will benefit all parties involved. Microsoft.Net technologies seem to be able to perform many criteria needed to web-enable the simulation model and use it as a standard platform to communicate between different software. Several researchers have based their work in .Net technologies. Kilgore (2002) a key player in using and promoting .Net technologies in simulation modelling, has examined the role of standards in the establishment of platform-neutral and language-neutral design patterns for object-oriented simulation libraries. The challenge is to balance competing desires for encapsulation of the structural representation of simulation objects and convenient, flexible and efficient control of objects. He also examines the potential for interoperability through a common open-source simulation software specification possibly implemented in .Net language. The role that web services could play in the evolution of standards for interoperable software applications and the opportunities this creates for standards for interoperable simulation applications and components is also examined. Web Services are a 'stack' or 'layers' of standards that enable one software application to interoperate with another application. Kilgore (2002) stated while web services can be implemented with .Net but web services are an industry standard and not proprietary to .Net or Microsoft. In 2003, Kilgore presented a tutorial for advanced simulation developers engaged in the use of object-oriented programming languages and libraries that support object-oriented, discrete event simulation. The focus is on the use of consistent design patterns that encourage usability, reusability and cross language compatibility. Emphasis is placed on designing and coding object-oriented simulation models to properly transfer simulation control between entities, resources and system controller. The emphasis and reviews by Kilgore, who focuses mainly on web- enabling simulation models with .Net had reinforced the importance of object oriented design in simulation modelling and integration to the web.

Besides Kilgore, Bosch (2003) described the philosophy, architecture and key features of a .Net-based simulation object model and a toolkit called HighMAST (Highpoint Modelling and Simulation Toolkit). HighMAST is a set of class libraries build on top of Microsoft's .Net platform. It addresses the needs, foundation solidity, modern development method and architecture freedom. The core engine is written in C# using a high performance algorithm and focused multithreading capability for performance, and the object-oriented architecture for comprehensibility and accessibility. Full-featured libraries include queues and events, resources and resource pools, collection classes of many types, PERT and CPM analysis modules, executives, and a base level model class with high customisation application state machine.

2.9.4 Integration Framework

The following examples are research and development examples of integration projects which include the simulation model as part of the framework to enhance performance in their area. For example, Jain et al. (2001) created sub-models representing the major sub-systems in the factory through a virtual factory shown in Figure 2.19.

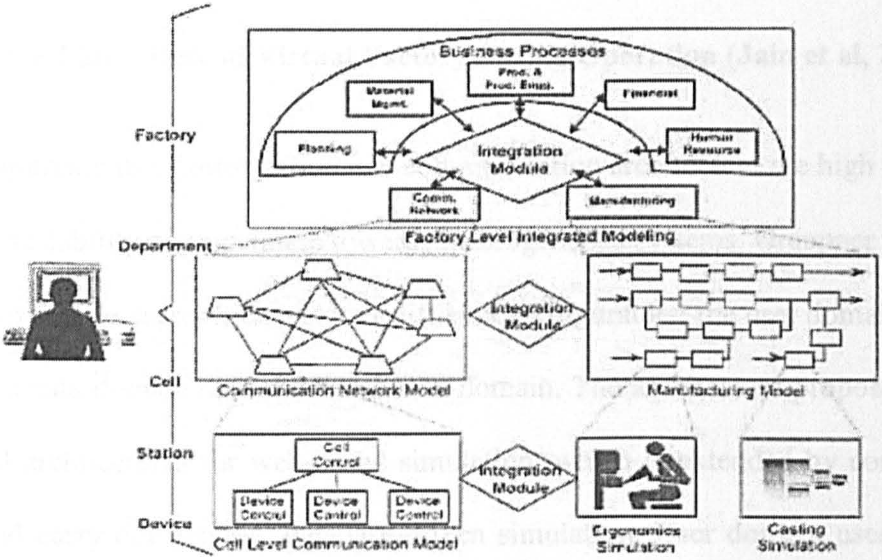


Figure 2.19 Proposed Functionality of Virtual Factory during Design and Installation (Jain et al, 2000)

This model includes a continuous improvement section with new technology, changes in requirements and suggestion introduction feeding into the virtual factory with performance measure, comparison with requirements, suggestion of corrective measures and recovery actions. A database with process sensors and product Quality Assurances and performance data feeding into the virtual factory from the actual processes (i.e. factory, cell, department, station and devices) is in the model shown in Figure 2.20.

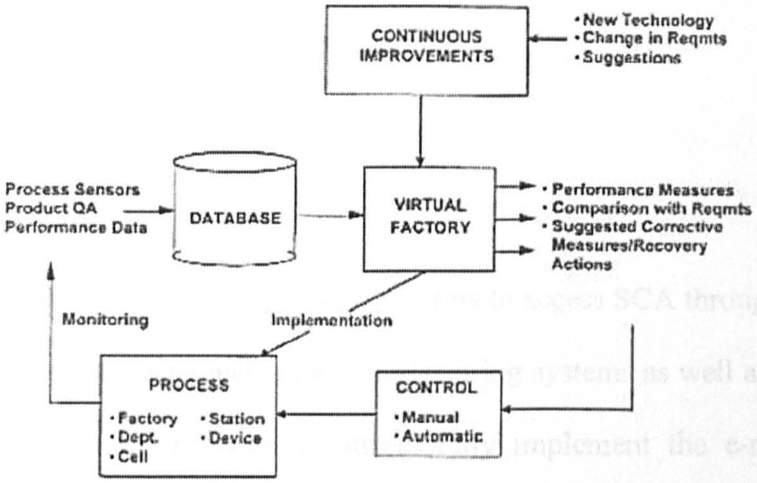


Figure 2.20 Role of Virtual Factory during Operation (Jain et al, 2000)

General requirements of information and communication architecture are high accessibility, reliability, scalability and openness towards heterogeneous systems. Graupner et al. (2002) proposed an architecture which has four different configurators: the user domain, the portal domain, the data domain, and the simulation domain. The architecture proposed is similar to standard architectures for web-based simulation, which is extended by components to manage and carry out generic, database-driven simulation. User domain uses HTTP and Java applet to run, portal domain uses GUI, data domain and simulation domain uses databases and SQL interface.

Chen et al. (1999) developed eSCA, a client server, web-enabled architecture and front-end system for IBM's Supply Chain Analyzer (SCA), a software tool and methodology for measuring, analysing and reengineering complex supply chain through a computing network with server-based and web-enabled functionality. Use case modelling has been utilised for graphical modelling.

The eManager version provides the functionality below:

- Interactive modelling (remote and local)
- Model catalogues library

- Seamless model/life transfer
- Batch experiments
- Post-simulation data analysis
- Web-enabled SCA

The web-enabled version provides a rapid way for users to access SCA through the web.

Lee (2003) discussed the fundamentals of e-manufacturing systems as well as the enabling tools for its implementation. In order to successfully implement the e-manufacturing systems, the followings need to be developed (Lee, 2003):

(a) predictive intelligence (algorithms, software and agents),

(b) scalable platform,

(c) common information communicator between devices and business,

(d) data-to-information-to-knowledge transformation tools,

(e) synchronisation systems for dynamic decision-making,

(f) tether-free communication systems to achieve flexible and low-cost installation of remote, online-monitoring,

(g) education and training for understanding the overall structure, and

(h) a new enterprise culture that has the flexibility of local dynamic decision-making and strength of global competition.

E-manufacturing is a new trend of enhancing manufacturing performance with computing technology, simulation modelling and integration with other applications definitely play an important role.

Eisenring and Platzner (2002) proposed a framework for a run-time reconfigurable system in computing to provide a methodology and design representation which allows plugging in different design and implementation tools. Front-end tools cover design capture, temporal partitioning and scheduling; back-end tools provide reconfiguration control, communication channel generation and final code composition.

All these large integration which involved not only simulation modelling experts but computing experts are great effort in developing the system to benefit the users and the industry.

2.9.5 Grid Technology

Grid Technology is a new technology and is reviewed in this research, as its benefit and development greatly enhance the performance of the proposed simulation framework. This research may not be able to apply the computing power supplied through Grid technology but the potential is high and hence the interest shown in this research. Academic applications of Grid computing are more focus on Molecular Sciences, Physics, Astrology and Logistic, rather than in manufacturing studies. In United Kingdom most current running Grid Project are focussing mostly on Sciences like biochemistry, bio informatics and more.

These are the topics of interest in the annual Grid conferences (e.g. Euroweb Conferences 2002, Cluster Computing and Grid Conference 2005, The 7th IEEE International Conference on Grid Computing, 2006) but are not limited to:

- Programming Models, Tools, and Environments
- Remote Data Access and Management
- Grid Middleware and Toolkits
- Grid Monitoring, Management and Organization Tools
- Internet-based Computing Models
- Performance Evaluation and Modelling
- Grid Architectures and Fabrics
- Cluster/Grid Integration Issues

- Grid Information Services
- Grid Security Issues
- Grid Object Metadata and Schemas
- Grid Applications
- Resource Management and Scheduling
- Computational Economy
- Advance Resource Reservation and Scheduling
- Scientific, Industrial and Social Implications

Although the topics suggested in the list above do not directly benefit the manufacturing sector, but the development and concepts used in computing can be extracted to help the computing issues in the integration of simulation model package and other components to provide a better solution package to users.

Reinefeld and Schintke (2002) had proposed a paper on concepts and technologies for a worldwide Grid infrastructure. Grids have been established as a new paradigm for delivering information, resources and services to user, and also manipulating distributed computing to speed up the process. The Grid Infrastructure is divided into three categories and its definition according to Reinefeld and Schintke (2002):

a) ***Information Grid*** delivers information on any kind of topic to any place in the world. Information can be reviewed by connecting a computer to the public telephone network via a modem, which is just as easy as plugging into the electrical power grid. This is a distributed, dynamic, and highly flexible environment, which is similar to the archive service that was used in early years of the Internet to locate files on ftp servers for downloading.

b) The ***Resource Grid*** provides mechanisms for the coordinated use of resources like computers, data archives, application services, and special laboratory instruments.

The core idea behind Resource Grid is to provide easy, efficient and transparent access to any available resource, irrespective of its location. Resources may be computing power, data storage, network bandwidth, or special purpose hardware.

c) The third kind of grid, the ***Service Grid,*** delivers services and applications independent of their location, implementation, and hardware platform. The services are built on the concrete resources available in the Resource Grid.

A major point of distinction between the last two grids lies in their abstraction level: The Service Grid provides abstract, location-independent services, while the Resource Grid gives access to the concrete resources offered at a computer site (Reinefeld and Schintke, 2002). Parallel distribution in the Grid structures plays a vital role in the application. The Service Grid provides the platform for the simulation to run distributed simulation with the specific optimisation rules applied to it. This enhances the performance of the simulation engine with faster speed and accuracy.

ENACTS- Grid Enabling Technologies organisation report in 2002 provided information that there are test beds and application project carrying out. They are Globus, Legion and UNICORE. There are Grid Molecular simulators on quantum chemistry, atom-diatom collisions, bioGrid, Charmm, Folding@Home and DMMVLBCN, various implementations that had been put to work. Although this is not directly related to manufacturing industries, but the technologies once proven successful can be transfer to manufacturing system optimisation.

2.10 Summary

Various areas of important topics are researched and reviewed in this literature review. Manufacturing industry is getting more challenging and a lot more effort and technologies are needed to deliver the expectation of the modern day customers. Philosophies for improvement are introduced and technologies are deployed to push the standards higher.

Manufacturing systems need to be revamped with new concepts and optimisation methods. The structure of manufacturing systems is changing to adopt the current market demands, and hence re-structuring is inevitable. Simulation modelling has been widely used but is not benefiting the manufacturing sector enough due to issues like lack of expertise and time consumed in constructing a model. The applications and benefits in the literature review proved the tool to be a most suitable tool to study the dynamic nature of the manufacturing system. Other applications that can be integrated to the simulation model are important to provide the services user expect. Process mapping techniques that form the front end of the simulation modelling project needs a standardise format to help users to describe the system in a more structured and complete manner. The Object-oriented approach is adopted for manufacturing system classification to realise the benefit of re-configuration and scalability. Web-based and standard platform integration to all types of simulation modelling packages is lacking behind hence the investment and development in the area. Other computing technologies like Grid will enhance the performance of the integrated simulation modelling framework making the tool more feasible and attractive.

Chapter 3 Manufacturing Classification with Object-oriented Representation

In this chapter, the classification of manufacturing elements are researched and described. The classification of the manufacturing elements is represented with object-oriented process mapping techniques. The object-oriented approach to model a manufacturing system is explained and illustrated. The generic features of manufacturing system from the classification are represented with UML diagrams for further integration to simulation model design. Section 3.1 discusses the manufacturing system classification and process modelling techniques. Sections 3.2 to 3.4 introduce the object oriented approach with the importance and contribution of UML diagrams. Section 3.5 and 3.6 presents the modelling concept involving a manufacturing system and explains design patterns. Example of system development with UML diagrams is provided in Section 3.7. Integration to software is described in Section 3.8. The objectives of this chapter are to explicitly represent manufacturing systems by encapsulation decision making in objects as part of the architecture, providing flexible methods for a scenario generation.

3.1 Manufacturing Classification

According to McCarthy (1995) classification enhances knowledge and understanding and enables predictions to be made about the manufacturing system behaviour. Engineering Systems Division of Massachusetts Institute Technology (MIT, 2002) has attempted to categorise classification studies into three types. First is an academic activity that indicates interest in forming a field of study and by analogy with other fields; a classification framework has often been a major step forward, and a significant accelerator to the development of a field. Second, the development of a framework for classification of manufacturing systems may help delineate the "intellectual boundaries" of engineering systems. The differentiation of manufacturing system from other complex systems is for this purpose. The third, and perhaps most important, reason for attempting to classify manufacturing systems is to contribute to the engineering and design of such systems. Achievement of this goal could be facilitated by differentiation between different classes and components of manufacturing systems. As the modern world relentlessly evolves towards a highly interactive and interdependent complex set of manufacturing systems, improvement of the ability to design such systems is becoming crucial.

As part of the useful background for this research, the working definitions used at MIT for *systems, engineering systems* and *complex systems* are as follows (Engineering Systems Division, MIT, 2002):

System: a set of interacting components having well-defined (although possibly poorly understood) behaviour or purpose; the concept is subjective in what is a system to one person may not appear to be a system to another.

A useful schema might suggest the most viable modelling and representation techniques to apply in different categories.

Engineering System: a system designed by humans having some purpose; large scale and complex engineering systems which are of interest to the Engineering Systems Division, will have a management or social dimension as well as a technical one.

Complex System: a system with numerous components and interconnections, interactions or interdependencies that is difficult to describe, understand, predict, manage, design, and/or change.

McCarthy (1995) grouped the existing methods of manufacturing systems classification into five general headings, as shown below:

- operational characteristics (job, batch, mass, project, intermittent, continuous, etc.);
- operational objectives (make to stock, make to order, etc.);
- operational flow structures (flowlines, group technology, etc.);

- a detailed sub-classification of one of the above (batch, flowline);
- a combination of one of the above.

These classification headings are supported by Constable and New (1976), who stated that all manufacturing systems can be defined by three characteristics: product structure, organizational structure; (flowline, cells, functional layout, etc.); and the nature of customer orders (make to stock and make to order).

The position of an operation on the volume-variety scale identifies the general approach to take in managing the operation. In manufacturing, these process types are traditionally grouped in order of increasing volume and decreasing variety as:

- Project/ Fixed Processes
- Jobbing Processes
- Batch Processes
- Mass Processes
- Continuous Processes

In most companies, there will not be a clear single process type. Most of the time, there will be combination or even different process types embedded in a large system. Four case studies analysed in this work provide examples of mixed and pure process types and layout. The case studies have provided a range of manufacturing systems with a wide range of attributes and characteristic. Theory building to identify key variables, the relationships and why the relationships exist is carried out with each case study. Some key managers of the system are interviewed and observations in the real environment are performed.

3.1.1 Representation of a manufacturing system

A manufacturing system is composed of an information control system as well as physical processes. The physical processes are concerned with the physical structure and flow of materials in the system for conversion and delivery of a product. The control information system in a manufacturing environment ranges from the highest level planning requirements of production schedules to the lowest level detail of machine control logic.

A manufacturing system consists of entities which relate to one another through some type of transaction. These entities exhibit specific behaviour patterns. The essential modelling problem is to reproduce the aggregate effect of individual behaviours, typically by representing the relevant entities, their behaviours, and transaction. Simulation software provides the means for creating, executing and observing these representations. The initial stage of representing all entities in a manufacturing environment is a time-consuming and complex. The approach presented in this research is based on an extensive domain analysis of discrete-part manufacturing systems.

The analysis of manufacturing systems usually entails an initial stage of understanding the system behaviours through some type of mapping of the problem involved. This is to identify problem areas such as bottleneck and disruptive areas. Not all problems lie in the system bottleneck. In many cases, the problem might not be in the resources; but in how they are managed in terms of scheduling, repetitive un-required handling or simply the case of unorganised layout and tools. Various techniques have been used to deal with each type of these problems in the subsequence stages. The issue in some cases is to find the best approach rather than first.

Many tools and modelling techniques have been introduced to assist developers in this critical task. Modelling techniques are useful in reducing the inherent complexities of manufacturing system description. The initial manufacturing system model must capture the nature of the system by describing system objects, flows, systems functions and processes. Hence a modelling language for system design must possess the following properties, some of which are based on Enterprise Modelling by Yu et al. (2000):

- It must be able to describe system entities, and the function and behaviour of the system;
- It should provide a unified platform that integrates system entities, flows and behaviour;
- It must be simple and understandable to developers and system experts;
- It must be capable of representing the system in a common software;
- It should be scalable.

3.1.2 Manufacturing System Elements

The physical entities and information control flows in each manufacturing system are different, but all manufacturing systems have fundamental elements, for example process. Five essential static classes have been identified, i.e.

- Process (e.g. Machining or Cleaning Workstations)
- Product (e.g. Windows or Doors)
- Resources (e.g. Facilities or Operators)
- Support Activities (e.g. Maintenance or Changeover)
- Flow (Physical Flow and Control Flow) (e.g. Parts Flow or Replenishment Signal)

A simple interaction diagram of components derived from the case study is illustrated in Figure 3.1.

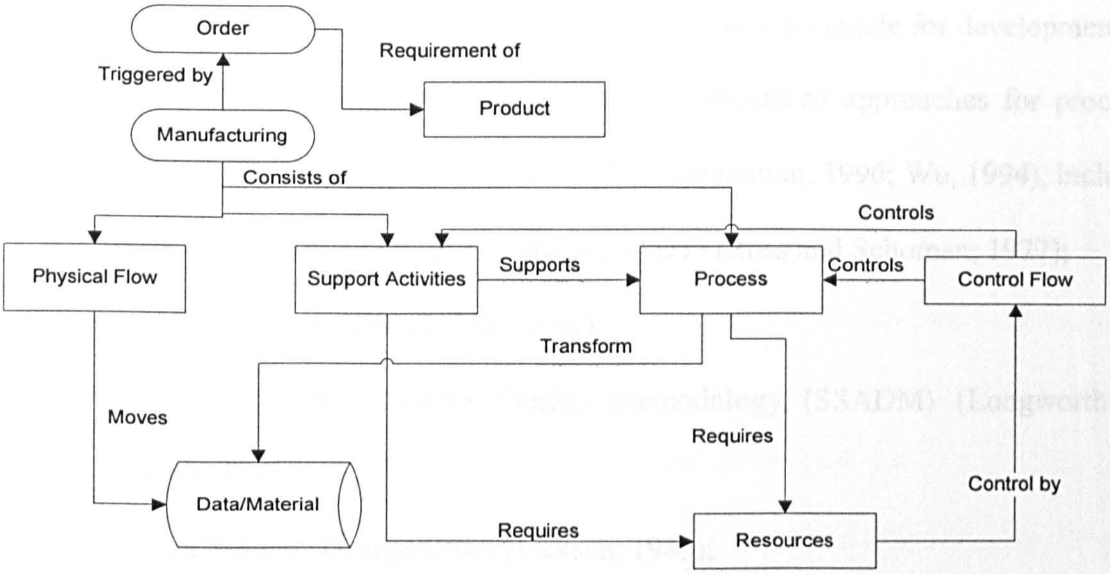


Figure 3.1 Sample of Manufacturing System Interactions

The manufacturing system is triggered by a product's order needs. The order is the requirement of a product. A manufacturing system consists of flows, support activities, and processes. The sole objective of the manufacturing system is for the processes to transform the data/material into products and services. The process requires resources like facility and labour, which controls by the control flow that carries out the processes. Support activities like maintenance require resources as well as support and affect the processes of the systems. The flow consists of physical flow which moves the data or material and control flow which controls the process, resources and support activities.

3.2 Process modelling methodologies and tools

Process mapping simply involves describing processes in terms of how the activities within the process relate to each other. There are many techniques which can be used for the process mapping. However, all techniques have two main features:

- They identify the different types of activities in the process;
- And they show the flow of materials or people or information through the process.

Process modelling methodologies originated from systems analysis which provided a detailed graphical description of business activities. The value of process modelling is well documented and noted for illustrating the big picture and as a vehicle for development and communication (Williams, 1994). Several different structured approaches for processes modelling have been identified (see, for example, Colquohoun, 1996; Wu, 1994), including:

- Structured Analysis Design Technique (SADT) (Ross and Schoman, 1977);
- Icam Definition (IDEF) (USAF, 1981);
- Structured System Analysis Design Methodology (SSADM) (Longworth and Nicholls, 1986);
- Jackson Systems Design (JSD) (Jackson, 1983);
- Structured Systems Analysis (SSA) (Gane and Sarson, 1979);
- Group de Recherche en Automatisation Integrere (GRAI) (Domeingts, 1985);
- Soft System Methodology (SSM) (Checkland, 1984);
- Data Flow Diagrams (DFD) (DeMarco, 1979);
- Concept Mapping (CM) (Neely and Byrne, 1992);
- Unified Modelling Language (UML) (Fowler and Scott, 1997); and
- Architecture for integrated Information Systems (ARIS) (Scheer, 1998).

The above are a mix of software and process based process modelling techniques. An appraisal of most process modelling tools can be found in *Process Product Watch* (Enix Consulting, n.d.). The major drawback of most of these traditional process-modelling approaches and tools is that they attempt to represent a dynamic system with a two-dimensional "static" image. According to Wu (1995), early research into Advanced Manufacturing Technology revealed a need for a medium that would assist communication between systems analysts. As a result, methodologies were developed in an attempt to quantify and communicate system concepts. Icam Definition (IDEF) is one of the system description techniques evolved from earlier techniques of Structured Analysis Design Technique (SADT). The term IDEF stands for Integrated Definition. It was developed by the US Air force to describe the information and organization structure of a complex manufacturing system. IDEF0 is a technique that can be used to specify completely the functional relationships of any manufacturing environment. IDEF1 is used to describe the relationships of any manufacturing item in the environment, such that a relational database model may be specified. IDEF2 is a simulation technique that can be used to investigate a system's dynamic behaviour. IDEF3 is for process design, and the latest addition, IDEF4, is an object-oriented approach to manufacturing software development.

These techniques may be used independently. IDEF0 is a methodology for the static functional specification of a manufacturing system. It is used to produce a functional model which is a structured representation of the functions of a manufacturing system and the flow paths of information and objects which inter-relate those functions. It is by nature of a 'top-down' approach. This type of approach exposes one new level of detail at time, that is, it begins the description process by modelling the system as a whole at the highest level and then decomposing the model level by level to describe each of the sub-systems within the system hierarchy (Wu, 1995).

The IDEF methodology has been utilized for many types of systems design situation and gained wide recognition as a powerful system description tool, particularly in the field of manufacturing systems engineering. However, of all the currently available tools for system description, none can be said to be the best for all purposes. When choosing the tool for a particular investigation, the advantages and disadvantages of the options should first be examined. This, of course, also applies to IDEF0. The IDEF series (IDEF0, IDEF1, IDEF1X, IDEF-TD, IDEF2, IDEF3) appear to be the most favoured in manufacturing. Examples of IDEF applications to aid BPR can be found in Bradley et al. (1995) and Kusiak et al. (1994).

GRAI integrated methodology (GIM) uses entity relationship diagrams (ERDs) and network models taken from SSADM and uses IDEF0 for operational modelling according to Barber et al. (2003). GIM is a combination of several static business mapping techniques by making use of GRAI grids and nets. While ARIS takes a functional perspective balanced by organisational or resource perspective using event drive process chains (EPCs); and uses an organisational chart for modelling human resources. Purdue enterprise reference architecture (PERA) is not a modelling framework but a detailed method for introducing computer integrated manufacture (CIM) and has been integrated into the generalised enterprise reference architecture and methodology (GERAM), which is a revision of the Computer Integrated Manufacturing Methodology Open Systems Architecture (CIMOSA) according to Barber et al. (2003). CIMOSA combines the ideas of IDEF, GIM and ARIS (Vernadat, 1996; Kosanke and Zelm, 1999; Berio and Vernadat, 1999) while GERAM has taken CIMOSA from being a reference architecture to a full scale methodology which can be used for implementing software, CIM, etc. Notation is critical in the process modelling. From Oscarsson and Moris (2002), the selection of notation or modelling tool to represent a system should consider the following criteria: neutral notation, generic notation, a recognised notation, user friendly, descriptive in several levels, and the in-house competence. These criteria also showed the future trend of the modelling technique.

3.2.1 Limitations of the Current Methodologies

Many process improvement methodologies consider only a single process or a small specific area and allow improvements to that one process, but do not always consider the effect of the changes on other processes within the system. It may be that improvements to the studied process or area may have a detrimental impact on the system as a whole. To be absolutely sure that process improvements benefit the system, then sometimes the entire system should be modelled and evaluated. It follows that a simulation model of the entire system should be developed. The results of studies show that when applied to small and discrete manufacturing processes, integrating static and dynamic modelling methodologies works extremely well. However, there are questions surrounding the application to large interrelated manufacturing processes and ultimately an entire manufacturing system. Static modelling tools are capable of building large models of complex systems but they cannot deal with the additional complexity imposed by the temporal perspective. Conversely, dynamic tools are not sufficiently scalable (due to hardware and software limitations) to allow the creation of large business models. Furthermore, when small individual process models are joined into a large hierarchical construct, the resultant model quickly becomes too big to run effectively. The time required to build to an entire system might not be available and tracking the source of problem and disruption of the system become difficult. Many existing tools are incompatible or require significant programming and software engineering skills beyond those normally found in most companies. An earlier observation was that business models are best created within a static modelling tool while for smaller scale processes, discrete event simulation models could be easier and faster to build. It follows that the creation of process models usually requires detailed knowledge of more than one modelling tool. Specific skills of this type are not usually available within many manufacturing companies. Companies that do possess a process modelling capability will rarely have more than one modelling tool and since they are not usually used on a day-to-day basis, the skills of the people who work with the models are frequently not maintained. Furthermore, as tools and techniques improve, so it is increasingly difficult for personnel to keep up to date.

IDEF0 is well suited for documenting the flows in a simulation model. It does not cover all the aspects of the model documentation and do not say much about the low-level logic, structure or dynamics. It cannot handle parallel processes well, but it plays an important role in giving an overall understanding of the simulation model. The quality of being comprehensive and broadly used among engineers makes the IDEF0 model documentation a good choice. Unified Modelling Language (UML) is useful to describe smaller parts of the system e.g. class diagrams to visualise the structure of elements and their associations, or sequence diagrams to give a more accurate descriptions of the element behaviour. The problem with UML is that not many people are familiar with the notation and the magnitude of the diagrams. Flowcharting on the other hand is a more popular tool used. The strengths of flowchart lie in their descriptive and intuitive syntax. Their weakness is that they can be complicated as the size grows with lots of branches which make traceability hard.

3.3 Introduction to the Object-Oriented Approach

The object-oriented paradigm provides a powerful solution to the process modelling needs of organisation in an ever-changing competitive environment (Shelton, 1994; Taylor 1994). An Object-oriented system is modelled at the level of individual entities within a problem domain. Decomposition of a problem domain with an OO approach is based on classification of objects and their relationships with each other, resulting in system entities which are self-contained in terms of their operations and the corresponding data, and that communicate explicitly with each other. The fundamental characteristics of the object-oriented approach listed below defined by Bennett et al. (2001) provide capabilities that could greatly improve the quality of modelling.

a) **Classification.** Under the object-oriented approach, real world phenomena (a process, activity or actor) are perceived as whole entities.

b) **Encapsulation.** All aspects of a given phenomena are encapsulated or contained within the representation of a class. An object represents the physical occurrence, or instance of a class of phenomena. Objects are the instances of a class that have been identified within the modelled system.

c) **Message Based Communication**. Communications is achieved through messages from one representation to another, no other interaction.

d) **Inheritance**. Specification of classes within an environment can be conducted at varying degrees of abstraction. Classes, have the ability to share their properties with more specialised forms of themselves, this is referred to as inheritance.

e) **Polymorphism**. Related to inheritance between classes in the object-oriented approach is the ability of classes, or more specifically object, to hide information. Polymorphism in terms of an object-oriented model means that a single message or command can have many meanings based upon the recipient of that message. A subclass interprets the meaning of a message based upon the internal definition of that message.

3.3.1 Industries Application of Object-Oriented Approaches

Traditional approach of simulation modelling direct map the system which do not include clear classification of elements that may lead to difficult in reconfiguration and reusability of the components. This section provides a quick overview of how object orientation has been used in industrial approaches. Georgian technology in USA has proposed a system named OOSIM in 1996 to direct mapping and model complex manufacturing system with high fidelity (Narayanan et al., 1998). The software is implemented in C++ and runs on Unix work stations. It uses X windows and OSF/Motif for graphical interfaces. Rather different from the architecture proposed in this research to use COTS simulation packages and more common software packages in the market. DEVS developed at the University of Arizona, USA proposes a methodology and software implementation with application to autonomous systems (Narayanan et al., 1998). OSU-CIM developed by University of Oklahoma State University, USA to modelling and simulation of discrete parts manufacturing systems, with emphasis on the separation of modelling processes from problem solving activities (Narayanan et al., 1998).

Flexsim is another UML based modelling tool developed by Artisan Software Tool Kit using C++ programming (www.flexsim.com). Flexsim is an object-oriented software environment used to develop, model, simulate, visualise and monitor dynamic flow process activities and systems. The Flexsim concept increases the value and lifecycles of model because objects are reusable and the models can be used on operational basis for either defining or for monitoring real systems.

The above are all the examples of researches and applications carried out to prove the feasibility in generating simulation architectures with an object-oriented modelling approach. Looking away from manufacturing system simulation modelling, the current pursuit in the area is to generate a standard business process modelling languages, which in some way is a representation of a workflow process. Business Process Modelling languages are still evolving, but the current contenders are all based in web-based workflow. There are five major business process definition languages being specified (Weyland and Engiles, 2003):

- Business Process Modelling Language (BPML)
- Business Process Execution Language for Web Services (BPEL4WS)
- XML Process Definition Language (XPDL)
- Unified Modelling Language (UML) 2.0
- Enterprise Distributed Object Computing (EDOC)

The Business Process modelling Initiatives (www.BPMI.org) developed an open specification for standardising the management of business processes that span multiple applications, corporate departments, and business partners, behind firewall and over the internet. BPMI.org defines open specification such as the Business Process Modelling

Language (BPML) and the Business Process Query Language (BPQL) that will enable the standards-based management of e-business processes with forthcoming business process management systems (BPMS), in much of the same way SQL enabled the standards-based management of business data with off the shelf database management systems (DBMS). BPMI.org complements initiatives such as J2EE, and SOAP that enable the convergence of legacy infrastructures toward process-oriented enterprise computing. BPML is a meta-language that provides an abstracted execution model for collaborative and transactional business processes based on the concept of a transactional finite-state machine. BPML suggested the XML schema for enabling the persistence and interchange of process definitions across heterogenous systems and modelling tools.

A conceptual model of a manufacturing system can be developed with various techniques. There are techniques like IDEF system definition and Hierarchical and Object-oriented Manufacturing System Analysis and Definition (HOOMA) presentation of OHMS structure (Wu, 1995), which can describe and map the processes and activities of manufacturing system in hierarchical form. Both of the techniques provide different systematic steps to describe the manufacturing system. Both of them have strength and weakness. IDEF is more of a functional and operational approach to process modelling, where HOOMA approach provide vital procedure for detail object-oriented modelling.

HOOMA utilises the useful features of the general methods of O-O analysis, Object-Oriented Analysis (OOA) and Hierarchical Object-Oriented Design (HOOD), but is developed to support specifically the requirements of system analysis and definition within the manufacturing context (Wu, 1995). This methodology has influenced this research. The method aims to bridge the division between a function-based approach and the pure O-O approaches. With a HOOMA model the flexibility needed due to recurrent organisational changes can be catered for. Class and objects may be added or changed without the necessity of significantly altering an existing model. In addition, HOOMA has the advantage of being able to represent dynamic aspects of advanced manufacturing system in terms of object states and interactions. However, the methodology is still in its development stages, end-end process modelling still required further attention and work. The analysis procedure of HOOMA is summarised in Figure 3.2, which shows the steps to be followed, the graphical tools related to these steps and the iterative process followed. A complete conceptual model of a manufacturing operation may require several such iterative cycles. This methodology provides the background to prove that the object-oriented approach is feasible in the integrated simulation architecture.

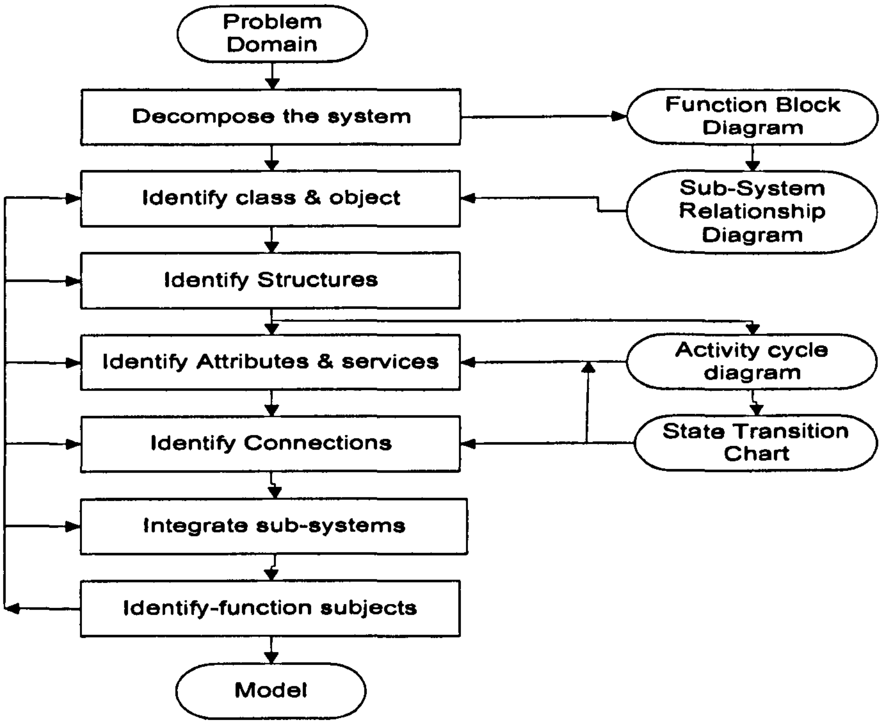


Figure 3.2 Summary of HOOMA Procedure (B.Wu, 1995)

3.4 Introduction to UML Diagrams

From the literature review, the Unified Modelling Language (UML) has been widely adopted by the software engineering community and its scope is broadening to include more diverse modelling tasks. The UML is neither a software development process model nor a system development life cycle tool. It is merely a notation/schema. The UML notation is used in a number of software process models to describe how the project flows through stages of development, and systems development life cycles, and to describe the steps necessary to complete phases of the project. In addition, many existing methodologies (including Hewlett-Packard's Fusion, Microsoft's Solution Framework, and Rational Software's Objectory) have incorporated UML into their methodologies.

UML was designed to give all those involved in the development process an organised and practical way to communicate about the systems during its development.

UML is collectively broken into three key views of an application: the static view, which is modelled using the use-case and class diagram; the dynamic view, which is modelled using the sequence, collaboration, and state transition diagrams; and the functional view, which can be represented by activity diagrams and more traditional descriptive narratives such as pseudo code and mini-specifications. There is actually a fourth view which overlaps with the static view called the architectural view. This view is modelled using the package, component, and deployment diagrams.

UML concepts and models can be grouped into the following concept areas.

- Static structure
- Dynamic behavior
- Implementation constructs
- Model organization
- Extensibility mechanisms

Ontologies include class/subclass hierarchies, relationships between classes, class attribute definitions and axioms that specify constraints. In UML, this ontology information is usually modelled in class diagrams and Object Constraint Language (OCL) constraints. Other UML diagrams such as state charts and activity diagrams are also useful for service and process-related ontologies. There are a number of good reasons why UML is a promising notation for a modelling approach:

- UML is a graphical notation based on many years of experience in software analysis and used by a variety of companies in a wide spectrum of industries and domains.
- UML is an open standard maintained by the OMG.
- UML has standard mechanisms for defining extensions for specific application contexts such as ontology modelling.
- UML is widely adopted in the software industry and taught in many university courses. Current techniques for ontology development are based on knowledge representations such as Knowledge Interchange Format (KIF) which are not widely known outside the AI research community.
- Real-world industrial agent-based systems need to interact with legacy enterprise systems, which often have existing UML models.

3.4.1 Manufacturing System Modelling with UML

The development of the object-oriented process mapping technique using various UML diagrams in the simulation and modelling area is driven by the desire to simplify or improve the process of creating simulation models. Of necessity, the resulting architecture will reflect the way in which its developers view and think about the application domain. In any discrete-part manufacturing system, raw materials enter the system. The materials are then transformed by resources including processing and movement, and finished products leave the system. Traditional simulation model, represent resources and queues but usually ignore the low level interactions in a manufacturing system that represent information flows. It is critical to expand the top level view in order to develop object-oriented representations of entities and their relationships in a complex system.

The decomposition of a system may be achieved in two different ways.

a) First, the system may be tackled bottom-up, i.e. the true Object-oriented fashion. One would approach the system and begin to identify Class & Objects. Once all the class and objects have been identified along with the attributes, services, connections and structures, these small components can then be integrated.

b) Secondly, the decomposition of a system can be based on sub-systems related to functions within the system. This step specifies the overall hierarchical structure of the system, and is very much a top-down approach. This seems in conflict with the pure object-oriented concept, but makes practical sense since a completely bottom-up process based on pure object-oriented concept is rather difficult to apply within the manufacturing context.

Alternatively it is feasible to adopt a hybrid approach in that the traditional top-down view is employed initially to produce an overall picture of the system and the bottom-up view can then be applied effectively.

UML has quickly been adopted as the standard modelling language for modelling software systems. The same modelling language can be used for the business models as for the software models (Eriksson and Penker, 1999). This research proposes a similar goal where UML is adopted for representing manufacturing system models. UML was defined to model the architecture of software systems. Even though there are similarities between software and business systems, there are also some differences. Manufacturing systems have many concepts that were not intended or suitable to execute in a program, such as the operators working in the shop floor, manufacturing production equipments, and rules and goals that drive the processes. Due to this, UML needs to be extended in order to more clearly identify and visualize the important concepts of processes, goals, resources, and rules of a business system. To address this limitation, a set of extensions based on the existing model elements of UML were created.

These extensions provide symbols for modelling the processes, resources, rules, and performance of a manufacturing system. These extensions form a basic framework for manufacturing extensions to UML (rather than a definitive set of manufacturing extensions) from which a manufacturing architect can add stereotypes or properties suitable and customised to the system.

According to Eriksson and Penker (1999), the standard extension mechanisms in UML that allow UML to adapt and to accommodate new concepts are:

a) **Stereotypes.** An extension of the vocabulary of the UML, which allows new building blocks from existing ones but specific to a problem to be created (Booch, 1998). Stereotypes may have their own visual icons that replace the icon which the existing UML element uses.

b) **Tagged values (properties).** An extension of the properties of a UML element, in which new information in that element's specification can be created (Booch,1998).

c) **Constraints.** An extension of the semantics of a UML element, allowing new rules to be added or modifying existing ones (Booch, 1998).

Although different manufacturing systems have different final aims and internal structures they use similar concepts to describe their structure and operation, and it is to represent these concepts the extension mechanisms in UML can been used for this purpose. The primary concepts used when defining the manufacturing system are:

a) **Resources.** The objects within the manufacturing system, such as tools, facility, labour, material, handling, and supplier that are used or produced in the system. The resources are arranged in structures and have relationships with each other. Resources are manipulated (used, consumed, refined, or produced) through processes. Resources can be categorized into physical form (e.g. parts), abstract form (e.g. finished order), and informational (e.g. parts routes) (each having their own stereotype).

b) **Processes.** The activities performed within the manufacturing system in which the state of resources changes. Processes describe how the work is done within the manufacturing system. Processes are governed by rules.

c) **Performance.** The purposes of the project, or the output the system as a whole is trying to achieve. Goals can be broken down into sub-goals and allocated to individual parts of the system, such as processes or objects. Goals express the desired states of resources and are achieved by processes. Goals can be expressed as one or more rules.

d) **Rules.** A statement that defines or constrains some aspect of the system, and represents controls. It governs how the business should be run (i.e., how the processes should execute) or how resources may be structured and related to each other. Rules can be enforced on the business from the outside by regulations or laws, or they can be defined within the business to achieve the goals of the system.

3.4.2 Limitation of UML Diagrams

Key to software engineering is supplying the proper drawing tool that provides integration with the coding environment or language. Using UML diagrams to represent or display the manufacturing system in an object oriented approach is different approach. However since the objective of representing the manufacturing system is to produce software that links to a simulation model, the approach is still valid. The UML solution supports the creation of integrated system models.

The Static structure diagrams either represent concepts from the real world and the relationships between them or are class diagrams that decompose a software system into its parts. For a manufacturing system representation, the class diagram will have all the basic classes of the manufacturing system like buffer, work cells, labour, etc to cover all the general elements. The sequence diagrams show the actors and objects participating in an interaction and the events they generate arranged in a time sequence. The sequence diagram shows the interaction between classes. It also shows the link of the classes through message passed around to trigger an action between two elements. Activity diagrams can be used to display the operation carried out in a class. This diagram describes the internal behaviour of a method and represents a flow driven by internally generated actions.

A detailed assessment of the eight different UML types of view/representation highlight how the representation does not have a system diagram that can provide a blue print or as overview of the project. There is also a level of complication in linking these diagrams. Although each plays an important role, there is no direct mapping between the different diagrams.

3.4.3 Class and Object Representations

Each class stores its own information, events and status for more detail descriptions to generate the coding. The status depends if the class is activated or not. If the particular class is irrelevant to the particular case study then the class will not be activated. Objects in the classes can be related in two ways, inheritance and by association.

Every class consists of three sections defined by Bennett et al (2001):

a) **Properties.** Represent information about an object. Some properties may be read-only by other objects, while others can be directly changed through coding. A property could also be another object.

b) **Methods.** Perform an action with an object. Methods are used for compound actions that perform a distinct task or may change the object's state significantly.

c) **Events.** These provide notification to and from the system control object that something has happened. For example, an object can trigger an exception that automatically calls a help or error object.

The major modelling abstractions in the architecture are organised within a class hierarchy, which is the standard way to take advantage of the inheritance properties of object-oriented approaches. A generic set of classes illustrated in Figure 3.3, represents the top level of elements in a manufacturing system.

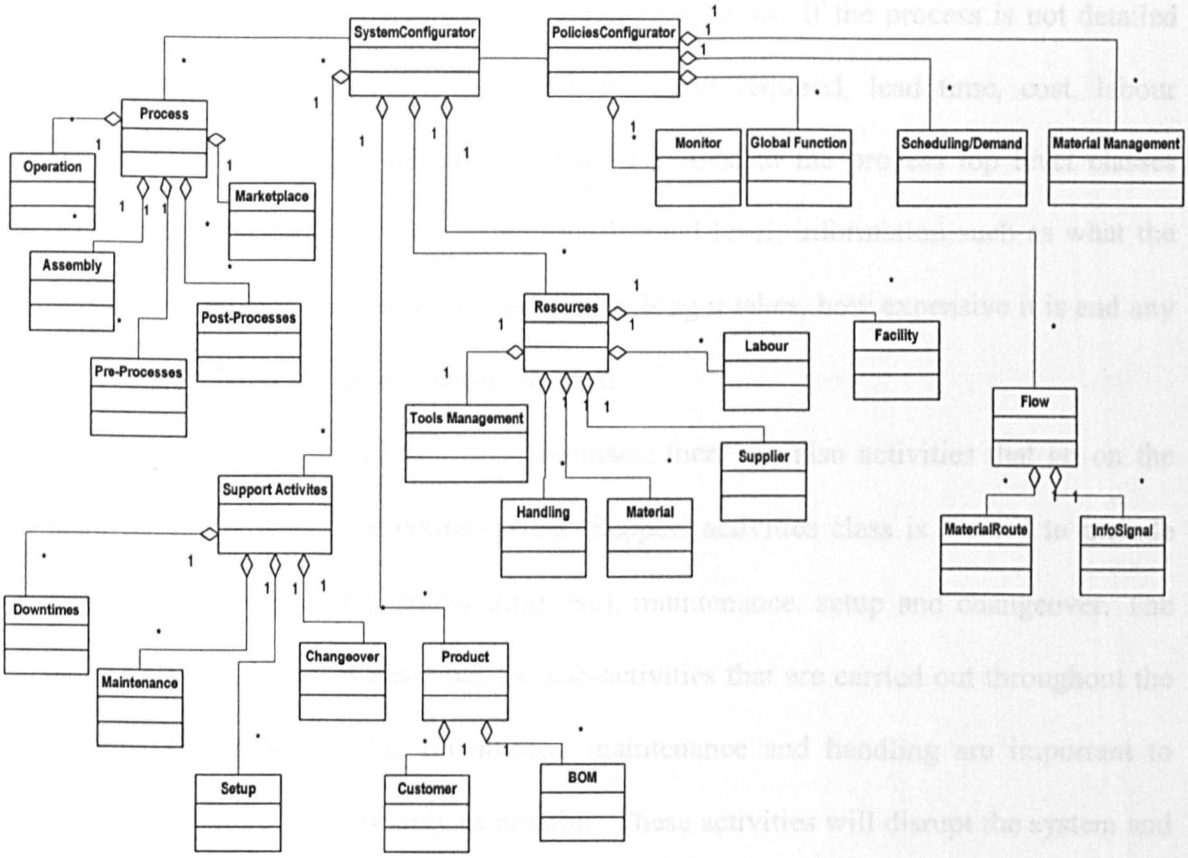


Figure 3.3 Some Basic Classes Illustrated for a Manufacturing System

More detailed elements can be created as instances of these classes, customised according to each case study. The system configurator class and the policies configurator class are the two classes at the top of the class structure. The decomposition between physical parts and control is achieved through separation of static data and dynamic data. The system configurator class incorporates all the static objects like process, support activities, resources, product and flow. The following section detail the key type used in the representation of a generic manufacturing system:

a) **Process Class**. Manufacturing environments generally consist of a number of activities such as operation, assembly, pre-processes, post-processes and marketplace. These activities are represented as classes under the process class umbrella. The process class describes the transformation of either data or material. Name and description of the process with its attributes are declared at a high level and those attributes that define the process will be inherited through the classes below. If the process is not detailed further, information about its function, resources required, lead time, cost, labour requirement and related sub-process can be defined at the process top level classes without drilling further down. At a more detailed level, information such as what the process do, what resources are required, how long it takes, how expensive it is and any number of related sub-processes are defined.

b) **Support Class.** Besides the actual processes, there are also activities that go on the shop floor that affect the entire system. Support activities class is created to include downtimes (i.e. cleaning, configuring, etc), maintenance, setup and changeover. The Support Activities class describes the sub-activities that are carried out throughout the system. The activities like downtimes, maintenance and handling are important to model the system as accurately as possible. These activities will disrupt the system and have a great impact on the production rate.

c) **Resources Class.** The Resource class describes the capability of the system to carry its intended action and covers tools management, handling, material, supplier, labour and facility. Resource objects are entities which can take many forms, e.g. operators, machinery tools, WIP area, trolleys and communication facilities. A resource can be described by its functionality, status, locations, methods of allocation/replenishment systems, who operates and maintains it resource.

d) **Product Class.** The Product class holds the information about the customer class and Bill of Material (BOM) class, for all the product range. A customer database consisting of detailed information like name, quantity and priority should be monitored closely.

e) **Flow Class.** The Flow class describes the relationships between processes. It might carry a signal, either physical i.e. a component or non-physical i.e. order or instruction. Signal objects move along flows, so that they are transformed by processes, which operate in a particular sequence. A flow has the characteristic of what it is moving, the processes it links and the information of the related flow. For example the Information Signal class carried attributes of description, the flows it travel along, its sub-items and what is being carried with it. By tracing the flows, the manufacturing system activities involved can be clearly represented and identified. The flow of the parts, sub-assemblies, control information and feedback can be viewed as static as well as dynamic. At the beginning of a study, these data of flow will be considered as static data. Material route class and information signal class are created.

f) **Policies Configurator.** The policies configurator class captures the knowledge and rules use to make decision. It captures information about constraint, approaches, and operational rule. Thus, they encompass many aspects of the manufacturing system, ranging from description of the systems objectives, to rules controlling how processes and functions should operates or instructions of how resources are managed. The performance of the system very much depends on the operational rules it adopts, hence having one central-point to experiment with alternative options is easier to manage. The Policies configurator class (Figure 3.4) is the differentiating point of this framework from other manufacturing system classification for modelling purposes. This class is specially created to contain dynamic data, which might require frequent access and regular modification for scenario generation.

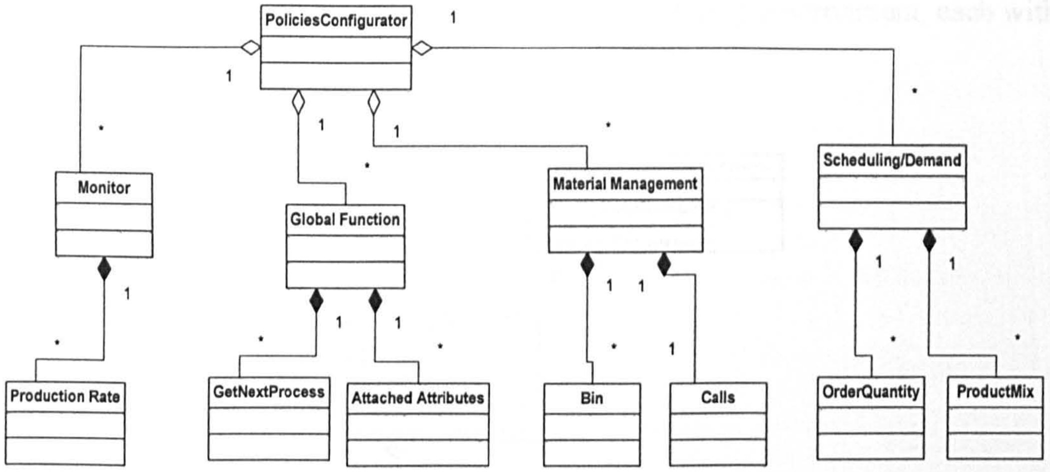


Figure 3.4 Policies Configurator View

This class consists of:

- **Monitor Class**. The monitor class holds all reporting variables to be displayed.
- **Global Function.** The global function class consist of all functions pre-programmed to be accessed by all classes. Using this approach no repetition is required and changes can be made easily and rapidly.
- **Scheduling/Demand.** The scheduling /demand class is also placed under the policies configurator class. If the problem analysed investigating a scheduling issue, this class will be the core focus. This displays the representation of job-splitting which is common to many types of manufacturing.
- **Material Management.** The replenishment class contains all the information of the resources involved. Profiles of supplies performance or material handling rates are reflected through this class to show the impact.

3.4.4 Attributes and Operations

A class is split into a number of sections. The first section carries the name of the class, the second section bears the attributes of the class, and the third section consists of the operation of the class. The attributes and operations of the classes can be public, and can be accessed by all other classes, or private, and are only for the class in use. Figure 3.5 shows the class structure created for the process in a manufacturing environment, each with an attribute of ID of the process.

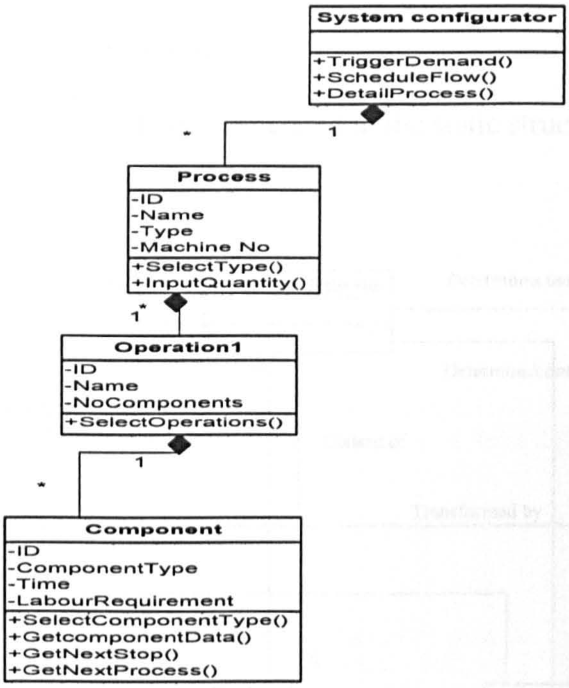


Figure 3.5 Process Class Structure

Actions specified can be described through selecting the type of operation from choices such as a single machine or multi-workstation machine, or whether it is manual, automatic process, continuous process. In "Input Quantity" action, the "quantity" of the process defines the number of identical machines/processes in that system. For the process class, there is an instance class of an operation class, which can be described as the machine in the process. The operation class has an ID, name of the operation, type and number of component the operation consists. In the select of operations, one has the choices of whether it has a loader, unloader, waiting buffer, conveyor, machine, and dispatch machine. For example in a wrapping process, the operations may involved a stacking operation and a wrapping operation, which in the real world maybe one combined machine but represented in a simulation model as separate machines in a module. The wrapping operation is then further divided into components. These components may consist of a conveyor, a load and unload machine, inbay and outbay buffers, wrapping machine and dispatch machine etc.

3.4.5 Modelling the Relationships

The interactions of the main classes generated in the static structure are shown in Figure 3.6 .

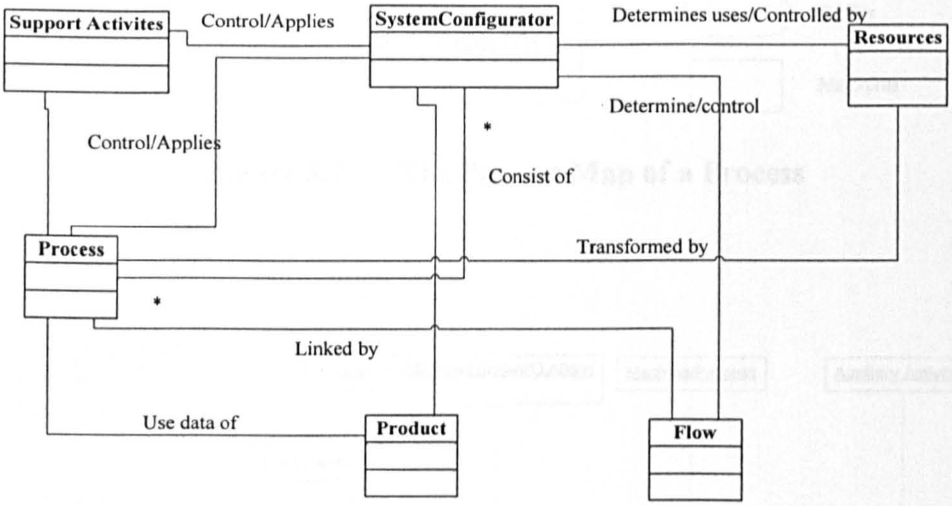


Figure 3.6 **Interactions of Main Static Classes**

The coupling mechanisms in the modelling architecture dictate how to establish the interrelationships between the manufacturing entities or resources (Narayanan et al., 1998). All interactions between classes occur through messages and events in each class. A UML sequence diagram is used to create links and instantiate manufacturing object classes. This diagram is used to model the behaviour and collaboration between manufacturing objects. Sequence diagrams are a powerful tool to model not only the dynamic behaviour of a system showing the interaction of each operation but also the sequence of steps representing the interactions. Figure 3.7 shows the component in a process cell. Figure 3.8 illustrates the sequence diagram for a machining process with waiting areas, with unspecified auxiliary activities (which can be customised according to the process) and a loader (which can be manual or automatic). At the left side of the diagram, the steps of the process are stated. The sequence diagram shows the timeline and messages needed to trigger a start of the next operation.

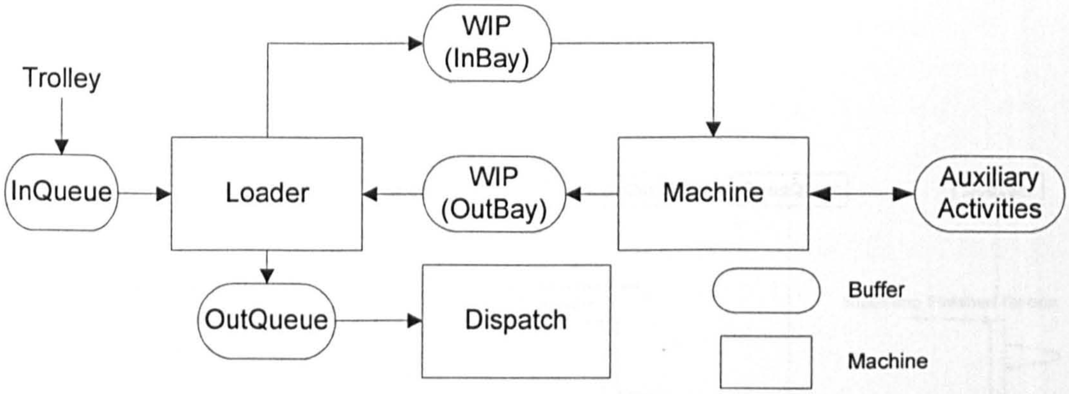


Figure 3.7 The Process Map of a Process

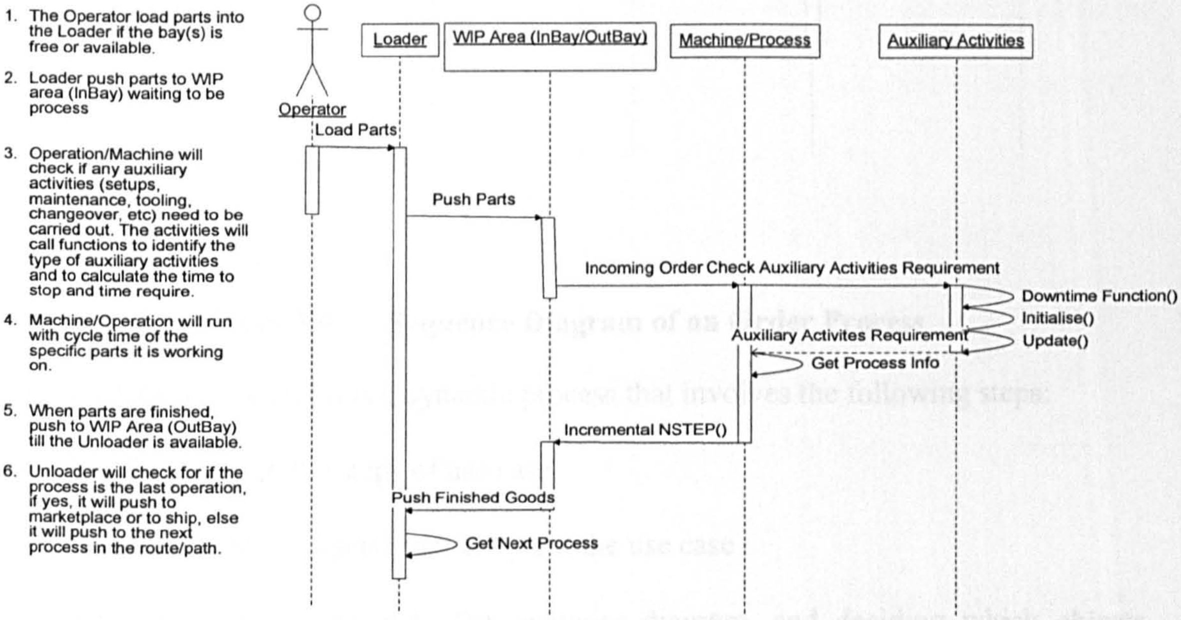
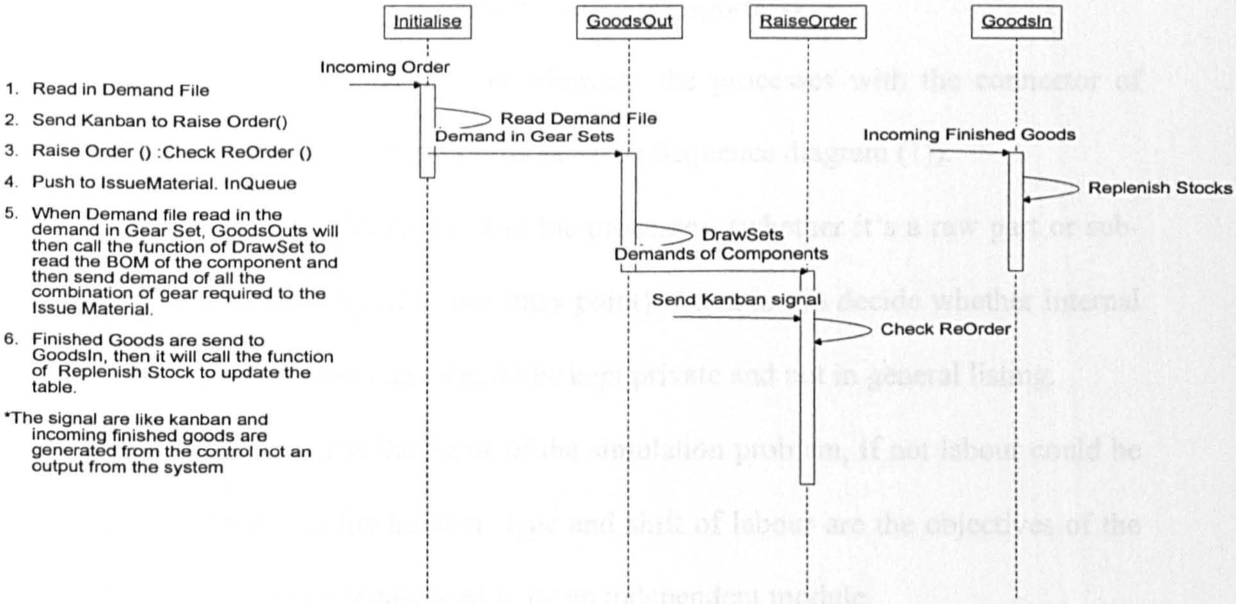

1. The Operator load parts into the Loader if the bay(s) is free or available.
2. Loader push parts to WIP area (InBay) waiting to be process
3. Operation/Machine will check if any auxiliary activities (setups, maintenance, tooling, changeover, etc) need to be carried out. The activities will call functions to identify the type of auxiliary activities and to calculate the time to stop and time require.
4. Machine/Operation will run with cycle time of the specific parts it is working on.
5. When parts are finished, push to WIP Area (OutBay) till the Unloader is available.
6. Unloader will check for if the process is the last operation, if yes, it will push to marketplace or to ship, else it will push to the next process in the route/path.

Figure 3.8 Top Level Sequence Diagram of a Process

Figure 3.9 illustrated an example of sequence diagram on order process in one of the case studies presented later which has a Kanban system as the replenishment system. The Kanban signal draws the required stock from goods out and this action triggers a flag to raise an order to check if any previous orders have been made manually or not, and a reorder signal will be made. Another class that lives in this simple system is the GoodsIn Class which counts the finished goods produce by the system and fills the stock which the Kanban first draws from.



1. Read in Demand File
2. Send Kanban to Raise Order()
3. Raise Order () :Check ReOrder ()
4. Push to IssueMaterial. InQueue
5. When Demand file read in the demand in Gear Set, GoodsOuts will then call the function of DrawSet to read the BOM of the component and then send demand of all the combination of gear required to the Issue Material.
6. Finished Goods are send to GoodsIn, then it will call the function of Replenish Stock to update the table.

*The signal are like kanban and incoming finished goods are generated from the control not an output from the system

Figure 3.9 Sequence Diagram of an Order Process

Creating a sequence diagram is a dynamic process that involves the following steps:

- Reading through the steps of use case
- Creating business objects that carry out the use case
- Adding business objects to the sequence diagram, and deciding which objects should carry out each responsibility
- Adding messages between objects on the sequence diagram. A message sent to an object in a sequence diagram creates a new operation on the receiving object.

3.4.6 Steps to Sequence Diagram Generation

1. Identify the main processes of the problem or area being studied to generate the simulation model. (From process plan or flow chart)
2. Identify the material handling type between processes. (For example, conveyor, trolley, AGV or any other material handling transporters)
3. Generate UML sequence diagram showing the processes with the connector of material handling connection. (to be saved as Sequence diagram (1)).
4. Identify all the material required in the processes. (whether it's a raw part or sub-assemblies without regard to the entry point). Attention to decide whether internal parts for a particular process should be kept private and not in general listing.
5. Identify if the labour is the focus of the simulation problem, if not labour could be listed universally. If the number, type and shift of labour are the objectives of the study then the labour issues need to be an independent module.
6. Identify the attributes required by the study to be attached to each key module to get the appropriate information.
7. Identify the additional modules that are required in the simulation: pre-process (order-processing, decanting process and kitting process) and post-process (recording and distribution).
8. Add pre-process or post-process modules to the Sequence Diagram (1) [from step 3]. (to be saved as Sequence Diagram (2)).
9. Identify the variables and functions which should be placed in the global control module or as individual module (which can be accessed universally and changed easily without affecting the entire structure). This concept is applied following the object-oriented philosophy.

10. Identify the information flow, which normally concentrate on the planning, control and scheduling of the processes and resources. This information flow will be placed in an independent module. Information about Kanban, scheduling policies and reporting variables will be stored in this module.
11. Design pattern of general process can be selected for customisation.
12. Design pattern of information flow will require more user inputs.

3.5 Manufacturing System Views

Extracting from the idea of Business modelling by Eriksson and Penker from Open Training (1999), a multi-views concept is applied to manufacturing systems. Following how a software system is modelled in a number of views (Kruchten, 1995); a complete manufacturing system model is demonstrated in a number of views. Views enable the model to be examined at different perspectives, and thus aid users to identify and clarify all aspects of the system. Each view is expressed in one or more diagrams. The diagrams can be of different types, dependent upon the specific structure or situation in the manufacturing system that it is depicting. Diagrams capture the processes, rules, goals, and objects in manufacturing systems, and their relationships and interactions with each other. The Extensions use three different views of a manufacturing system, and they are:

a) **Manufacturing System Performance View** represents the overall objectives of the manufacturing analysis. This view describes the goal structure for a project, and illustrates problems that must be solved in order to achieve these goals.

b) **Manufacturing System Process View** covers the manufacturing processes that represent the activities and value created in the system. This view illustrates the interaction between the processes and resources in order to achieve the goal of each process, as well as the interaction between the different processes.

c) **Manufacturing System Behavioural View** represents the individual behaviour of each key resource and process in the manufacturing model and how they interact with each other.

The views are not separate models; they are different perspectives on one or more specific aspect of the system. Combined, the views create a complete model of the manufacturing system.

3.5.1 Manufacturing System Performance View

The *Manufacturing System Performance View* depicts the project's output. It is an image of where the project is headed. This view sets up the overall strategy for the project, defines the goals of the project, and acts as a guide for modelling the other views. The ultimate result of the Manufacturing System Performance View is a definition of the desired future state of the system, and how that state can be reached. The primary result is expressed in an objectives statement, one or more goal/problem models, and sometimes also a conceptual model. Extracting from Eriksson and Penker from Open Training (1999), *objectives statement* is a short text document that outlines the vision of the project some time into the future, and the *goal/problem model* is a UML object diagram that breaks down the major goals of the projects into sub-goals, and indicates the problems that stand in the way of achieving those goals. The *conceptual model* is a UML class diagram that defines important concepts and relationships in the system to create a common set of terminology. Figure 3.10 shows a performance diagram in which output results have been broken down into more individual sections. Shown with the performance elements are problems which hinder the achievement of that result, and this typically leads to the identification of further area for investigating.

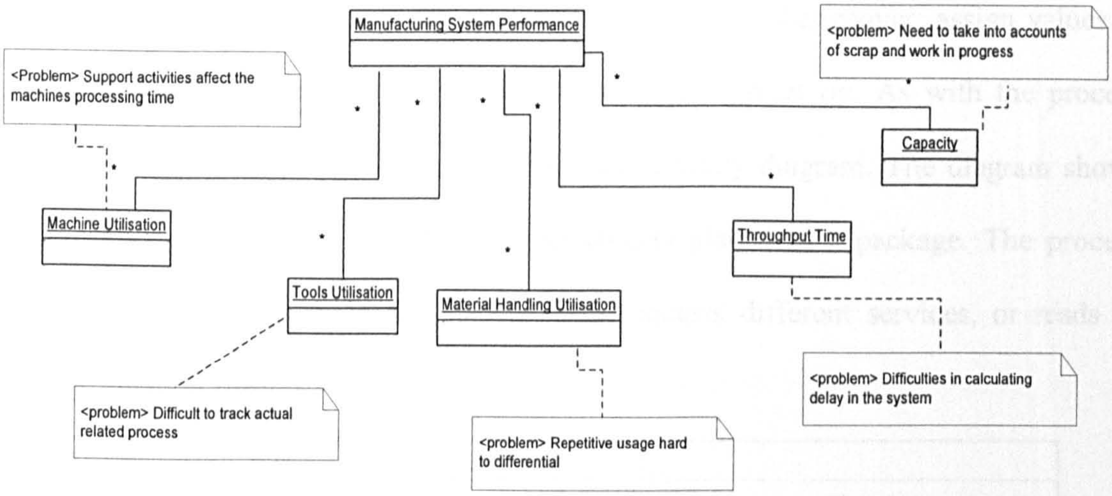


Figure 3.10 A Performance Diagram based on a UML Object Diagram

3.5.2 Manufacturing System Process View

The Manufacturing System Process View is at the center of manufacturing system modelling. As previously discussed, the processes show the activities required to achieve an explicit goal and their relationships with the resources participating in the process. Resources include tools, labour, material, handling, facility, and supplier, and can be consumed, refined, created, or used (i.e., act as a catalyst) during the process. There are relationships between a process and its resources, between different processes that interact, and there is a coupling of processes to performance goals. A process diagram (based on a UML activity diagram) can also show how manufacturing operation events are generated or received between different processes, (i.e., as a means to interact or communicate between processes).

Figure 3.11 shows a process diagram (based on an activity diagram) where the relationships between different objects in the sequence diagram are shown. This diagram also makes use of swimlanes, which are used to show the organizational habitat of the process (it can also be used to show who is responsible for the process). The example presented show the depth of detail of what rules and functions are carried out in a particular process and not at the high level representation only. For example: update the work in progress (WIP) to count the amount in and out for changeover; assign values to variable which are the performances measurement and further on. As with the process diagram, it is based to a large extent on the UML activity diagram. The diagram shows how the processes write or read to different objects placed in a package. The process communicates with objects in the package and requests different services, or reads or writes information from it.

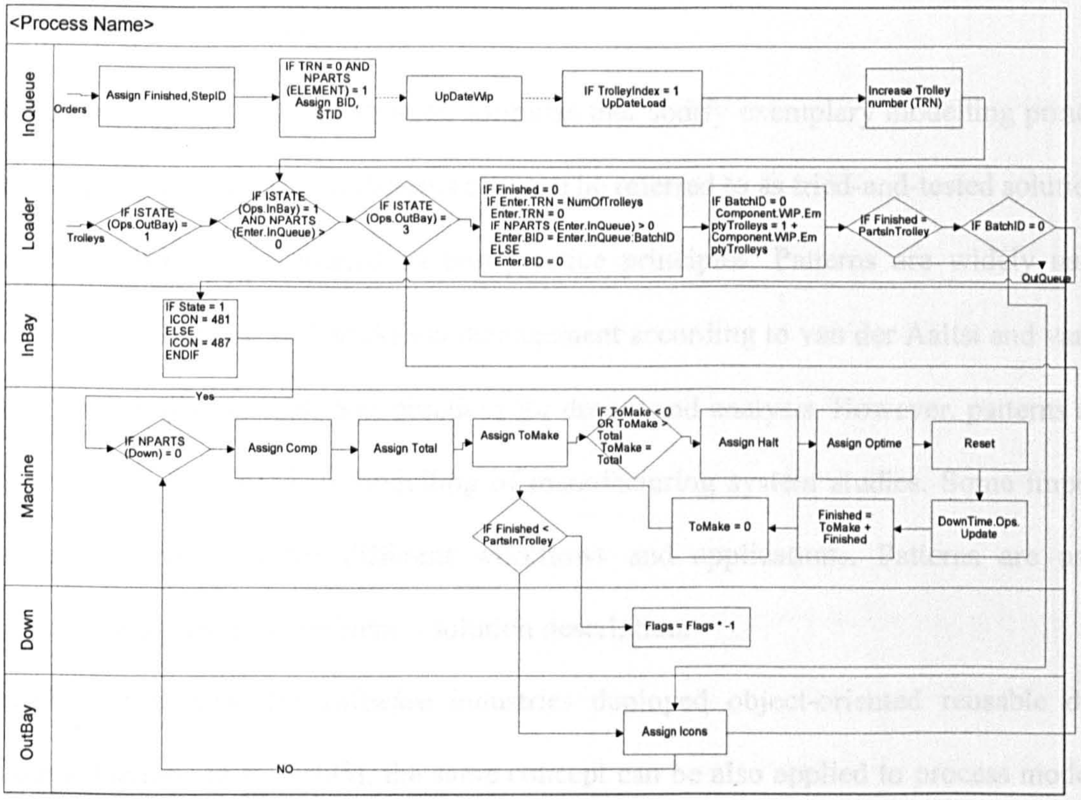


Figure 3.11 Process Swimlane Diagram based on an Activity Diagram

3.5.3 Manufacturing System Behavioural View

The *Manufacturing System Behavioural View* illustrates both the individual behaviours of resources and processes in the system as well as the interaction between several different resources and processes. The behaviour of the resource objects is governed by the Process View, which shows the overall main control flow of the work performed. However, the Manufacturing System Behavioural View looks into each of the involved objects in more detail: their state, their behaviour in each state, and possible state transitions. The

Behavioural View also shows the interaction between different processes, such as how they are synchronized with each other. By doing so, the Behavioural View is an important tool to use when allocating the exact responsibility for different activities, and when defining the exact behaviour of each resource that takes part in each process. The Behavioural view makes use of state chart diagrams, sequence diagrams and collaboration diagrams. Process diagrams can also be used to show interaction between processes.

3.6 Design Patterns

Patterns are named problem-solution formulas that codify exemplary modelling principles according to Larman (2002). Patterns also can be referred to as tried-and-tested solutions to modelling problems expressed as best-practice principles. Patterns are widely used in software development and workflow management according to van der Aaltst and van Hee (2004) as a way to capture best practices for design and analysis. However, patterns so far are not extensively used in modelling of manufacturing system studies. Some important patterns are common for different workflows and applications. Patterns are usually presented in the form of problem – solution description.

Learning from how the software industries deployed object-oriented reusable design patterns (Gamma et al., 1995), the same concept can be also applied to process modelling of manufacturing systems as well. The methodology consists of developing 'creational', 'structural' and 'behavioural' patterns. Below are the definitions of the different patterns by Gamma et al. (1995).

- Creational design patterns abstract the instantiation process. They help make a system independent of how its objects are created, composed, and represented. A class creational pattern uses inheritance to vary the class that's instantiated, whereas an object creational pattern will delegate instantiation to another object. These patterns encapsulate knowledge about which concrete classes the system uses. They hide how instances of these classes are created and put together.

- Structural patterns are concerned with how classes and objects are composed to form larger structures. Structural class patterns use inheritance to compose interfaces or implementations. Rather than composing interfaces or implementations, structural object patterns describe ways to compose objects to change the composition at run-time, which is impossible with static class composition.
- Behavioural patterns are concerned with algorithms and the assignments of responsibilities between objects. Behavioural patterns describe not just patterns of objects or classes but also the patterns of communication between them. These patterns characterise complex control flow and shift the focus away from just flow of control but the way objects are interconnected. Behavioural class patterns use inheritance to distribute behaviour between classes. Behavioural object patterns use object composition rather than inheritance.

In this research, the design pattern focused on creational and behavioural patterns to be reusable and reconfigured in the form of a library. The behavioural pattern are selected through a set of collected sequence diagrams and later customised with details and specification to each problem or case.

The creational pattern in a manufacturing system is covered using a general class diagram which consists of all possible elements in the manufacturing environment. The creational pattern consists of a main diagram, which shows the relationships of the classes. It contains design patterns like process, support activities, resources, and product, which are static data to be defined and stored in the database. The flow class, which represents the material flow, may hold dynamic characteristic if the manufacturing system has multi-routes or changeable options.

- The product design pattern is to create the product configuration and upgrade its customer record. For a new customer, a new record can be generated.
- The process design pattern is to create the processes with all its individual components that make up the process.
- The support activities design pattern is to create subclasses of downtimes, changeover, setup and maintenance, which are instantiated.
- The resources design pattern is to create subclasses of facility, labour, tool management, handling, and supplier, which are instantiated.
- The flow design pattern is to create subclasses of material routes and information routes, which are instantiated.

The process design pattern is linked to the main system configurator and operates as the core of the configuration process. An example of a creational pattern can be illustrated with a new product. The new product introduces new attributes which may be permanent or temporarily. The product class is detailed with instances for the new attributes and functions to be performed.

In this section, an example of behavioural patterns is discussed to show the benefits of having a library of design pattern to choose from. The user creates the object or classes before using the sequence diagram to illustrate the relationship between the classes and the rules that link them. The sequence diagrams complement and reinforce each other. A manufacturing system problem may have multiple patterns of sequence diagrams embedded in them and not just one.

Figure 3.12 shows a general process A with operations of marketplace, decant (pre-processes), conveyor and machine interacting with other classes like order, flow, support activities, and resources. This sequence diagram enables the user to specify the object of the process and define the rules to trigger each class. The user can also select the components or classes in the sequence diagram for customisation purposes. The behaviour of how the classes visit each other and interact depends on the rules and logic specified.

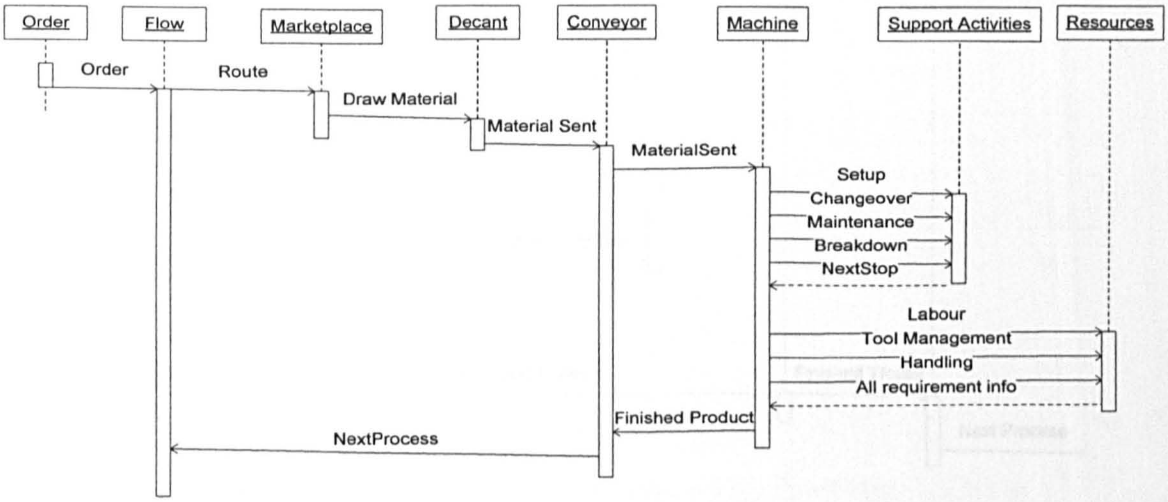


Figure 3.12 Sequence Diagram of General Process A

The patterns of sequence diagram describe aspects of the problem that are likely to change. Some of the types of communications between classes or objects are encapsulated and some are distributed depending on the purpose of the study. When collaborating objects refer to each other directly, they become dependent on each other, and that can have an adverse impact on the layering and reusability of a system. Senders and receivers of message or rules in the system can be decoupled. Figure 3.13 is another example of a process with interaction to the support activities of downtimes that has a big effect on processing time in many actual manufacturing cases.

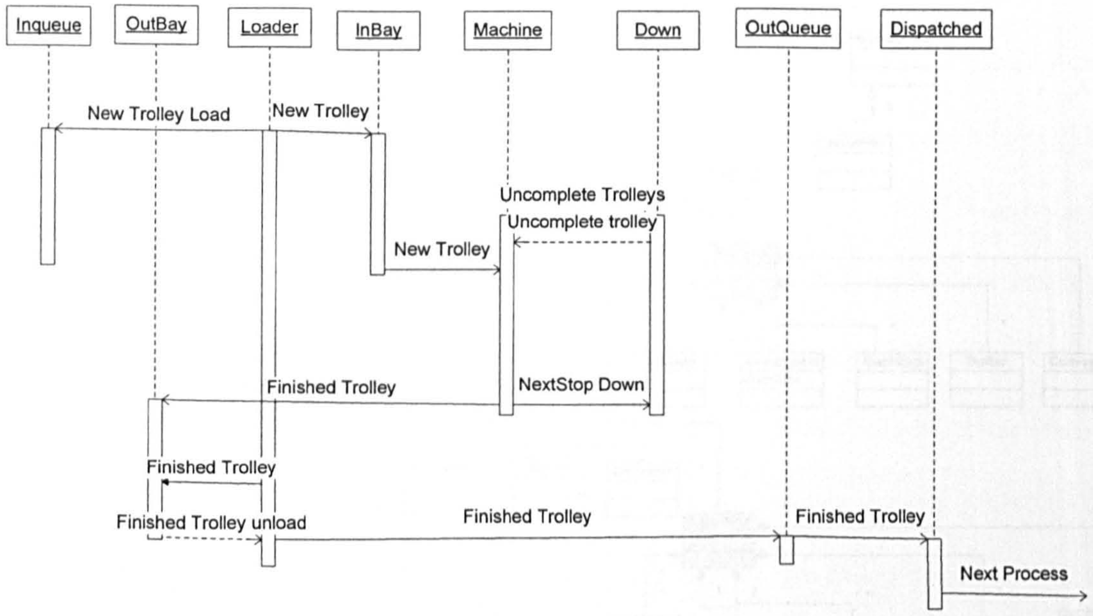


Figure 3.13 Sequence Diagram of General Process B

The structural patterns will later be developed into different classic layout of a factory, like a single route continuous system, multi-route production system or even process-based workstation, and in future work to translate using the XML language.

3.7 System Development: A simple example of Class Diagram and Sequence Diagram

This example is based on one of the case study manufacturing environment with 4 processes and an assembly workstation in the end. The processes consist of operation class and assembly class. The other 3 classes like pre-processes, post-processes and marketplace are not in used, hence not activated. In this case, the activated classes are highlighted in different colour in Figure 3.14.

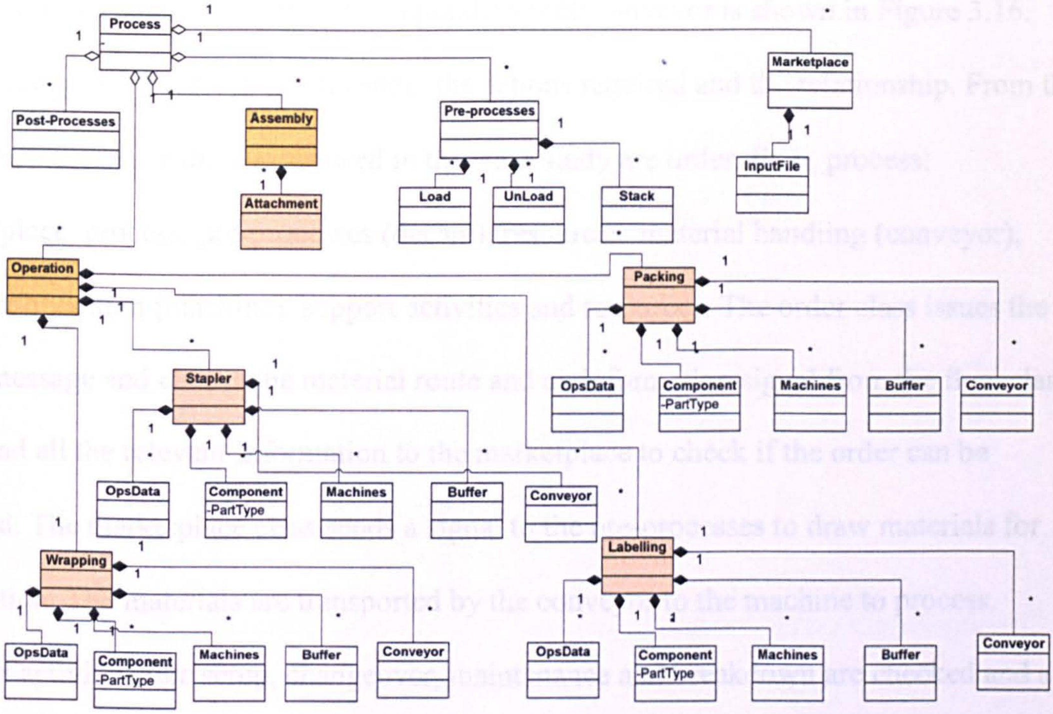


Figure 3.14 Process View Class Diagram

The Class Diagram describes all the elements required for the system or process, and the attributes and variables attached to each. One of the objectives of this case study is to study the impact of changeover of components. Hence the support activities view is provided in Figure 3.15.

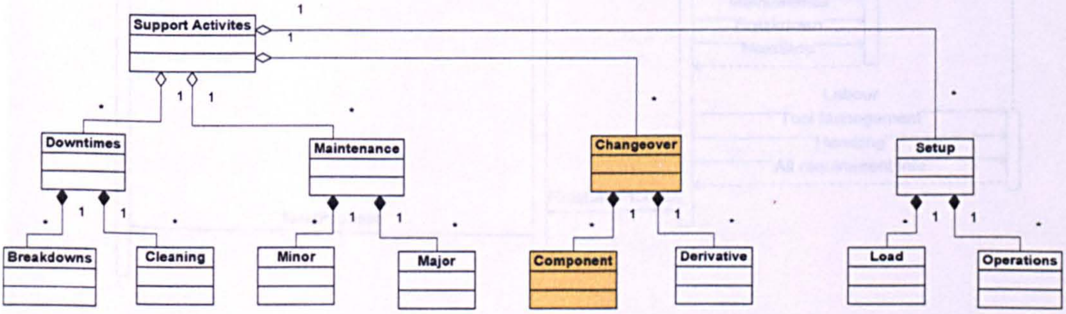


Figure 3.15 Support Activities View Class Diagram

The support activities of changeover and the instances of component are activated and highlighted for presentation. Below are examples of three sequence diagrams providing the choices of flexibility, combinations of classes and the interactions.

The start process design pattern of an operation with conveyor is shown in Figure 3.16. The messages between the classes show the actions required and the relationship. From the diagram, we can see the classes used in this case study are order, flow, process: marketplace, process: pre-processes (decant), resources: material handling (conveyor), process: operation (machine), support activities and resources. The order class issues the order message and checks the material route and an information signal from the flow class will send all the relevant information to the marketplace to check if the order can be fulfilled. The marketplace class sends a signal to the pre-processes to draw materials for production. The materials are transported by the conveyor to the machine to process. Support activities like setup, changeover, maintenance and breakdown are checked and a fed back when the signal for machine stops for those events are returned. Requirement of resources are continually measured.

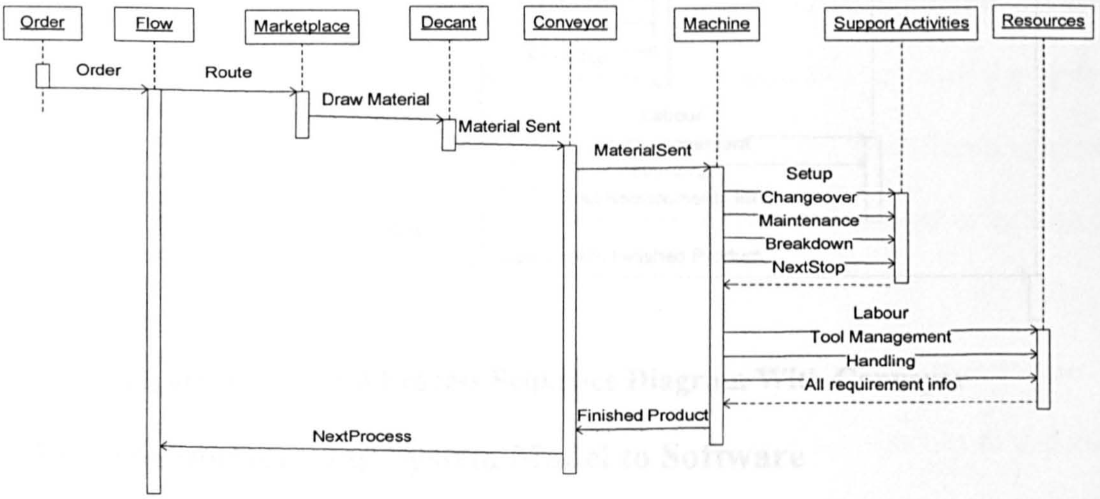


Figure 3.16 Start Process Sequence Diagram With Conveyor

Figure 3.17 shows a machine in the middle of a system which does have the direct contact with the order class. The final machine shown in Figure 3.18 is used to update the finished products in a marketplace, which are later sent to distribution.

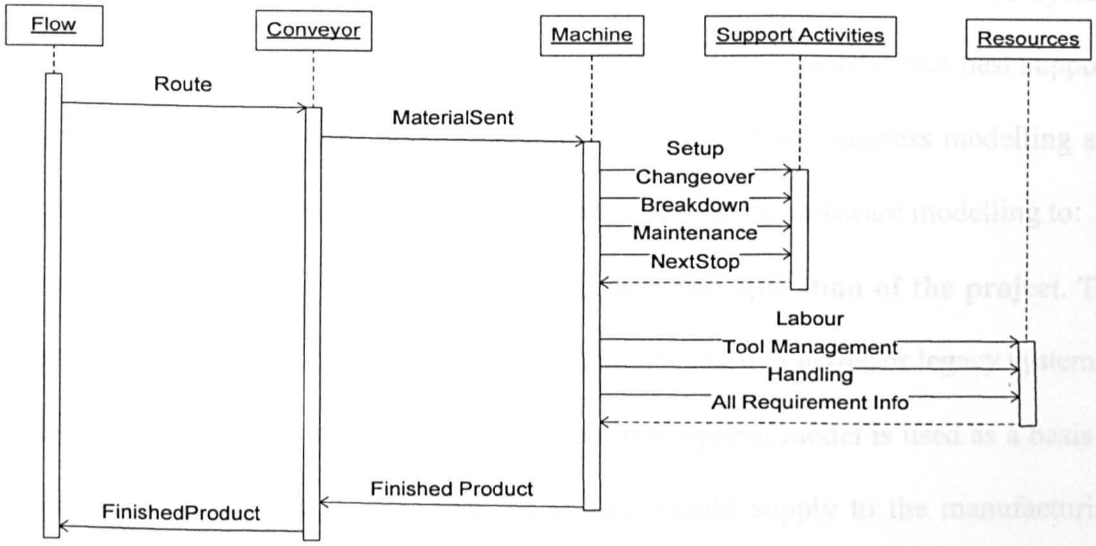


Figure 3.17 Intermediate Process Sequence Diagram With Conveyor

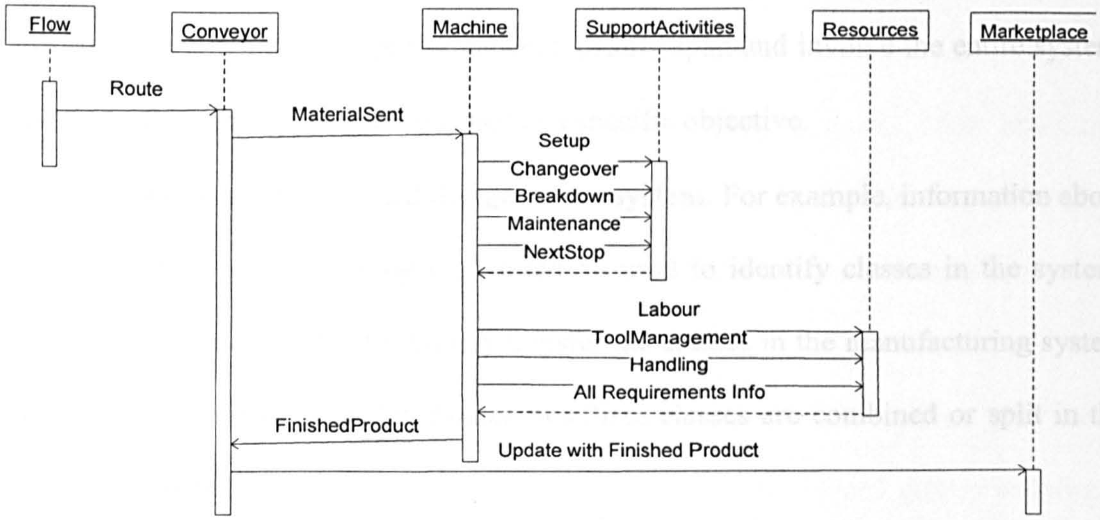


Figure 3.18 End Process Sequence Diagram With Conveyor

3.8 From Manufacturing System Model to Software

As previously discussed, manufacturing system modelling is the way to actually know if the elements defined for a system are the "right" or "optimal" requirements for that system. There are also other uses of the manufacturing system model, as many of the objects and relationships found in the manufacturing system model will also be objects and relationships in the information system model used to control the system. It is important to realize that this is not a one-to-one mapping and a critical analysis must be made of the manufacturing system model to see what is applicable for a specific information system. The ultimate goal is of course to create the integrated simulation model that best supports and fits the projects. Similar to other modelling tool for example business modelling and enterprise modelling, the manufacturing system model is used in software modelling to:

- **Identify the software systems that best supports the operation of the project.** The systems can be an existing systems, new systems, standard systems, or legacy systems.
- **Find functional requirements.** The manufacturing system model is used as a basis to identify the correct set of rules that the system should supply to the manufacturing processes.
- **Find non-functional requirements.** These requirements, such as robustness, security, sensitivity, availability, and performance, typically span and involve the entire system. They are often generic and not attached to a specific objective.
- **Act as a basis for analysis and design of the system.** For example, information about resources in the manufacturing model can be used to identify classes in the system. However, it is not possible to directly transfer the classes in the manufacturing system model to the simulation model. Sometimes these classes are combined or split in the simulation model,
- **Identify suitable components.** Modern software development makes use of modularity: autonomous packages of functionality that are not specific to a certain system but can be used across several systems. Most of technology has concentrated on technical components, but there has been an increasing interest in defining business components that encapsulate a specific and reusable area of business functionality according to Eriksson and Penker (1999). This business software also benefits the manufacturing system models. Manufacturing system models are a good way to identify areas of functionality and to define the appropriate set of services.

3.9 Conclusions

Several researches have recognised the problems with traditional simulation techniques in representing the manufacturing system especially control (Platzman et al., 1986; and Ruiz-Mier et al., 1989). Recently there has been a growing interest in the object-oriented approach applied to the simulation modelling of manufacturing systems (Adiga et al., 1991; and Narayanan et al., 1994). Modular design, software reusability, and potential of natural mappings are the primary reason for this interest (Narayanan et al., 1994). Although many research efforts conceptually make a distinction between physical objects and decision making objects, most do not have an explicit control structure such as the one proposed in this research. HOOMA have provided the basis for further pursuing in the use of object-oriented and function-based approached.

The number of tools supporting in this research UML is growing rapidly. More important, the process adaptations and the support of the UML will continue to develop. The UML software provides many tools to cover the needs of modelling various scenarios or views of a manufacturing system.

A unified representation of the physical process and information system provides a common modelling tool which efforts can be coordinated among several groups working in the different domains of scheduling, shop floor and logistics control, and information system. Since the framework helps adapt to the changes of the physical process and information system affecting each other in a consistent manner, the modelling output enhances integration of the manufacturing system.

Chapter 4 Exploring UML Methodology in Industrial Case Studies

This chapter explores the use of the UML methodologies proposed in the Chapter 3 with three industrial case studies. These simulation modelling projects had been carried out in the traditional approach and are used as reflect case studies to validate the UML approach compared to the traditional approach. Each case study is described in detail with all the project requirements and model descriptions. The class diagram and sequence diagram for each system is illustrated to demonstrate the functionality and validity of the diagrams proposed. At the end of this chapter, the conclusions on the UML approach and applicability are discussed based on the case studies.

4.1 UML Approach to describe manufacturing systems

The object-oriented UML methodology proposed in the Chapter 3 describes the manufacturing elements in a manufacturing system using class diagrams. Different perspectives of the system are also illustrated. The separation of physical material and information flow is the main feature of the proposed methodology. The flows are described with sequence diagrams. In each of the case studies below, the full simulation project carried out is illustrated and explained. The case studies start with the process characteristic, deliverables, assumptions, data collection, model design, simulation modelling design, results generated, and future work . UML methodologies are then performed on these case studies. Starting with a general class diagram, then a detailed class diagram with instances specified to the case study, and finally sequence diagrams to describe manufacturing systems.

4.2 Case Study 1: Beverage Mixing Company

This project is the first attempt to simulate a simple manufacturing system. Therefore, the development stages of the case study are shown in Figure 4.1 in flowchart format. The project is carried out in a structured manner, following guidelines of Banks et al., (1995) with modification to suit this project.

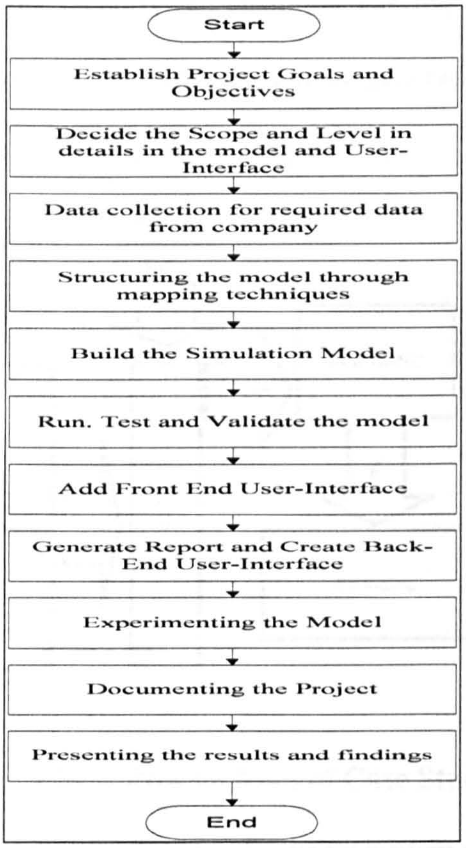


Figure 4.1 Flowchart of Development Stages

4.2.1 Process Characteristic

The company is a beverage manufacturer with product ranges from canned and bottled beverages to a mixture of powder for vending machines. The focus of the case study is on a production Line 9 in the company which is a relatively new addition to the activities of company aimed at retail customers. The line handles 15 main products and some of which are packaged in glass jars of varying sizes, generating a total of 20 products. The line was designed with a degree of flexibility to deal with different types and sizes of jars however this also results in the line being less efficient due to changeover downtimes which can amount to 6 hours for certain products. At the time of this study the line could meet steady state demand with demand peaks or shortfall in production output handled through introducing shifts and overtime. The company views this market as one with growth potential and therefore is more receptive to customer varying needs, however small, and view some products as loss leaders in anticipation of generating more substantial future orders. An overview of the process is shown in Figure 4.2.

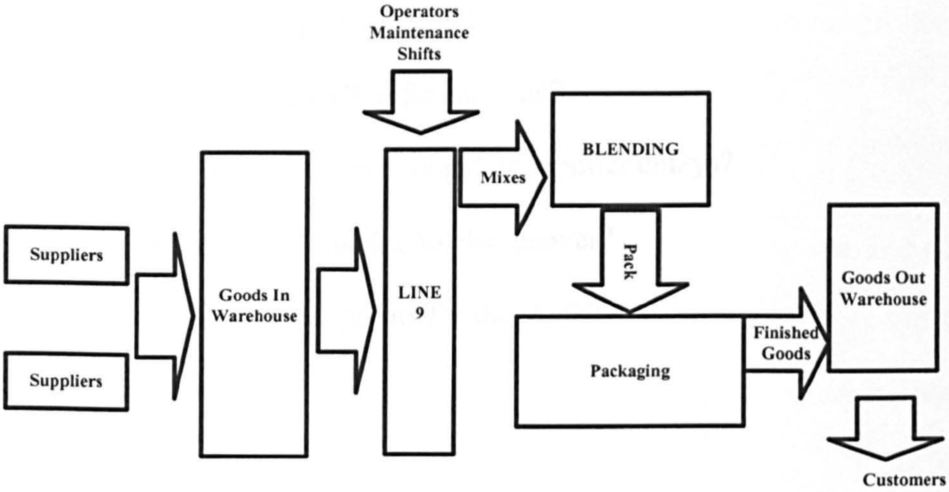


Figure 4.2 Process Map of Case Study 1

Figure 4.2 illustrates the processes in the manufacturing system starting from supplies of raw material to warehouse. The materials are sent directly for packaging or blending depending on the order. Most products of Line 9 require blending or mixing of the ingredients. Hence, most products go through the blending process. The blended products are packaged into jars and are subsequently sent to the warehouse.

4.2.2 Objectives of Case Study 1

At present, there does not seem to be a clear guideline for assessing the viability of existing and new products. The purpose of the project is to build a model that will simulate the operations of line 9 with the initial aim of answering the following:

- Is the current set of operations the most efficient way of running this line?
- What is the impact of reducing product variation on process efficiency?
- Can we propose a set of criteria to assess existing and new products for this line?
- Is there a better way of managing stock and therefore increase stock turn?
- What is the cost of processing each order?
- How best do we manage scheduling for this line?
- How does the line react to varying demand or supplier delays?
- What is the cost of the downtime due to changeover?
- What are the optimum re-order points for the stock?
- Make to stock or order?

4.2.3 Assumptions

A number of assumptions were made at an early stage of the project. These were approved by the company and covered issues affecting the model but not directly studied. Some of the key assumptions are noted as follows:

- Raw Materials are ordered in bulk including the mixture and jars.
- Raw Materials including jars are always available. There is no waiting in any machine.
- Operators only needed for changeover and are always available. It is assumed that transportation, material handling and machine operation is automated. No shift pattern is set up.

- The setup time in the simulation model only includes changeover without consideration of maintenance time and breakdown time.
- No machine breakdown time and maintenance time were included in this model.
- Total blend time includes the blend time element: raw material receiving, preparation time, mix time, QC check and line filling.
- There are no alternative routes and no products other than the 20 products listed are produced on this line.
- Each machine can only process one job at a time.
- Raw material cost is the total cost of pack, which is drawn from the line's bill of material file.
- No material handling time is included, hence no extra allowance time given.
- In the simulation model, all finished goods are sent to the warehouse, and no finished goods are sent directly to delivery. The company has decided to test the impact of warehouse storage cost, charging a dummy value for a pack as it enters the warehouse.

4.2.4 Data Collection

The data provided in this case study provided a basis to what is needed to model a simple manufacturing system and be able to output some useful results. Operation data such as scheduling orders, blend time and packaging time, and the bill of materials for both blend and packaging were provided by the company. The main area of study is the changeover effect of different number of operators with different combination of labours types, where each type holds a different cost per hour. The different scheduling method also provides a different combination of products to make these yielding different changeover effects. The speed of production for each product was also provided.

4.2.5 Product Configuration

The raw material for this line is ordered in bulk and any supplier constraints are not studied. There is an economic reorder level, supplier lead time and pallet order quantity for the raw material. Hence this has to be taken into consideration in the problem. Products are drawn from the warehouse in pallet sizes. Excessive storage of raw material adds to storage cost, obsolete/damage risk and handling fees. Bill of material of the product blend is provided. Some raw materials are shared or common across similar products.

4.2.6 Layout

The physical layout of the process is not an issue in this case study but the storage of raw material is. Temporary work in progress stored around the machines is disruptive and, against health and safety procedures and obviously space demanding. The area of this line is limited, hence space is precious. Therefore, scheduling and planning of the order are key issues to address in the simulation model.

4.2.7 Downtimes

The company has provided extensive data on product changeover time. Changeover time data is provided for different options of operator types and number. The maximum number of operators that can be assigned for changeover is 3. The changeover time in this case will be less, with a difference of up to 2 hours. The types of labour are Grade 1, Grade 2, and packer where each is assigned a different hourly rate.

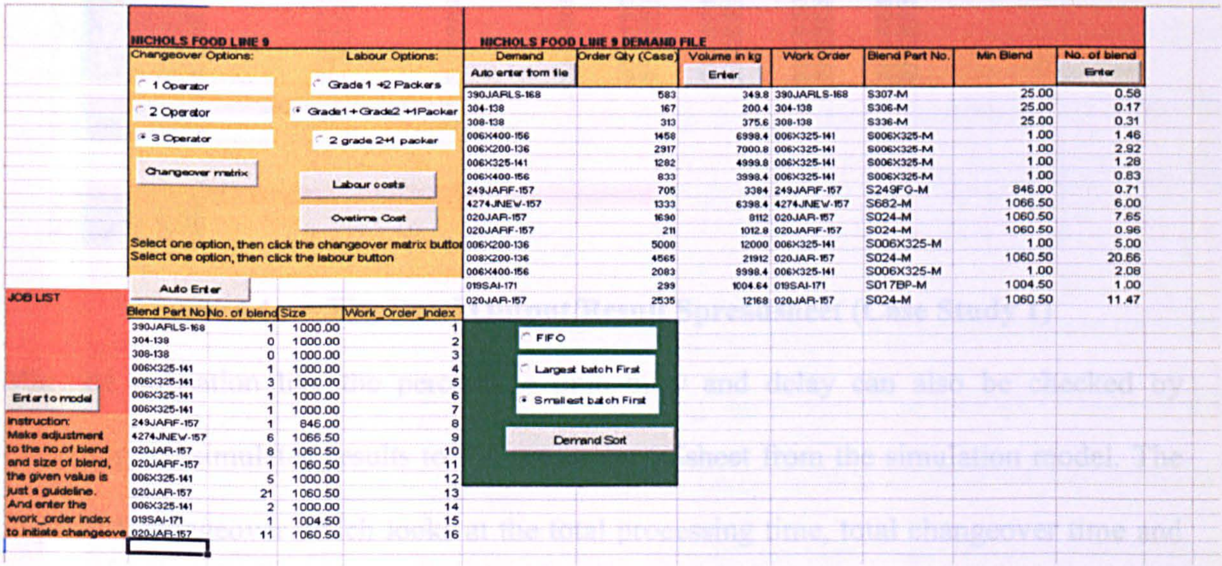
4.2.8 Experimentation

Experimentation is carried out on the model to analyse several elements that affect the company's decision making on whether to accept the customer order or not. The key factors are the total cost including labour cost (with different combination of labour skill), the blend and pack cost, machine utilisation and changeover time involved.

In this project, the cost of different grade operator is a nominal cost to represent the effect and not the actual salary per hour. Other information like blend time, pack time, blend cost and pack cost are real data.

4.2.9 User Interface

An Excel Spreadsheet has been created as a user interface between the user and the simulation model. The idea is that the user need not necessarily access the simulation model to change the parameters of the experimentation on the system. The Excel input worksheet is used to select and modify the model scenarios' parameters. The input user interface is a simple page that gives the user options of choosing between one to three operators and the combination of labour used (Figure 4.3).



NICHOLS FOOD LINE 9

Changeover Options:
○ 1 Operator
○ 2 Operator
● 3 Operator

Labour Options:
○ Grade 1 +2 Packers
● Grade1 + Grade2 +1Packer
○ 2 grade 2+1 packer

Select one option, then click the changeover matrix button
Select one option, then click the labour button

JOB LIST

Instruction:
Make adjustment to the no.of blend and size of blend, the given value is just a guideline.
And enter the work_order index to initiate changeove

Blend Part No	No. of blend	Size	Work_Order_Index
390JARLS-168	1	1000.00	1
304-138	0	1000.00	2
308-138	0	1000.00	3
006X325-141	1	1000.00	4
006X325-141	3	1000.00	5
006X325-141	1	1000.00	6
006X325-141	1	1000.00	7
249JARF-157	1	846.00	8
4274JNEW-157	6	1066.50	9
020JAR-157	8	1060.50	10
020JARF-157	1	1060.50	11
006X325-141	5	1000.00	12
020JAR-157	21	1060.50	13
006X325-141	2	1000.00	14
019SAI-171	1	1004.50	15
020JAR-157	11	1060.50	16

NICHOLS FOOD LINE 9 DEMAND FILE

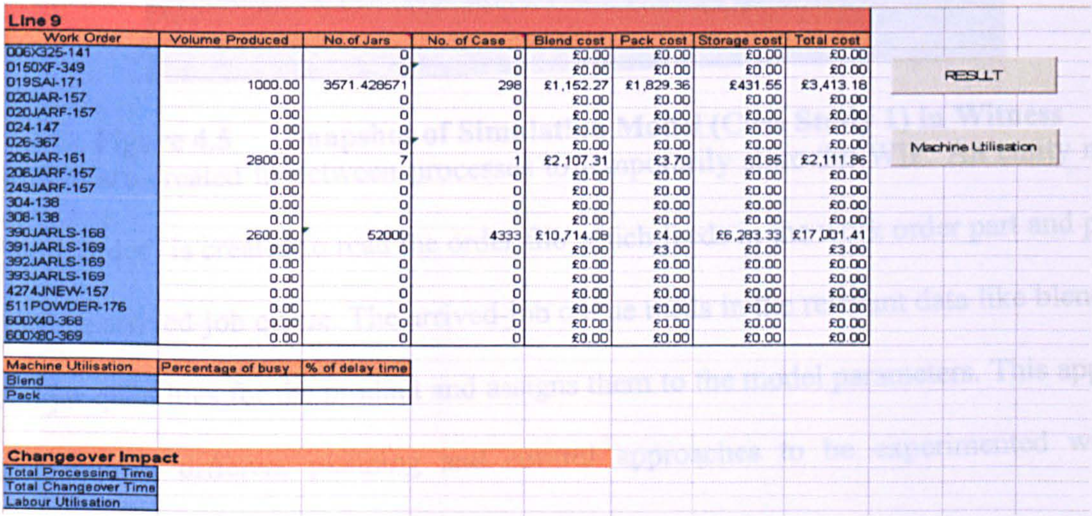
Demand	Order Qty (Case)	Volume in kg	Work Order	Blend Part No.	Min Blend	No. of blend
390JARLS-168	583	349.8	390JARLS-168	S307-M	25.00	0.58
304-138	167	200.4	304-138	S306-M	25.00	0.17
308-138	313	375.6	308-138	S336-M	25.00	0.31
006X400-156	1458	6998.4	006X325-141	S006X325-M	1.00	1.46
006X200-136	2917	7000.8	006X325-141	S006X325-M	1.00	2.92
006X325-141	1282	4999.8	006X325-141	S006X325-M	1.00	1.28
006X400-156	833	3998.4	006X325-141	S006X325-M	1.00	0.83
249JARF-157	705	3384	249JARF-157	S249FG-M	846.00	0.71
4274JNEW-157	1333	6398.4	4274JNEW-157	S682-M	1066.50	6.00
020JAR-157	1690	8112	020JAR-157	S024-M	1060.50	7.65
020JARF-157	211	1012.8	020JARF-157	S024-M	1060.50	0.96
006X200-136	5000	12000	006X325-141	S006X325-M	1.00	5.00
008X200-136	4565	21912	020JAR-157	S024-M	1060.50	20.66
006X400-156	2083	9998.4	006X325-141	S006X325-M	1.00	2.08
019SAI-171	299	1004.64	019SAI-171	S017BP-M	1004.50	1.00
020JAR-157	2535	12168	020JAR-157	S024-M	1060.50	11.47

○ FIFO
○ Largest batch First
● Smallest batch First

Figure 4.3 The Excel Input User Interface (Case Study 1)

The operators are divided into Grade 1, Grade 2 and Packer depending on their skill level and this is reflected in their cost per hour. Other useful information like work orders, order quantity in kilograms (kgs), blend part number (which can be automatically matched by the macro to actual quantity), minimum blend quantity each time and the number of blend (which is calculated automatically) are displayed for traceability. After the initial display of key data, the user decides on the blend schedule by selecting the number of blend and size.

The output worksheet provides the calculation of volume produced in the period of time specified by the user, the number of jars required and the cases needed to store the jars (Figure 4.4). These quantities provide the user with an idea of the required materials for the demand specified. The cost to blend and pack is also calculated. This information provides the user with an indication of the feasibility of the orders.



Line 9

Work Order	Volume Produced	No.of Jars	No. of Case	Blend cost	Pack cost	Storage cost	Total cost
006X325-141		0	0	£0.00	£0.00	£0.00	£0.00
0150XF-349		0	0	£0.00	£0.00	£0.00	£0.00
019SAI-171	1000.00	3571.428571	298	£1,152.27	£1,829.36	£431.55	£3,413.18
020JAR-157	0.00	0	0	£0.00	£0.00	£0.00	£0.00
020JARF-157	0.00	0	0	£0.00	£0.00	£0.00	£0.00
024-147	0.00	0	0	£0.00	£0.00	£0.00	£0.00
026-367	0.00	0	0	£0.00	£0.00	£0.00	£0.00
206JAR-161	2800.00	7	1	£2,107.31	£3.70	£0.85	£2,111.86
206JARF-157	0.00	0	0	£0.00	£0.00	£0.00	£0.00
249JARF-157	0.00	0	0	£0.00	£0.00	£0.00	£0.00
304-138	0.00	0	0	£0.00	£0.00	£0.00	£0.00
308-138	0.00	0	0	£0.00	£0.00	£0.00	£0.00
390JARLS-168	2600.00	52000	4333	£10,714.08	£4.00	£6,283.33	£17,001.41
391JARLS-169	0.00	0	0	£0.00	£3.00	£0.00	£3.00
392JARLS-169	0.00	0	0	£0.00	£0.00	£0.00	£0.00
393JARLS-169	0.00	0	0	£0.00	£0.00	£0.00	£0.00
4274JNEW-157	0.00	0	0	£0.00	£0.00	£0.00	£0.00
511POWDER-176	0.00	0	0	£0.00	£0.00	£0.00	£0.00
600X40-368	0.00	0	0	£0.00	£0.00	£0.00	£0.00
600X80-369	0.00	0	0	£0.00	£0.00	£0.00	£0.00

Machine Utilisation	Percentage of busy	% of delay time
Blend		
Pack		

Changeover Impact

Total Processing Time	
Total Changeover Time	
Labour Utilisation	

Figure 4.4 The Excel Output/Result Spreadsheet (Case Study 1)

Machine utilisation like the percentage time busy and delay can also be checked by extracting the simulated results to the output spreadsheet from the simulation model. The impact of changeover which looks at the total processing time, total changeover time and labour utilisation is also reported. This assists the user in making a decision on whether the customer order should be accepted or not.

4.2.10 Simulation Modelling Approach

The two processes, blending and packing are represented as single machine for each process and not multi process workstation shown in Figure 4.5.

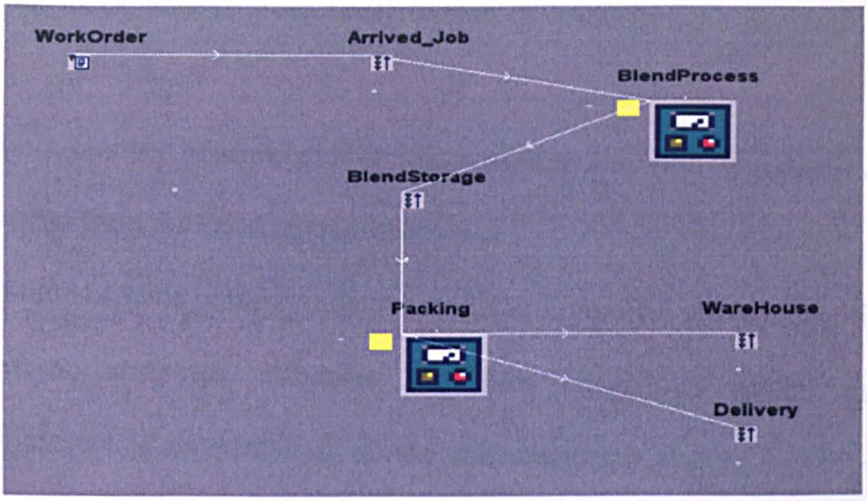


Figure 4.5 Snapshot of Simulation Model (Case Study 1) in Witness

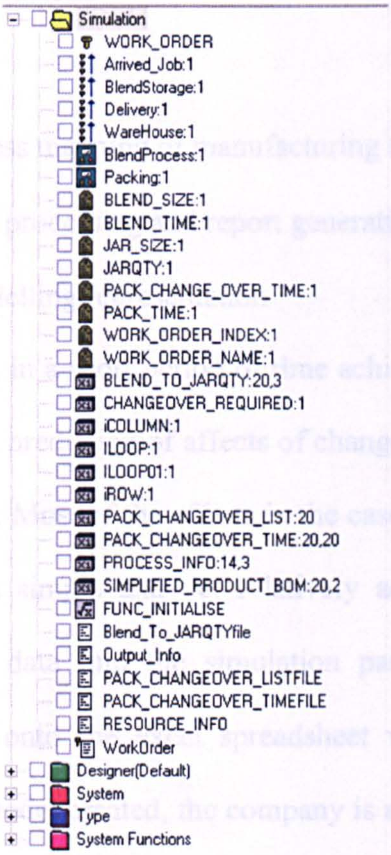
Buffers are created in between processes to temporarily store the WIP. An entity named "work order" is created to read the order file which feeds in the work order part and pushes it to the arrived-job queue. The arrived-job queue reads in the relevant data like blend time and jar quantities for the product and assigns them to the model parameters. This approach has enabled different planning and control approaches to be experimented with by changing the feeding excel order file.

In the user interface, options of different planning and scheduling techniques are provided to sort orders before exporting the work order to the model. The options created in this case study are first in first out (FIFO), largest batch in first or smallest batch in first. Although there are many more techniques to sort the order like shortest lead time or longest lead time to be produce first, these are not included in this case study as the user specified the possible solution to scheduling orders as practised in the company. Currently the model sends all production of finished goods to the warehouse, which triggers a dummy cost of storage.

In the simulation model, only the packing machine requires a changeover when production changes. This is created as a setup which is triggered by a value change to product type. The expression used is 'work_order_index' as attribute, and the setup time is read from an array named as 'pack_change_over_time', which is loaded to the simulation model at initialisation.

At initialisation a number of simulation model parameters as well as product operational information is read from the excel spreadsheet.

The display of the elements of the simulation model in Figure 4.6 provides the list of parts, machines, buffers, attributes, variables and files created to model this simple manufacturing system. Representation of the manufacturing system in the simulation model is simple and easy to understand.



- ☐ Simulation
  - ☐ WORK_ORDER
  - ☐ Arrived_Job:1
  - ☐ BlendStorage:1
  - ☐ Delivery:1
  - ☐ WareHouse:1
  - ☐ BlendProcess:1
  - ☐ Packing:1
  - ☐ BLEND_SIZE:1
  - ☐ BLEND_TIME:1
  - ☐ JAR_SIZE:1
  - ☐ JARQTY:1
  - ☐ PACK_CHANGE_OVER_TIME:1
  - ☐ PACK_TIME:1
  - ☐ WORK_ORDER_INDEX:1
  - ☐ WORK_ORDER_NAME:1
  - ☐ BLEND_TO_JARQTY:20,3
  - ☐ CHANGEOVER_REQUIRED:1
  - ☐ iCOLUMN:1
  - ☐ ILOOP:1
  - ☐ ILOOP01:1
  - ☐ iROW:1
  - ☐ PACK_CHANGEOVER_LIST:20
  - ☐ PACK_CHANGEOVER_TIME:20,20
  - ☐ PROCESS_INFO:14,3
  - ☐ SIMPLIFIED_PRODUCT_BOM:20,2
  - ☐ FUNC_INITIALISE
  - ☐ Blend_To_JARQTYfile
  - ☐ Output_Info
  - ☐ PACK_CHANGEOVER_LISTFILE
  - ☐ PACK_CHANGEOVER_TIMEFILE
  - ☐ RESOURCE_INFO
  - ☐ WorkOrder
- ☐ Designer(Default)
- ☐ System
- ☐ Type
- ☐ System Functions

Figure 4.6 Elements in the Simulation Model (Case Study 1)

4.2.11 Summary of Results

The results from this model show that the production line is really inefficient with machine utilisation below 40%. Estimated work hours of 19200 minutes are needed to complete the orders when the simulation model showed that just 6137.25 minutes is required. This discrepancy could be due to a number of reasons. First it could be that the input data used is not realistic. Second, it could be that the actual production line takes a lot more unidentified time to setup, transport, maintenance as well as other activities that had been assumed to be negligible in the simulation model. The changeover impact is critical due to the nature of the line. The demand of this line is very customer-driven, and existing schedule are interrupted to serve urgent orders or re-prioritise customers' jobs.

4.2.12 Discussions and Conclusions

Key model features:

- Fast and scalable process mapping of manufacturing systems
- Excel spreadsheet data processing and report generation
- Simple simulation modelling representation

The simulation model project, in a short period of time achieved its objectives in terms of its technical aims, providing a prediction of affects of changeover and therefore, achieving the specific aim of the project. Most of the efforts in the case concentrated on representing the system under study in a simple and yet relatively accurate way. Using an excel spreadsheet to directly feed data into the simulation package as well as the results generated directly displayed onto the excel spreadsheet was also key. With the user interface and the simulation model created, the company is able to use the tool to simulate different scenarios in order to reduce lead time and costs, sustain and improve production.

The Excel-Witness capability has proven to be very powerful and flexible and the model provided a practical tool to the company.

4.2.13 Future Work

The company has decided that the integrated excel spreadsheet with the simulation model can be detailed further with more real data for more scenario generation and experimentation. Due to the company's confidential nature of the business, the work has been carried out in-house.

4.2.14 UML Representation

4.2.14.1 Class Diagram

The elements of the manufacturing system in the case study are classified according to the general class diagram proposed in Chapter 3 as shown in Figure 4.7. The simple manufacturing system consists of two machines in this case study.

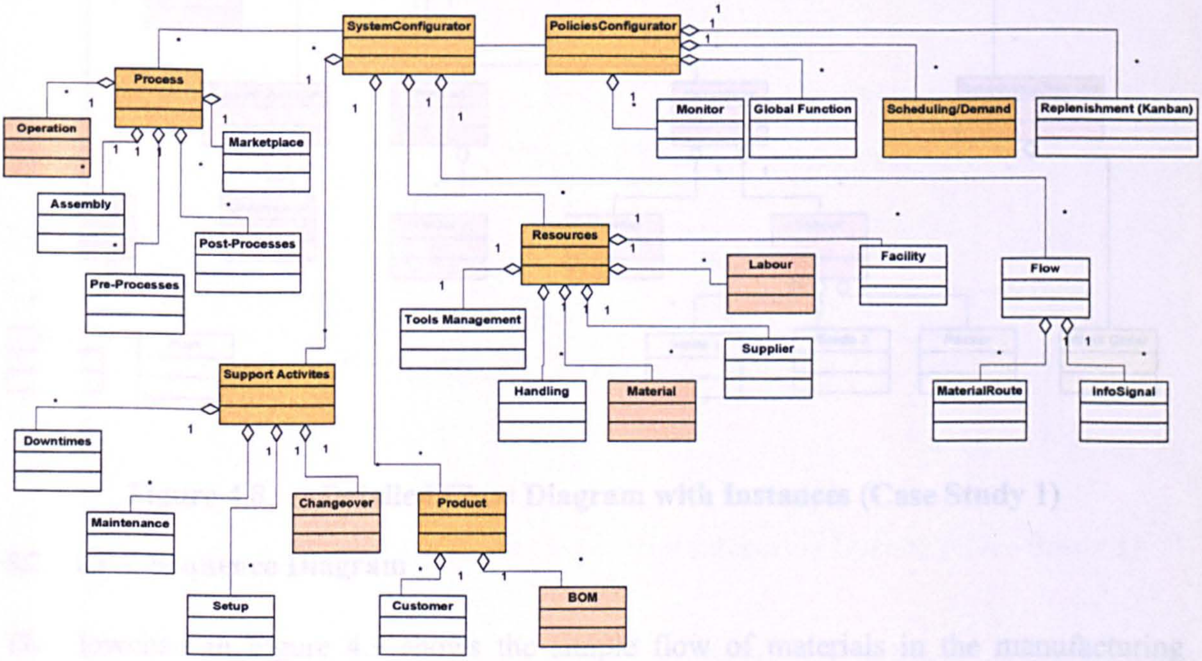


Figure 4.7 Case study 1 Main Class Diagram

Due to the large impact of changeover, the problem being study is narrow, but the quantity and scope of data that is required to generate a reasonable output is relatively large.

Figure 4.8 illustrates the instances created based on the class diagram in Figure 4.7. Classes like BOM, Changeover and Material are derived from data file directly in this case study. The data are not classified into sub-classes or instances. The work order instances created in the scheduling/demand class holds the changes of order and scheduling method. In the Labour class, the instances of the three type of labour: Grade 1, Grade 2, and Packer; are dynamic instances. Labour types could change over time and new instances can be created which old instances can be de-activated or terminated permanently. Attributes for each type of labour for example cost per hour and training level are exclusive to each instance. The Operation class in this case study consists of blend and pack; operations can be added as the model is expanded.

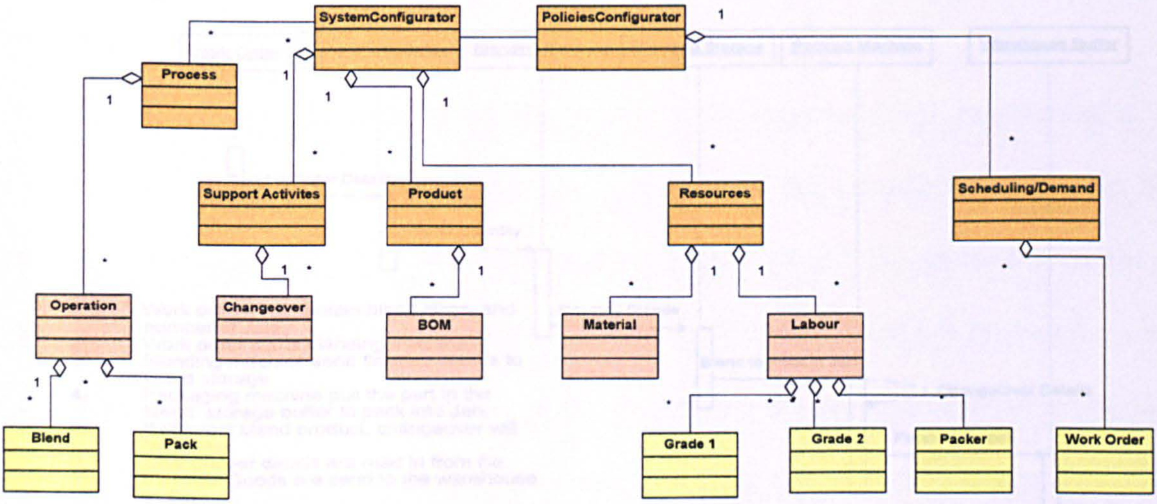


Figure 4.8 Detailed Class Diagram with Instances (Case Study 1)

5.2.14.2 Sequence Diagram

The flowchart in Figure 4.9 shows the simple flow of materials in the manufacturing system of the case study omitting the decision making rules. This flowchart is translated to a sequence diagram to represent the flow of information with dotted arrows and physical flow with solid arrows and how both flows trigger each operation in Figure 4.10.

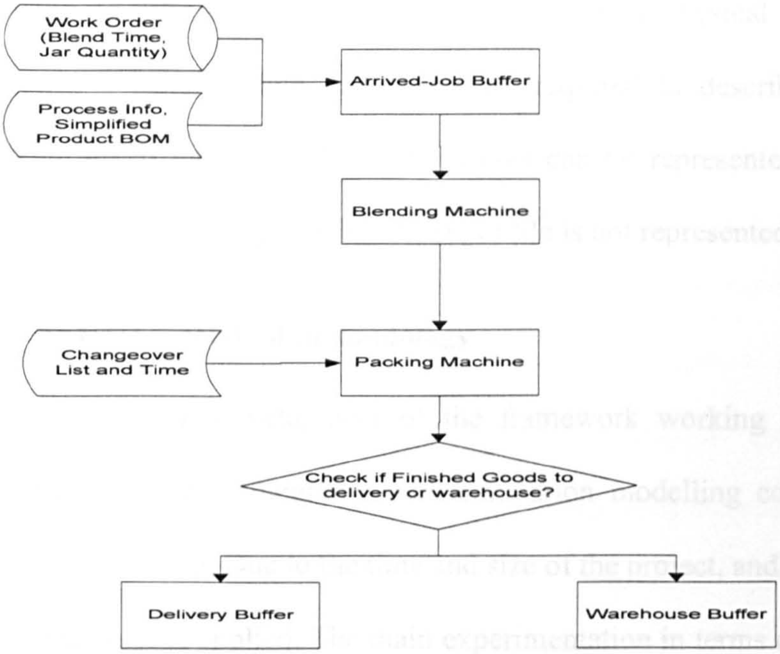
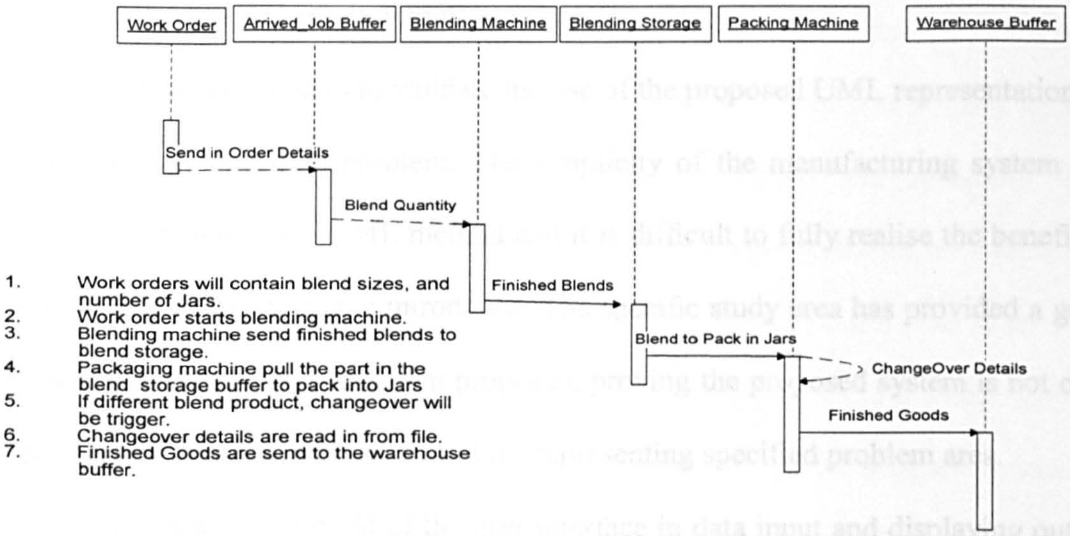


Figure 4.9 Flowchart of the Manufacturing System (Case Study 1)



1. Work orders will contain blend sizes, and number of Jars.
2. Work order starts blending machine.
3. Blending machine send finished blends to blend storage.
4. Packaging machine pull the part in the blend storage buffer to pack into Jars
5. If different blend product, changeover will be trigger.
6. Changeover details are read in from file.
7. Finished Goods are send to the warehouse buffer.

Figure 4.10 Sequence Diagram of the Manufacturing System (Case Study 1)

The above flowchart and sequence diagram represent two different modelling tools displaying different information. The flowchart displays the required data or input files for each process and decision making points to perform its function. The sequence diagram shows the sequence of events, the classes involved and the messages or signals used to trigger the following operations or classes and whether it is a physical or information signal. Each presents a benefit. Both techniques are required to describe the process accurately. Although detail interaction between classes can be represented in swimlane diagrams through UML activity diagrams but the input file is not represented.

4.2.15 Applying the UML proposed methodology

This case study triggered the development of the framework working when external component like Microsoft excel integrated with simulation modelling could provide a flexible decision support system. Due to the time and size of the project, and the simplicity, a subset of UML techniques is applied. The main experimentation in terms of a simulation modelling approach is in integrating Excel with the simulation model for a functional user interface for data input and result output.

The case study provided a basis to validate the use of the proposed UML representation on a smaller and more specified problem. The simplicity of the manufacturing system has limited the exploration of the UML method and it is difficult to fully realise the benefit of the proposed modelling technique introduced. The specific study area has provided a good validation on the general class diagram proposed, proving the proposed system is not only for large complex systems but can be used for representing specified problem area.

This case study shown the benefit of the user interface in data input and displaying output result. Besides that, the importance of sufficient and quality data is highlighted.

4.3 CASE STUDY 2: Foam Production Company

4.3.1 Process Characteristic

Continuing from the first case study, this case study provides a more detailed level of modelling a manufacturing system. This case study is on a small enterprise producing foam material. The Company provides practical and novel solutions for mattress and accessories in the health sector. Initially the products were solely hand made by covering foam rubber with a plastic sheet. New technologies resulted in two different types of material which contributes to two different methods of manufacturing were introduced. The company has over 80% of the UK market and exports worldwide to manufacturers of operating table throughout Europe, Japan and the USA. The company is a dynamic company, which is continually improving its product range, its services to its customers.

An analysis of the current production process and time highlighted a large variation between production time and the calculated lead time. This concluded that there is a large amount of waste in the system. Due to this the company has difficulty in keeping up with delivery/due dates. Growth is stagnant due to the limitation and constraint from inaccuracies in the production system which affected the capacity. Based on a particular production schedule for the day, the required moulds are brought out of the store. Each mould represents one product or component. The moulds go into a cycle where they are prepared for filling, and are filled. They are left for some time for the product to cure and are then de-moulded. Depending on the number of products required, the mould goes back into the cycle or is pulled out of the cycle and back to the store. The product is then worked upon by other operations in the finishing section before it is packaged and shipped to the customer. The products are made-to-order for customer and no stock is available. Hence delay in shipment incurs penalties.

The objective of the simulation model is to study the optimum number the mould and lid of each product with synchronisation of the system in mind. Therefore, preparation and cleaning of the mould and lid is a critical process in the system, to make sure when the moulds and lids are ready.

4.3.2 Objectives of Case Study 2

- Simulating the process of scheduling the moulds and lid and the maximum number of parts in the system.
- Show the effect of over or under scheduling. Synchronisation of the flow is important.
- The allocation of labour to area of work.
- Reduce work in progress in the system
- Reduce lead time of the manufacturing process
- Improve throughput to be able to attain more orders
- Better visual management for minimum control

4.3.3 Assumptions

To focus on the main issues of the case study, the following assumptions are made in the construction of the model:

1. Machines do not breakdown
2. Every operator comes to work
3. Allowances for operators are kept to a minimum
4. There are no raw material supply problems
5. All cycle times lie within the values obtained from the work-study

6. The orders are scheduled on a first in first out basis and no order, which is not on the schedule, is pushed into the cycle
7. There are no defects in production
8. Operators are allocated specific roles

4.3.4 Product Configuration

The company employed two different technologies with two different materials, to produce two bespoke products. The routes used for both are similar but some processes are different. The two processes use different types of mould and lids. Due to the confidentiality of the product details, we named the products as Product A and Product B. These two products are produced by low-pressure injection moulding. Fibreglass moulds and lids are the tooling required for the moulding process. The tooling comes in various sizes and shapes. Product A requires more operations to provide high protection and surface finish compare to Product B. Both types of products must have a minimum conductivity to pass a quality criterion. They should not have any cosmetic damage on their upper surfaces and sides. In addition to this certain customers require that the Product B be of a particular hardness/firmness, and the thickness is one determining factor, which in turn is operator skill dependent.

4.3.5 Layout

The shop floor has adopted a process-type layout where the product moves around to each of the process station. Shelves are set up as the temporary storage area and also as a divider between processes.

4.3.6 Material Handling

Due to the sizes of the foam product and moulds, the products are manually placed on conveyors roller to move around to the various workstations.

4.3.7 Marketplace

The finished products are left on shelves at the end of the process for a day to further cure. Due to the nature of the product family, where products are made-to-order, no marketplace for raw materials or finished goods is allocated.

4.3.8 Downtimes

For the injection moulding machines setup time are required at the start of each operation. This is an initial setup required at the start of each production day.

4.3.9 Experimentation

Experiments were carried out to establish optimum/maximum values using the simulation model. The results are not of high accuracy but only act as a guidance. The results are more or less on the high side as the model assumes no failures, delays and any other setback. The key experiments carried out on:

- Experiments to establish the optimum number of moulds
- Experiments to establish the optimum number of workers
- Experiments to establish work distribution among workers

4.3.10 Simulation Modelling Approach

A simulation model was developed to display the organisation of the manufacturing processes and visually represented the idea of production synchronisation. Operators are also clearly placed at their work station envelope to represent the working area they should be in and the operations they are responsible for which is shown in Figure 4.11. The display is beneficial for training purposes especially using this simulation model to explain to the workforce task allocation and sequence of the manufacturing system flow.

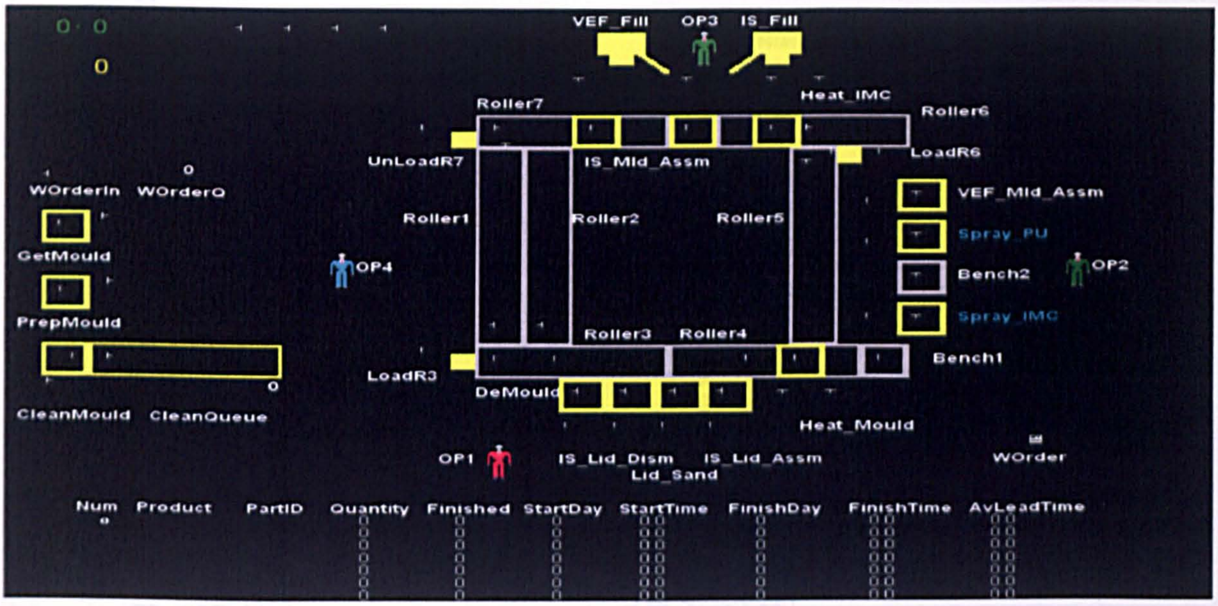
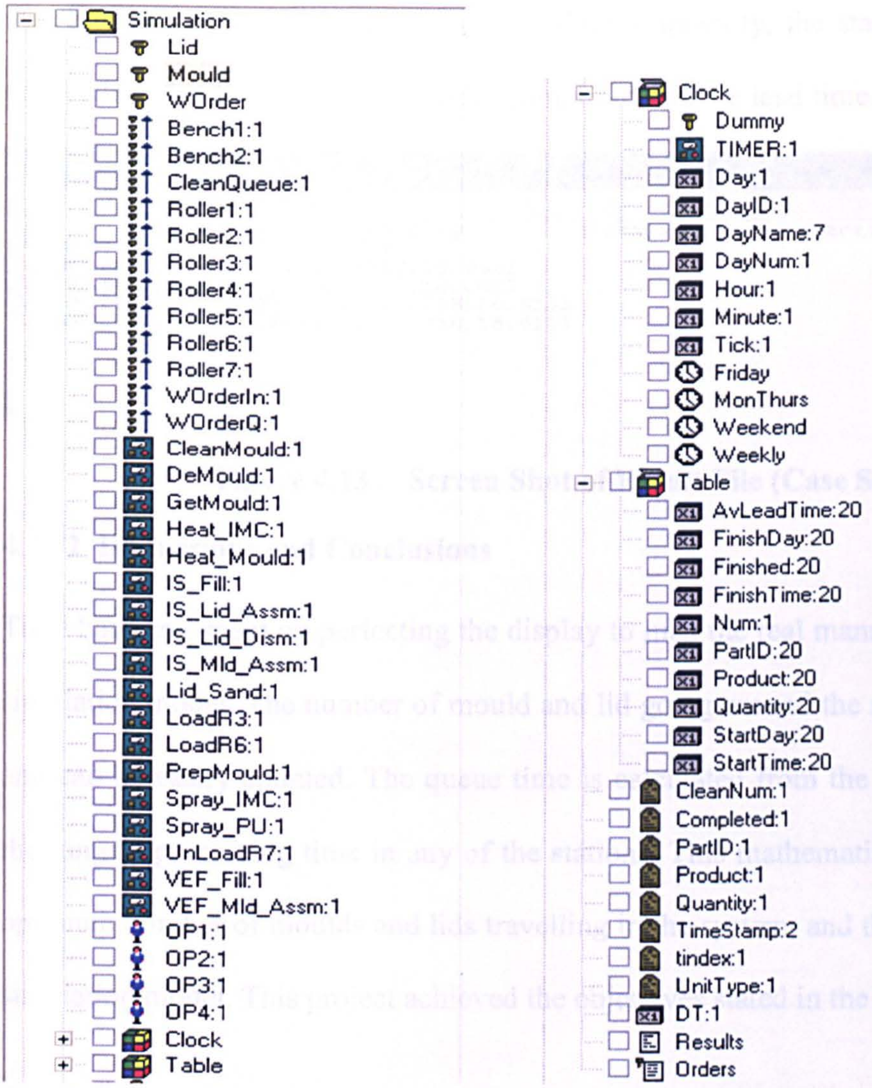


Figure 4.11 Snapshot of the Simulation Model (Case Study 2)

A table at the bottom of the snapshot of the simulation model (Figure 4.11) displays critical variables for the study. This enhances the monitoring process making it easier for the user to know the performance at any time of simulation.

4.3.10.1 Elements in the Simulation Model

Buffers created in the simulation model are a temporary storage that might be an allocated space, or shelves. The operator from the next process picks up the products from the buffers. Some buffers like the WOrderIn and WOrderQ are logical buffers created in the simulation model to temporary store the work order input from the Excel demand file and find out the how long an order takes to finish. Some of the machines created are actually a workstation, where some represent a manual process that needs carrying. Figure 4.12 illustrates the elements created in the simulation model.



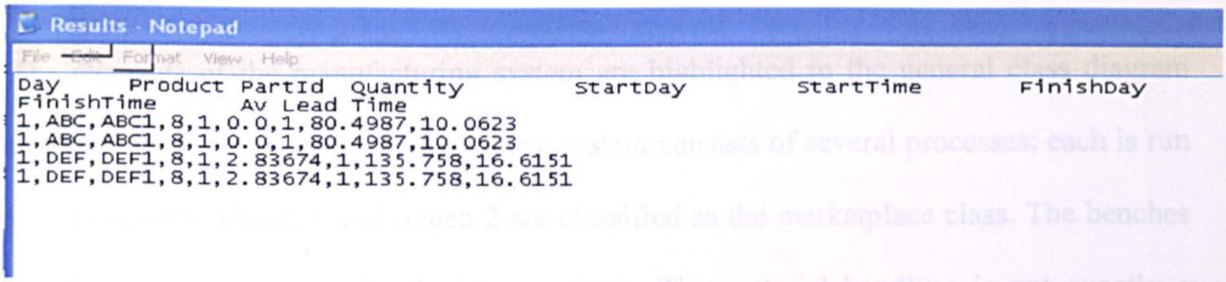
- ☐ Simulation
  - ☐ Lid
  - ☐ Mould
  - ☐ WOrder
  - ☐ Bench1:1
  - ☐ Bench2:1
  - ☐ CleanQueue:1
  - ☐ Roller1:1
  - ☐ Roller2:1
  - ☐ Roller3:1
  - ☐ Roller4:1
  - ☐ Roller5:1
  - ☐ Roller6:1
  - ☐ Roller7:1
  - ☐ WOrderIn:1
  - ☐ WOrderQ:1
  - ☐ CleanMould:1
  - ☐ DeMould:1
  - ☐ GetMould:1
  - ☐ Heat_IMC:1
  - ☐ Heat_Mould:1
  - ☐ IS_Fill:1
  - ☐ IS_Lid_Assm:1
  - ☐ IS_Lid_Dism:1
  - ☐ IS_Mld_Assm:1
  - ☐ Lid_Sand:1
  - ☐ LoadR3:1
  - ☐ LoadR6:1
  - ☐ PrepMould:1
  - ☐ Spray_IMC:1
  - ☐ Spray_PU:1
  - ☐ UnLoadR7:1
  - ☐ VEF_Fill:1
  - ☐ VEF_Mld_Assm:1
  - ☐ OP1:1
  - ☐ OP2:1
  - ☐ OP3:1
  - ☐ OP4:1
  - ☐ Clock
  - ☐ Table

- ☐ Clock
  - ☐ Dummy
  - ☐ TIMER:1
  - ☐ Day:1
  - ☐ DayID:1
  - ☐ DayName:7
  - ☐ DayNum:1
  - ☐ Hour:1
  - ☐ Minute:1
  - ☐ Tick:1
  - ☐ Friday
  - ☐ MonThurs
  - ☐ Weekend
  - ☐ Weekly
- ☐ Table
  - ☐ AvLeadTime:20
  - ☐ FinishDay:20
  - ☐ Finished:20
  - ☐ FinishTime:20
  - ☐ Num:1
  - ☐ PartID:20
  - ☐ Product:20
  - ☐ Quantity:20
  - ☐ StartDay:20
  - ☐ StartTime:20
- ☐ CleanNum:1
- ☐ Completed:1
- ☐ PartID:1
- ☐ Product:1
- ☐ Quantity:1
- ☐ TimeStamp:2
- ☐ tindex:1
- ☐ UnitType:1
- ☐ DT:1
- ☐ Results
- ☐ Orders

Figure 4.12 Elements in the Simulation Model (Case Study 2)

4.3.11 Results

The product results generated by the simulation model are a file named Result.dat in the working directory of the model. This file can be opened using any text editor such as Notepad or a spreadsheet such as Excel. The model should be rewound at the end of each run to update this file. The data from the file can be used in the rest of the simulation model if it is constructed or in any analysis of the moulding cell. A screen shot of the result file is shown in Figure 4.13. The result collection format starts with the day of recording the results, the product with the product ID, the quantity, the start day and start time of production, the day and time the order completed and the lead time.



```
Day       Product PartId  Quantity           StartDay           StartTime          FinishDay
FinishTime         Av Lead Time
1,ABC,ABC1,8,1,0.0,1,80.4987,10.0623
1,ABC,ABC1,8,1,0.0,1,80.4987,10.0623
1,DEF,DEF1,8,1,2.83674,1,135.758,16.6151
1,DEF,DEF1,8,1,2.83674,1,135.758,16.6151
```

Figure 4.13 Screen Shot of Result File (Case Study 2)

4.3.12 Discussions and Conclusions

Time has been spent on perfecting the display to map the real manufacturing system to the simulation model. The number of mould and lid going around the system is clearly shown and can be easily counted. The queue time is calculated from the curing time divided by the longest processing time in any of the stations. This mathematical calculation gives an optimum number of moulds and lids travelling in the system, and this is validated with the simulation model. This project achieved the objectives stated in the beginning.

4.3.13 Future Work

This simulation model is created as a one-off model to study the mould and lid flow for this case study. The result collected from this simulation project has triggered a change of working on the shop floor. The layout had been rearranged and the management of stock are clearer and reduce the lead time by 30% in the first few weeks. This simulation model has lead to an IT project to look at scheduling of the order/demand.

4.3.14 UML Representation

4.3.14.1 Class Diagram

The elements of the manufacturing system are highlighted in the general class diagram shown in Figure 4.14. The manufacturing system consists of several processes; each is run by an operator. Bench 1 and Bench 2 are classified as the marketplace class. The benches are for products to wait for further processes. The material handling is not exactly a physical material handling devices but an operation to load and unload the conveyors manually. Figure 4.15 illustrates the instances created based on the class diagram in Figure 4.14. The instances are created specific to this manufacturing system.

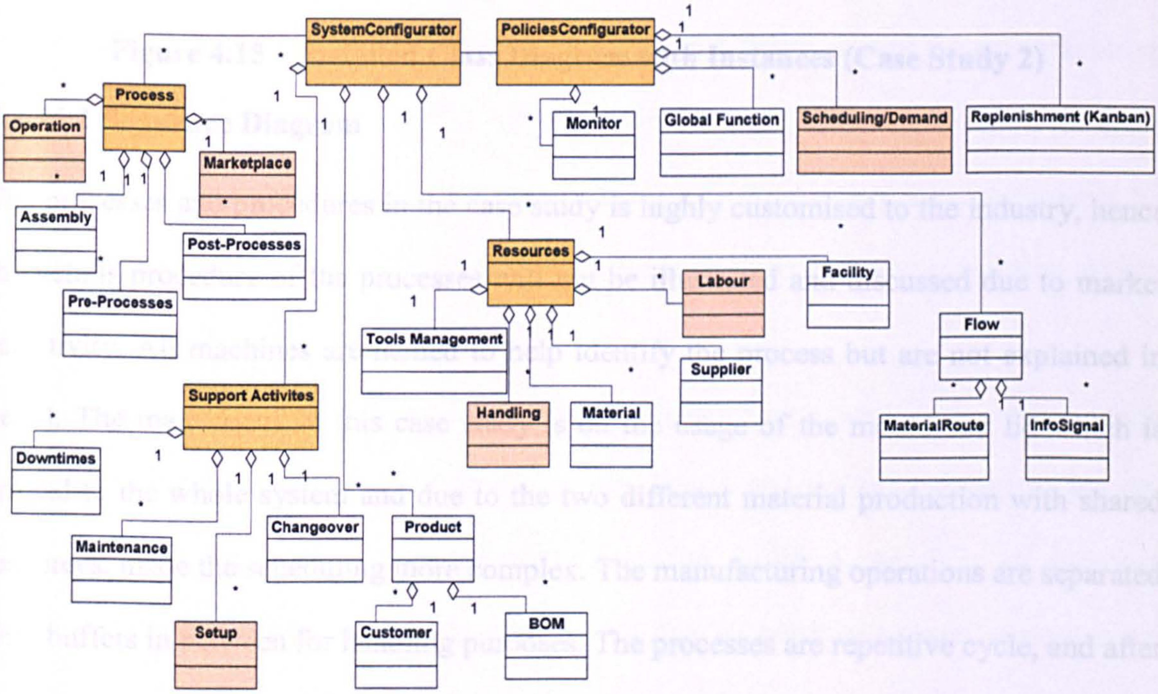


Figure 4.14 Case Study 2 Main Class Diagram

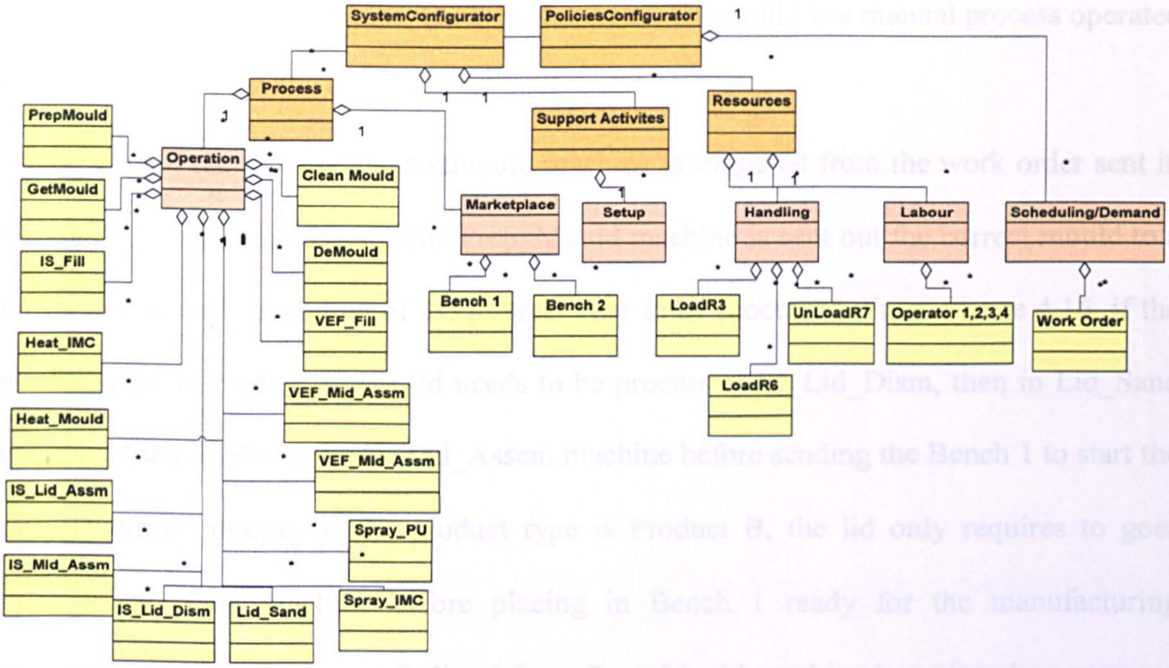


Figure 4.15 Detailed Class Diagram with Instances (Case Study 2)

4.3.14.2 Sequence Diagram

The processes and procedures in the case study is highly customised to the industry, hence the details procedure of the processes will not be illustrated and discussed due to market sensitivity. All machines are named to help identify the process but are not explained in detail. The main focus of this case study is on the usage of the mould and lid which is critical to the whole system and due to the two different material production with shared resources, made the scheduling more complex. The manufacturing operations are separated with buffers in between for handling purposes. The processes are repetitive cycle, and after the last stage the product is left on the shelf over night for settling purposes before further finishing operations are carried out.

The sequence diagram has taken account of the optimum flow from the simulation model created. Get_Mould machine and Prep_Mould machine are not physical machines but a process to trigger the start of mould and lid preparation process. These are logic machine created to represent the process. On the other hand, De-mould is a manual process operated by an operator.

At the start of the process, the Getmould machine is triggered from the work order sent in through an Excel spreadsheet. The Prep_Mould machine is sent out the correct mould to a buffer and the lid depending of the product type to be processed. From Figure 4.16, if the product type is Product A, the lid needs to be process in IS_Lid_Dism, then in Lid_Sand machine, then finally to the IS_Lid_Assem machine before sending the Bench 1 to start the manufacturing process. If the product type is Product B, the lid only requires to goes through Lid_Sand machine before placing in Bench 1 ready for the manufacturing processes. Moulds are sent to Roller 4 from Prep_Mould machine to wait to be processed in the Heat_Mould machine before ending up in Bench 1, ready to start the manufacturing process. The mould and lid used in the manufacturing system travel through different operations and finally ending in a buffer to cure for a set time before they go through the de-mould process followed by the cleaning and preparation for the next round through the process.

From Figure 4.17, the mould and lid is release triggered by a work order. After going through the related manufacturing processes, the mould and lid will be sent to the de-mould process. The machine then sends the mould to Roller 4, which is an allocated location. The description above has shown that the sequence diagrams created have successfully described the detail interaction of the classes and the sequence of the operations.

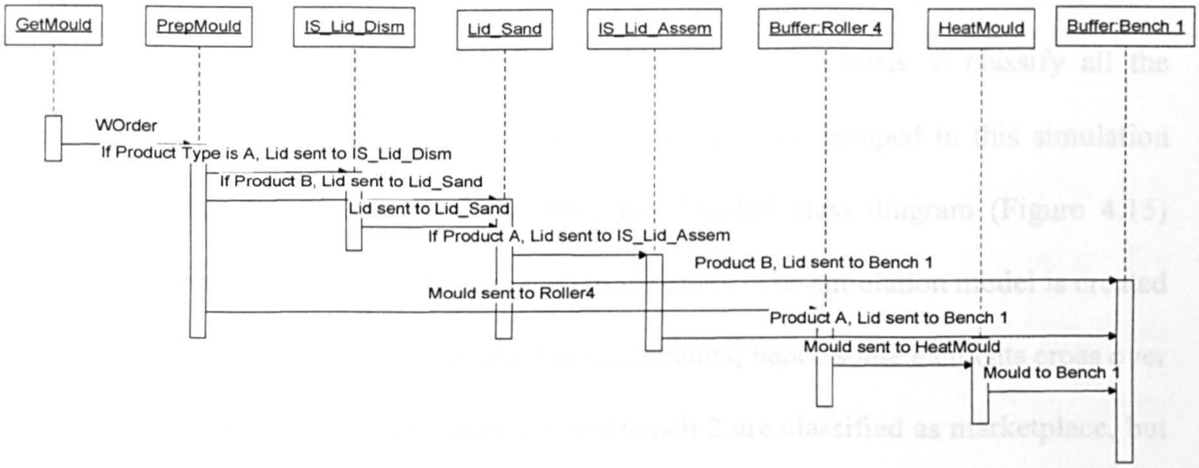


Figure 4.16 Sequence Diagram of Mould and Lid Preparation at the Start of the Process (Case Study 2)

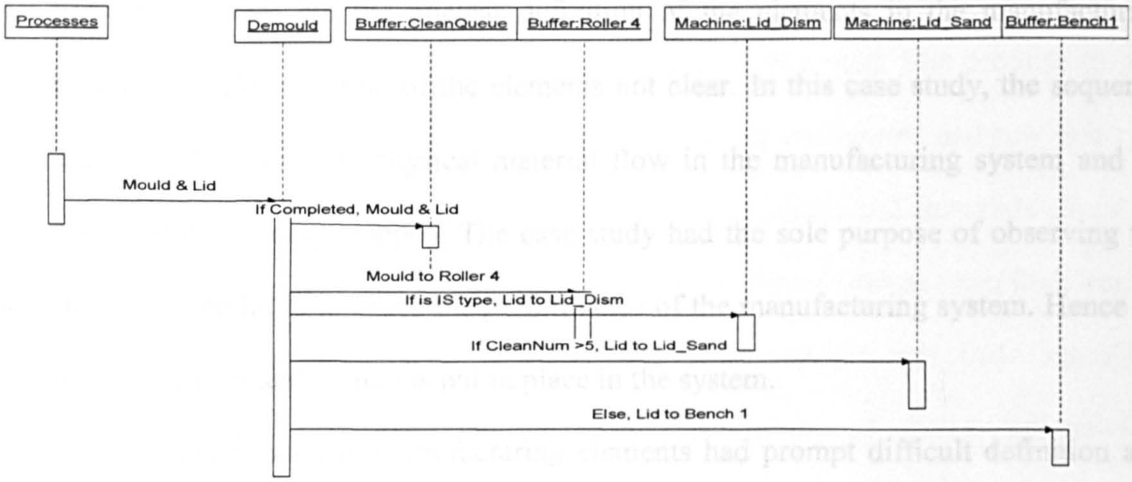


Figure 4.17 Sequence Diagram of Mould and Lid Preparation After Processes (Case Study 2)

4.3.15 Applying the UML proposed methodology

In this case study, the main aim is optimising production with the mould and lid being the constraint through simulation modelling. This example showed the criticality and importance of synchronisation in a manufacturing system. The rate of production depends on the bottleneck instead of the fastest machines or workstations and subsequently the number of moulds in the system at any one time is dictated by the bottleneck. The simulation model has been created to observe the mould and lid flow with operator allocation. The proposed UML class diagram has provided a basis to classify all the elements in the manufacturing system. The machines are not grouped in this simulation model as functional modules. This has made the detailed class diagram (Figure 4.15) messy with all machines classified under operations class. The simulation model is created without clear classification of the manufacturing elements; hence some elements cross over two different classes. For example, bench 1 and bench 2 are classified as marketplace, but can also be viewed as part of the material handling system. This case study validated the proposal that a class diagram can be used in a made-to-order process-type layout manufacturing system but the unclear definition of the elements in the manufacturing system made the classification of the elements not clear. In this case study, the sequence diagram is used to map the physical material flow in the manufacturing system and no information flow is being mapped. The case study had the sole purpose of observing the flow of mould and lid to improve the performance of the manufacturing system. Hence no control or replenishment system is put in place in the system.

The unclear classification of manufacturing elements had prompt difficult definition and difficulty in clearly process modelled the elements. This has prompted the importance of the Object-oriented UML approach in process modelling, which will benefit the later modular design of simulation model objects.

4.4 Case Study 3: Stationary Products Production Line

4.4.1 Process Characteristic

This case study is based on a stationary goods manufacturer trying to improve their production line for better labour utilisation and control, and increased capacity. The existing shop floor has 6 parallel individual manually operating lines. Each production line requires 5 operators to operate the line. The company needed to cut down on labour intensive process and material handling. Hence a new proposal of using some of the existing machines and a purposed built assembly machines that offers better productivity. The product is manufactured through multiple fabrication and assembly processes starting with stapler and ending with packing and the output are recorded. The produce to ship process involves a number of machines, material handling conveyors, and raw materials like sides, flats and stapler. The execution level of operations and materials flows are monitored and controlled by information management activities such as shop floor control and product tracking as well as PLC controllers. Schedulers and their associated information system prepare production schedules to coordinate production output activities in Figure 4.18.

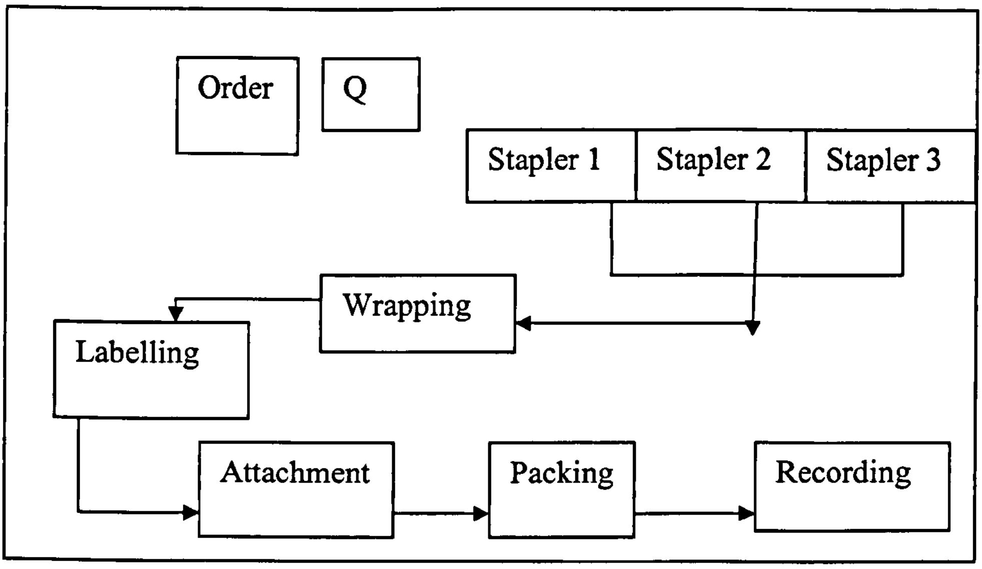


Figure 4.18 Process Map of the System Proposed (Case Study 3)

4.4.2 Objectives of Case Study 3

- Synchronisation of flow of product
- Identification of number of labour and validate if the number proposed is feasible
- The timing of packing machine that dictate the production line scheduling
- The PLC logic on assembly and conveyors will be programme using the simulation findings
- The effect of changeover if product option is high (e.g. 8 types of sizes and colours)

4.4.3 Assumptions

The building of the simulation model required a number of assumptions. Actual material handling, replenishment, assembly and pack strategies had to be defined before simulation development. This involved such assumptions as:

- A single route continuous production line linked by a conveyor either automated or manual.
- Flats, Sides, Stapler and wraps need to be counted as it enters the system to check against production requirements. There is no limit on the input materials but control management is required.

- Materials like Glue, Button, Clip, Locks and Pull tab are of unlimited supply.
- The assembly machine-Pack is in two stages, first 5 components (named LWrCarcass in Model) are assembled, and then 2 of these assembled part into 1 naming Carton. It is an in-line pack station.
- An order file is fed in from the user, hence scheduling is flexible.
- The layout in the simulation model will follow the layout of the plant although the measurements are not to scale.
- The maximum number of parts in the Assembly machine dictates the pull of parts upstream.

4.4.4 Product Configuration

The product has a wide range of configurations with different labels, colours and sizes. This configuration yields high changeover and downtimes on certain machines. The demand/order is differentiated by the colours, labels and sizes. Variations on colours and labels are set to the customers' order, hence the product mix are high.

4.4.5 Layout

The proposed layout is a production line with 3 stapler parallel in the beginning. The continuous production line with automatic material handling like the conveyor is used to facilitate the large quantity flowing through. This new design saves on the number of operators working on the line and with an accurate logic programmed on conveyors; the flow will be smooth and not interrupted.

4.4.6 Downtimes

Downtimes are activities that stop the machine and affect production. There are 6 downtimes activities; and they are fetch, refill, setup, change colour, change size and change label. These downtimes activities have great impact on the utilisation rate of the machines and resources like labour. Planning and control of the shop floor should take into account these activities.

4.4.7 Marketplace

The materials are fed in batches and despatched in batches in this manufacturing system. There is a main stocks station for all the materials, which are delivered directly from the warehouse. Individual workstations have internal supply of materials that require replenishment on a regular basis from the main stock station.

4.4.8 Material Handling

The parts are transported in a conveyor system which is controlled via a number of rules programmed in the PLC. Conveyors are separated as general conveyor transporting from one workstation to another; and internal conveyor that transport inside a workstation.

4.4.9 Experimentation

Experimentation on the simulation model started with achieving a synchronised flow on the proposed new design. The results indicated that the assembly machine is the key to set the pace of the system. Experimentation with labour utilisation was then carried out. Experimentation on a full year order is carried out with optimum number of labour and the workstations' setting to check if targeted capacity can be achieved.

In this case study, data are collected from the existing system, hence the figures are real and accurate. Although some uncertain events like breakdown are ignored in this simulation model, the results are still reasonably valid. The conveyor length required for the system and controlling rules are identified through the simulation model.

4.4.10 Simulation Modelling Approach

The simulation model provided the visual aid to ensure that all the required processes were taken into account and the continuous and optimum flow of the system shown in Figure 4.19 are achieved. The proposed layout is illustrated in the simulation model although not in scale. The model displays the flow of material, indication of needs of labour and the working area of the labour, and indication of strategic control points. The simulation model also keeps count of the raw material required by the system. Work has been put into displaying the elements in the simulation model, making it animated like the real life shop floor (Figure 4.19).

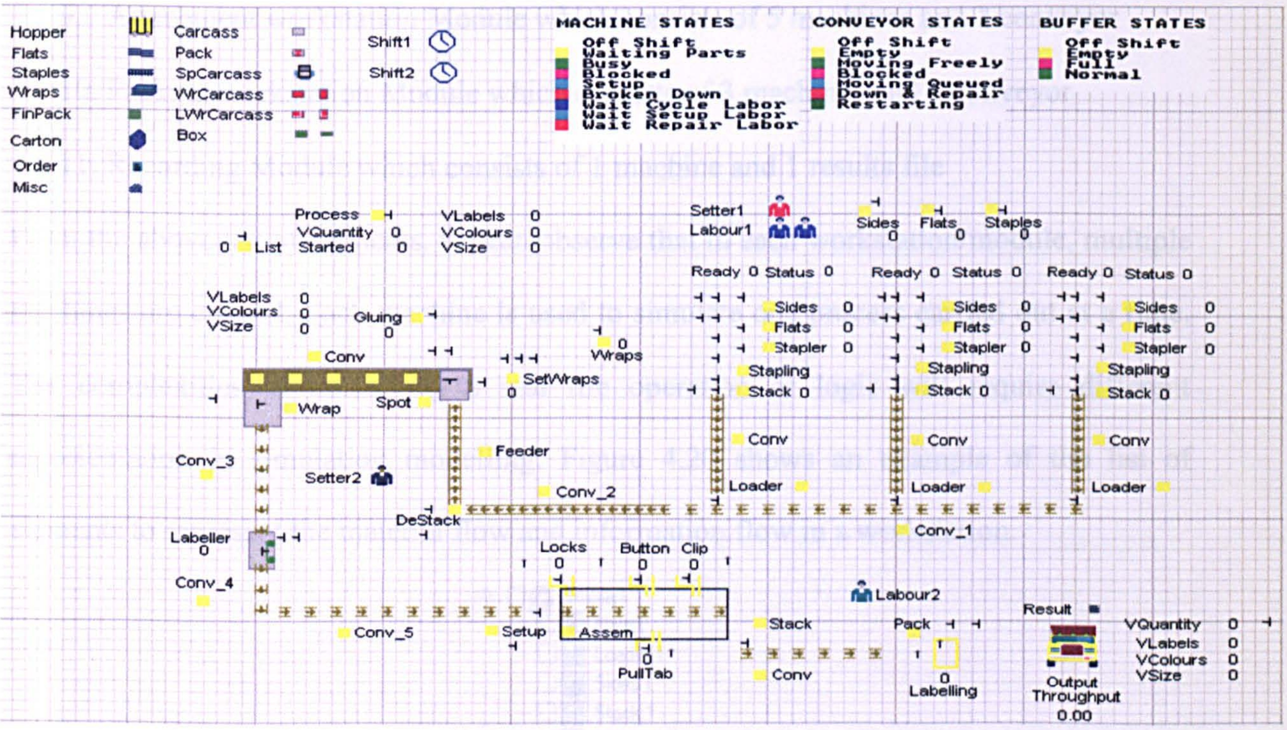


Figure 4.19 Snapshot of simulation model (Case Study 3)

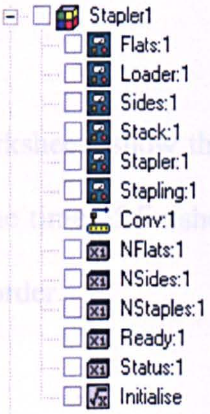
4.4.10.1 Elements in the Simulation Model

The simulation model contains a number of elements as follows:

1. 14 parts: (Box, Carcass, Carton, FinPack, Flats, Hopper, LWrCarcass, Pack, SpCarcass, Staples, Wraps, WrCarcass, Misc, Order)

2. 5 Conveyors
3. Labour (Labour 1, Labour 2, Setter 1, and Setter 2)
4. Orders Module which has a order list read from a order file
5. Queue Module consist buffers to keep check on the materials used
6. Staplers 1, 2 and 3 workstation Module which consists of 6 machines and 1 conveyor
7. Wrapping workstation Module which consists of 5 machines, 2 conveyor and 1 buffer
8. Labelling workstation Module which consist of 1 machine
9. Attachment workstation Module which consists of 5 machines and 1 conveyor
10. Packing workstation Module which consists of 3 machines and 1 conveyor
11. Recording Module which consists of 1 machine and 1 results file

From the above list of elements, we can observe that in each workstation/module, multiple machines are created. Each machine is used to simulate one process carried out at a time. The complexities of mimicking a real life operation or logic will require different representation in simulation modelling. Figure 4.20 shows an example of the list of elements to represent the material flow and information flow in a workstation.



- ☐ Stapler1
  - ☐ Flats:1
  - ☐ Loader:1
  - ☐ Sides:1
  - ☐ Stack:1
  - ☐ Stapler:1
  - ☐ Stapling:1
  - ☐ Conv:1
  - ☐ NFlats:1
  - ☐ NSides:1
  - ☐ NStaples:1
  - ☐ Ready:1
  - ☐ Status:1
  - ☐ Initialise

Figure 4.20 The Elements in Stapler Module (Case Study 3)

4.4.10.2 Simple process flow in the model

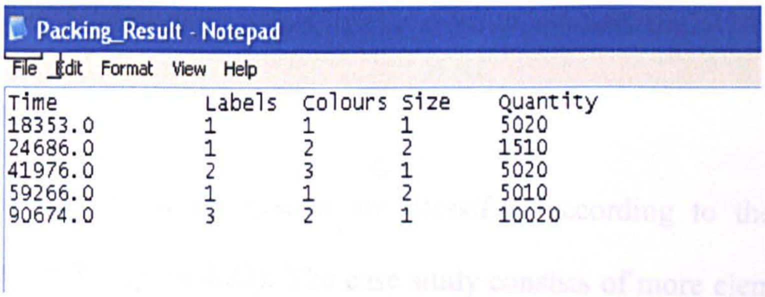
The following is a list of steps involved in the process flow:

1. Order Module starts with a list of orders;
2. Q-module consisting of buffers of raw material: sides, flats and staples starts counting;
3. 3 Stapler Machines draw materials from Q-module after receiving order from Order module. When finished each with own internal conveyor send the parts to Conv_1;
4. Conv_1 then delivers to Conv_2
5. Then to Wrapping module;
6. After finishing the parts are send to Conv_3
7. Then to Labelling module, after complete labelling, parts are placed on to Conv_4;
8. Then to Conv_5 to the attachment module;
9. The internal conveyor(Assem) then pushes the parts to the stack machine in Packing module;
10. When labelling in Packing module is finished, the output will be pushed to Recording module.

Controls are attached to each conveyor represented in the form of rules and constraints.

4.4.11 Results

The results from the packing worksheets show that the targeted capacity can be achieved. The data in Figure 4.21 shows the time of finished production, the label type, the colour, the size and the quantity for that order.



```
Time                Labels  Colours Size     Quantity
18353.0             1       1       1        5020
24686.0             1       2       2        1510
41976.0             2       3       1        5020
59266.0             1       1       2        5010
90674.0             3       2       1        10020
```

Figure 4.21 Example of Packing Result (Case Study 3)

In the case study the proposed number of labour operating on the production line is sufficient. From the existing layout to this new design, nearly 2/3 of operators are reduced.

4.4.12 Discussions and Conclusions

The simulation model has enabled the company to implement the change proposed in a more structured manner. The logic used in the simulation model provided a good basis to program the PLC on the assembly and conveyors. The reduction of labour requirement has freed up the operator for other tasks in the factory and has tremendous saving on the overhead of this production line. The production is running smoother without disruption from labour dependant problems like absenteeism and human error.

4.4.13 Future Work

Results from the simulation model supported the feasibility of the proposed new design system. Work has immediately been done to start the changes in the shop floor. The system has successfully been implemented replacing the existing 5 production line and cut down on labour usage and provided more space. Control of the new system is time-saving, good visualisation and provided better production performance.

4.4.14 UML Representation

4.4.14.1 Class Diagram

Elements of the manufacturing system are classified according to the class diagram proposed in Chapter 3 (Figure 4.22). The case study consists of more elements than in the first 2 case studies. Both static and dynamic sides of the proposed class diagram are explored. Figure 4.23 illustrates the instances created based on the class diagram in Figure 4.22.

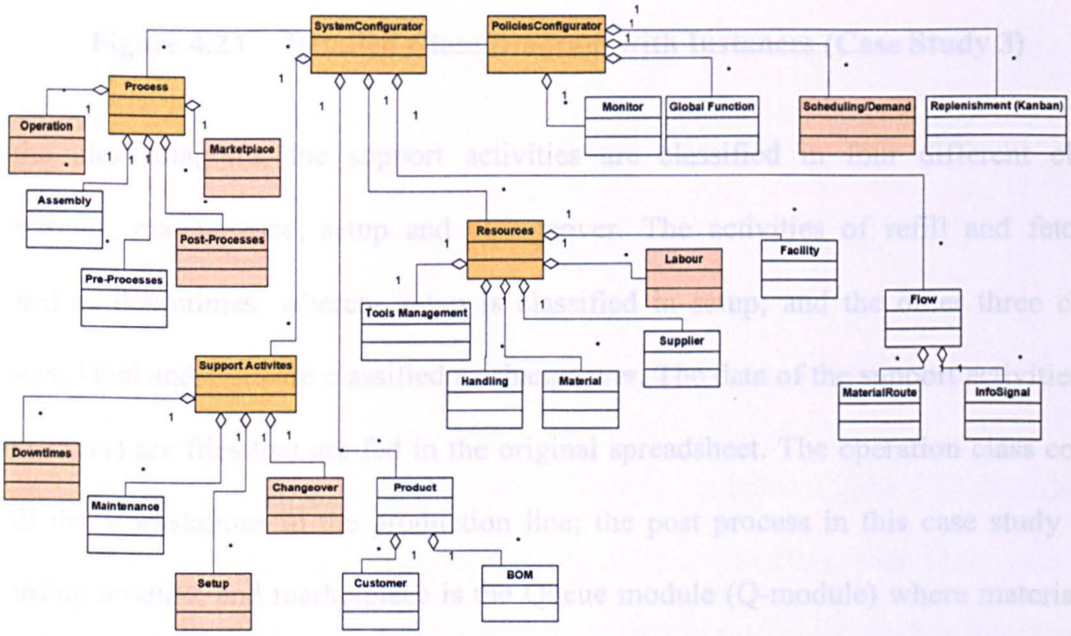


Figure 4.22 Case Study 3 Main Class Diagram

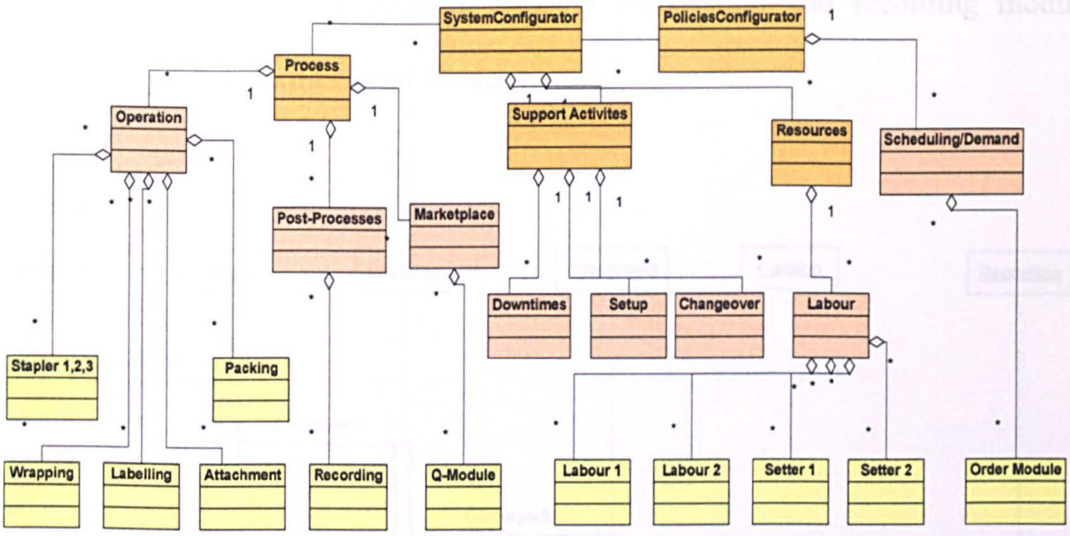


Figure 4.23 Detailed Class Diagram with Instances (Case Study 3)

In the class diagram, the support activities are classified in four different classes: downtimes, maintenance, setup and changeover. The activities of refill and fetch are classed as downtimes, whereas setup is classified in setup; and the other three change colours, label and sizes are classified as changeover. The data of the support activities (e.g. changeover) are files that are fed in the original spreadsheet. The operation class consists of all the workstations in the production line; the post process in this case study is the recording module; and marketplace is the Queue module (Q-module) where materials are held. There are four types of labour: labour 1, labour 2, setter 1, and setter 2, each have different skill levels, working envelope and responsibilities. Finally the dynamic scheduling/demand class is represented by the order module in the system.

4.4.14.2 Sequence Diagram

The main workstations in the manufacturing system and the connections between the workstations are shown in Figure 4.24. The Sequence diagram shows that the UML diagram has the properties to describe a flow of the continuous production system. The main processes of the manufacturing system (e.g. Order, wrapping workstation, labelling workstation, attachment workstation, packing workstation and recording module are connected by physical entities and the conveyors.

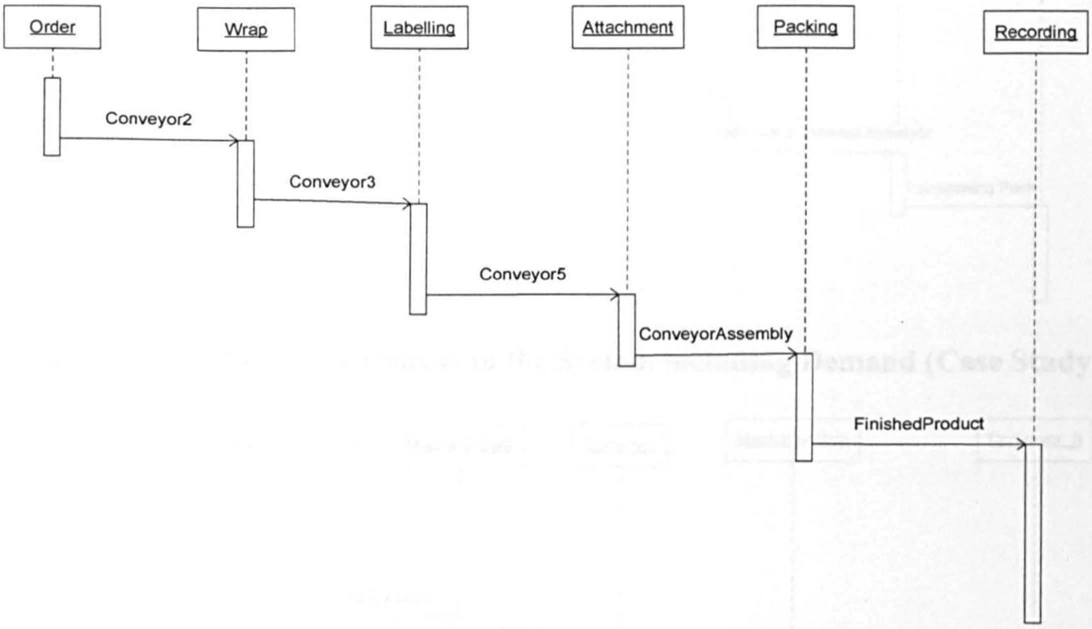


Figure 4.24 Main Processes Flow in the System (Case Study 3)

Figure 4.25-Figure 4.28 illustrate the detailed flow in a process. Figure 4.25 illustrates the start of the process in this production system in detail. Starting with order sent to the stapler. The stapler machine will require the assistance of the Queue module machine to do the checking and send the materials to the correct stapler machine to work on. The order machine acts as a pre-process operation and is viewed as a dynamic scheduling/demand class that demands frequent monitoring and modification. Figure 4.26 and Figure 4.27 illustrate a simple process in the workstation that does not have a pre-process operations or a post-process operation. Figure 4.28 displays the flow in an assembly cell which also acts as a recording module as a post-process class.

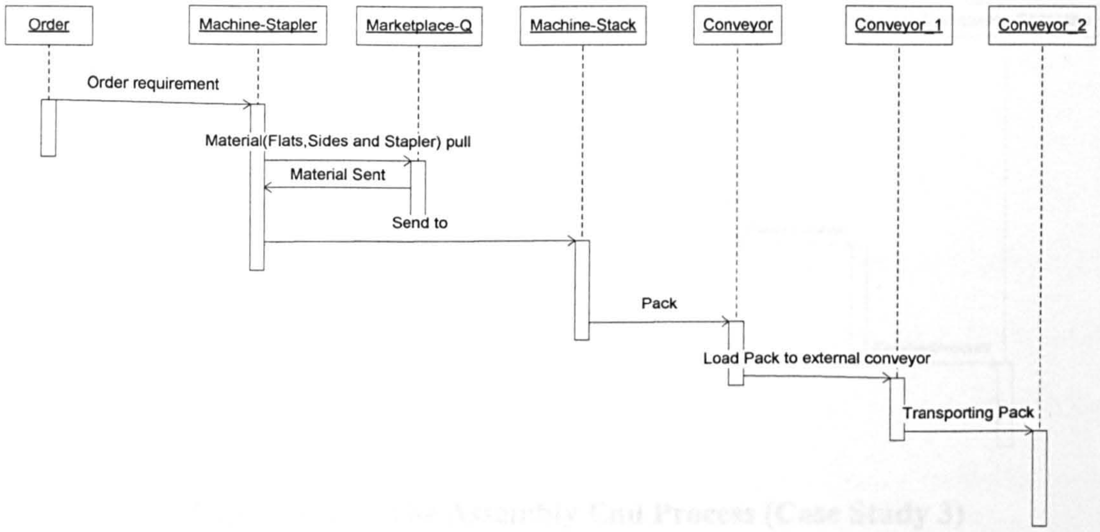


Figure 4.25 The Start Process in the System including Demand (Case Study 3)

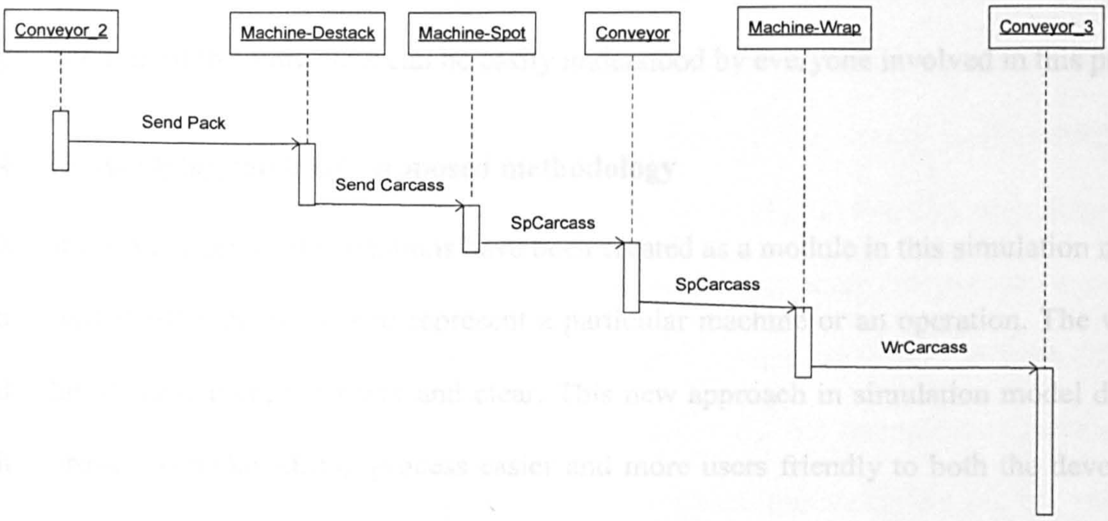


Figure 4.26 A Middle Process in the System (Case Study 3)

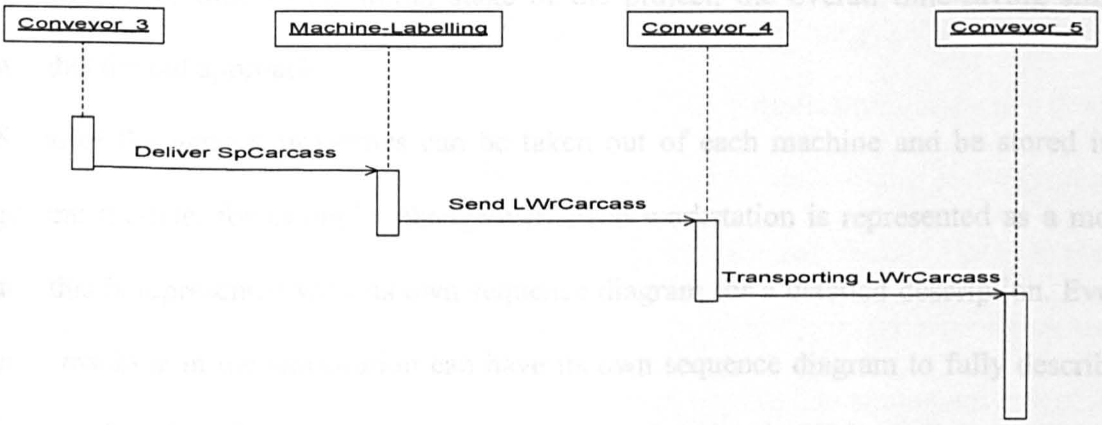


Figure 4.27 The Labelling Process Flow (Case Study 3)

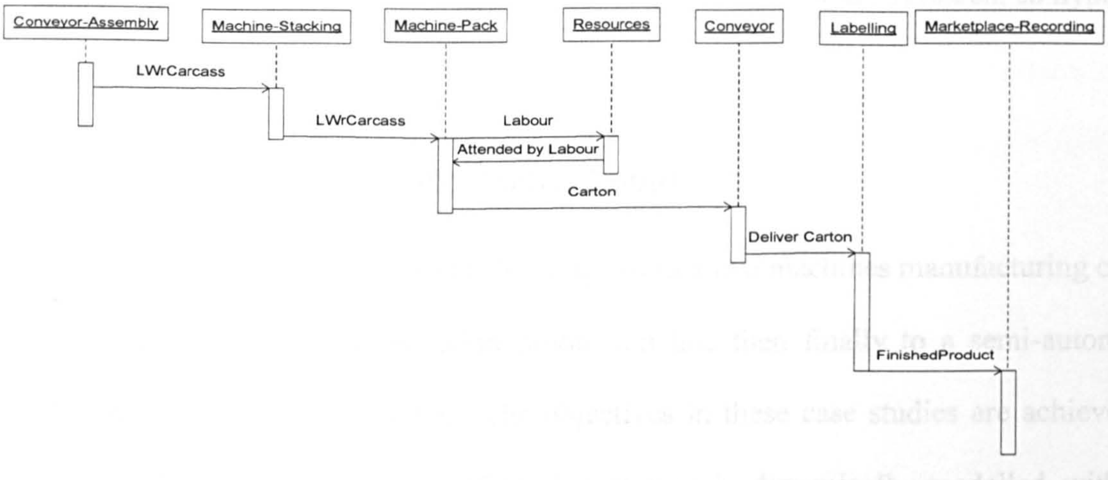


Figure 4.28 The Assembly End Process (Case Study 3)

These figures show clearly the representations and connections of each machine in the workstation and also the connection between the workstations. Communication and presentation of the work flow can be easily understood by everyone involved in this project.

4.4.15 Applying the UML proposed methodology

Machine, work cell or workstations have been created as a module in this simulation model as a self containing process to represent a particular machine or an operation. The visual display is more comprehensive and clear. This new approach in simulation model design has proven to make editing process easier and more users friendly to both the developer and user. Although classifying the elements in the system and implementing this design required more time in the initial stage of the project, the overall time-saving still out-weights the old approach.

Some of the general properties can be taken out of each machine and be stored in one general module, for example: changeover. Each workstation is represented as a module, and this is represented with its own sequence diagram for a detailed description. Even so, each machine in the workstation can have its own sequence diagram to fully describe the rules and logic utilised. There is no diagram or function in UML to link all the related diagrams together. Microsoft Visio as the modelling tool used in this research, so hyperlink can be added to link the related diagrams.

4.5 Conclusions of the UML Methodology

The case studies presented in this chapter range from a two machines manufacturing cell to a single continuous multi-workstation production line then finally to a semi-automated flexible type manufacturing system. The objectives in these case studies are achieved as stated. The behaviour of the manufacturing system is dynamically modelled with the simulation software. These systems are classified with the UML class diagram approach proposed. Firstly the manufacturing elements in the case studies are classified with the general proposed class diagram. Then it is detailed with the class instances which are specified to each case study. The flow of the manufacturing system is illustrated with sequence diagrams. From the case studies, it can be concluded that sequence diagram is able to describe and illustrate specific small system to larger, more complex processes in a manufacturing system. Each case study's sequence diagrams are illustrated from different perspective of the system according to the area being study. For example the Case Study 1, the sequence diagram easily illustrated the entire manufacturing system but not showing the input data required. Case Study 2's sequence diagram showed the detail working from one work station to the next but not the entire picture. Case Study 3's sequence diagrams are illustrated in multi-layer. First the entire flow of the manufacturing system is described, then the flow of each workstation. Further illustrations of the working in each machine in the work station are possible but all these diagrams are not linked. The last two case studies' sequence diagrams illustrate the physical flow of the manufacturing system and not the information and control flow. The traditional approach to simulation modelling has demonstrated that the information control flow is not clearly represented and sometimes not embedded. The essential goal of process mapping the manufacturing system is to accumulate all information of the system, the location of the bottleneck, and to describe the processes' details and this has been achieved through the UML methodology proposed.

Chapter 5 Modular Simulation Modelling in Manufacturing

The benefits of an object-oriented approach in classification and representation of manufacturing system identified in Chapter 4 triggered the modular design in simulation modelling objects. In this chapter, a modular design of manufacturing system components for simulation modelling project is presented. The primary reason for building manufacturing simulation models is to provide support tools that aid the manufacturing decision-making process. Simulation models are typically a part of a case study commissioned by manufacturing management to address a particular set of problems. The objectives of the case study determine the types of simulation models, input data, and output data that are required. General simulation modelling components libraries and interface data standards could simplify the simulation analyst's job and significantly improve the simulation case study process. From the case studies presented in Chapter 4, a set of data collection criteria and a general manufacturing system questionnaire is developed and explained.

5.1 Introduction of simulation for manufacturing systems

Manufacturing systems consist of various types of machines (processing or assembly machines, material handling equipment, inspection stations, etc.) and the operating control procedures used to determine how the equipment is to be operated. Together, these items determine the capability and capacity envelope for the system.

A manufacturing system may move from one configuration to another in two ways identified by Shewchuk and Moodie in 1998. First, the configuration may be changed intentionally, to adopt a more favourable match between capability or capacity required (desired) and what is available. A certain amount of investment (time, effort, etc.) is required to effect such changes. The second is when the configuration changes on its own due to component wear (e.g. changes in process capabilities, processing rates, etc.) or unreliability (e.g. machine breakdowns).

Simulation modelling is well known to be able to improve performances, streamline processes, analyses, optimises, reports and balances, and is a technology that has been proven to be able to transform business and manufacturing systems. Simulation models take into account the variability of a process and can offer confidence intervals for results indicating the likelihood of different scenario occurrences. It's the accuracy that this type of detail provides that sets simulation capabilities above static analyses such as spreadsheet calculations. Simulation allows for a dynamic picture of a process over time to be generated. An animation of any business and manufacturing process helps communicate the operational messages as the simulation graphical displays show how the status of a business or system changes. These displays range from abstract process diagrams and simple plan schematics to full virtual reality factories and operations. Simulation is widely used in almost all industry sectors. It has universal applicability to any system which consists of a series of process steps which progress on an event basis. In discrete simulation models, typically events are the start or finish of a process or work step. Working in a simulated environment gives you the opportunity to make key decisions quickly in response to business needs as they arise. It also is the key link for driving business performance. Simulation solutions coupled with other features such as optimisation, and 3D visualisation help connect data to processes to deliver key metrics or KPIs for a more balanced approach to business. Significant benefits can be achieved including:

- Better use of resources through the identification of bottlenecks and spare capacity
- Validation of new processes prior to launch
- Improved customer service levels

- Reduced costs and lead-times

From Dewhurst et al. (2002), the typical output from a simulation project can be summarised in Table 5.1.

Problem domain	Typical decisions	Typical model output requirements
Physical	Facility location and layout Material handling equipment	Overall facility and equipment costs, transport distance and difficulty
Volume	Machine options, staffing levels	Machine costs, labour costs, quantity processed
Time	Optimised production, scheduling policies	Throughput time, bottlenecks, total work in progress
Quality	Effect of quality systems (e.g. statistical process control or total productive maintenance), skills analysis	Scrap levels, throughput time (due to breakdowns or unavailable skills), overall cost of quality
Cost	Customer portfolio analysis, business process re-engineering, make or buy, capital investment	Activity-based costs of flow entities (for both customer and product types), value added analysis for activities, long-term cash flows
Revenue	New product introduction, product pricing, reaction to environmental change	All of the above

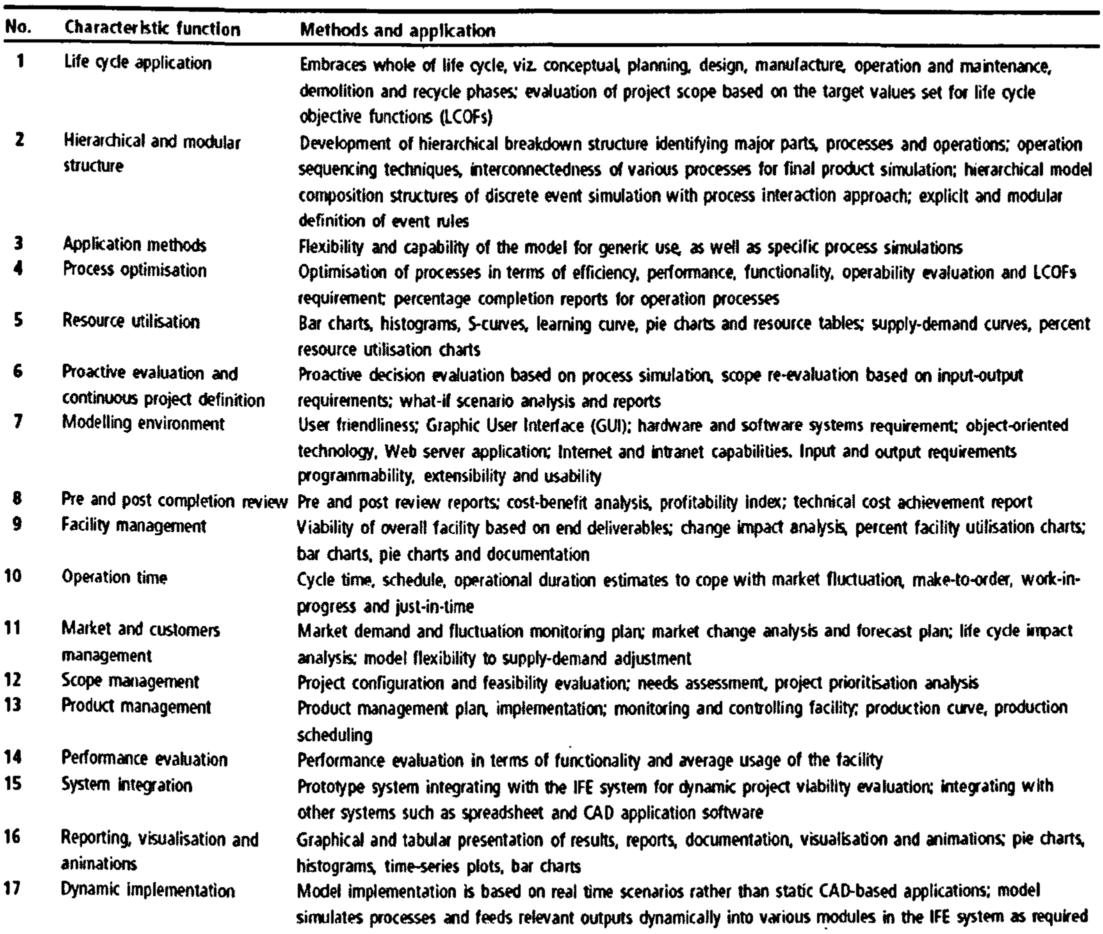
Table 5.1 Typical decision which benefit from simulation modelling (Dewhurst et al., 2002)

Doloi and Jaafari (2002) have compiled a table listing the application and purpose of simulation modelling in various fields shown in Table 5.2. The authors have divided the existing systems based on an extensive literature review into three main fields:

- Construction-oriented simulation systems,
- Manufacturing-oriented simulation systems, and
- General-purpose simulation systems.

These systems could be further divided into two classes:

- In-house, typically proprietary systems which are generally developed as prototype systems; and
- Commercial systems, which are available in market or developed and employed within research institutions.



No.	Characteristic function	Methods and application
1	Life cycle application	Embraces whole of life cycle, viz. conceptual, planning, design, manufacture, operation and maintenance, demolition and recycle phases; evaluation of project scope based on the target values set for life cycle objective functions (LCOFs)
2	Hierarchical and modular structure	Development of hierarchical breakdown structure identifying major parts, processes and operations; operation sequencing techniques, interconnectedness of various processes for final product simulation; hierarchical model composition structures of discrete event simulation with process interaction approach; explicit and modular definition of event rules
3	Application methods	Flexibility and capability of the model for generic use, as well as specific process simulations
4	Process optimisation	Optimisation of processes in terms of efficiency, performance, functionality, operability evaluation and LCOFs requirement; percentage completion reports for operation processes
5	Resource utilisation	Bar charts, histograms, S-curves, learning curve, pie charts and resource tables; supply-demand curves, percent resource utilisation charts
6	Proactive evaluation and continuous project definition	Proactive decision evaluation based on process simulation, scope re-evaluation based on input-output requirements; what-if scenario analysis and reports
7	Modelling environment	User friendliness; Graphic User Interface (GUI); hardware and software systems requirement; object-oriented technology, Web server application; Internet and intranet capabilities. Input and output requirements programmability, extensibility and usability
8	Pre and post completion review	Pre and post review reports; cost-benefit analysis, profitability index; technical cost achievement report
9	Facility management	Viability of overall facility based on end deliverables; change impact analysis, percent facility utilisation charts; bar charts, pie charts and documentation
10	Operation time	Cycle time, schedule, operational duration estimates to cope with market fluctuation, make-to-order, work-in-progress and just-in-time
11	Market and customers management	Market demand and fluctuation monitoring plan; market change analysis and forecast plan; life cycle impact analysis; model flexibility to supply-demand adjustment
12	Scope management	Project configuration and feasibility evaluation; needs assessment, project prioritisation analysis
13	Product management	Product management plan, implementation; monitoring and controlling facility; production curve, production scheduling
14	Performance evaluation	Performance evaluation in terms of functionality and average usage of the facility
15	System integration	Prototype system integrating with the IFE system for dynamic project viability evaluation; integrating with other systems such as spreadsheet and CAD application software
16	Reporting, visualisation and animations	Graphical and tabular presentation of results, reports, documentation, visualisation and animations; pie charts, histograms, time-series plots, bar charts
17	Dynamic implementation	Model implementation is based on real time scenarios rather than static CAD-based applications; model simulates processes and feeds relevant outputs dynamically into various modules in the IFE system as required

Table 5.2 Definition of Characteristic Functions for an Idealised Process Simulation Model (Doloi and Jaafari, 2002)

Assumptions and Rules applied to the simulation model are set out before the start of the project. These assumptions outline elements that are not studied and assumed as a static or of unconstrained value. Rules are ways with which the manufacturing system operates at the actual shop floor level and how interactions between components are to be carried out.

5.2 Model Generation

5.2.1 Design Methodology of Manufacturing Systems

Continuing from the object-oriented UML approach to describe manufacturing systems, a clear understanding of the design methodology of a manufacturing system is important. According to Rao and Gu (1997) a design methodology of manufacturing systems can be defined as a set of procedures that analyses and segregates a complex manufacturing system design task into simpler manageable sub-design tasks while still maintaining their links and interdependencies. This process of segregation, analysis and generation of solutions should lead to the development of a design methodology. The methodology proposed by Rao and Gu (1997) assumes the availability of the product designs and broadly includes the following steps:

- Step 1 Requirements of manufacturing system design.
- Step 2 Determination of manufacturing operations.
- Step 3 Selection and design of machines.
- Step 4 Design of manufacturing system configuration.
- Step 5 Design evaluations.
- Step 6 Implementation of system.
- Step 7 System reconfiguration.

This design methodology outlines and specifies the steps needed to be taken in designing a manufacturing system. It is up to the system designer to come up with approaches to implement the methodology. The detail explanation by Rao and Gu (1997) on the proposed design methodology idea can be found in Appendix B. The idea contains many important steps and concept which influence this research.

5.2.2 Project Planning

Besides a structured design methodology, a project plan to manage the simulation study is critical as shown in Figure 5.1 based on Banks et al. (1995) guides but is modify to suit the simulation projects proposed in this research. Simulation case studies are conducted to analyse and improve the efficiency and effectiveness of manufacturing organisations, systems, and processes.

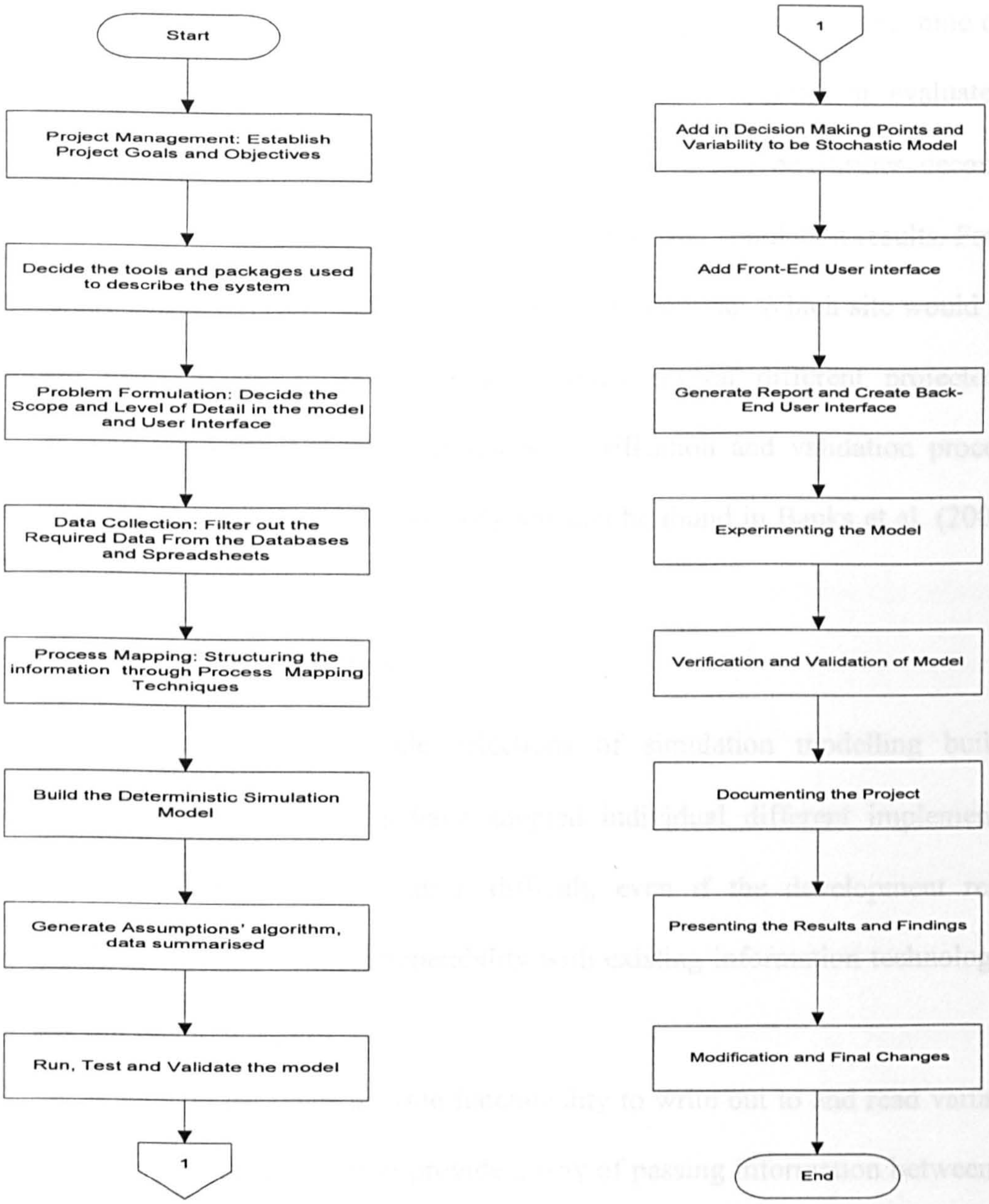


Figure 5.1 Project Plan for a Simulation Modelling Project

Studies are designed to solve specific problems and get answers to specific questions. And these studies often model some aspect of current operations and validate the effect of some hypothetical change(s) to those operations. The performances of current and proposed systems are evaluated according to some set of metrics. If the simulation validates that sufficient improvements can be expected, then the proposed changes are implemented. The objectives of the project define the reasons for performing the simulation. Some examples of study objectives might be to evaluate the best site for a new plant, create a better layout for an existing facility, to determine the impact of a proposed new machine or to change the entire set of machines on shop floor production capacity, or evaluate alternative scheduling algorithms. A high level study objective can be further decomposed into individual questions that may be answered directly from simulation results. For example if the study objective is site selection, one question might be: Which site would result in the lowest expected overall operating costs given several different projected levels of production for a selected set of products? Verification and validation process are also important features in a simulation study and can be found in Banks et al. (2000) and Law and Kealton (2000).

5.3 Simulation packages

In the market, there are wide selections of simulation modelling building tools. Unfortunately many packages have adopted individual different implementations and model object definitions making it difficult, even if the development resource was available to enable model interoperability with existing information technology system is costly and required expertise.

Many simulation packages provide functionality to write out to and read variables from a spreadsheet package in order to provide a way of passing information between models. In many cases this provides little more than the passing of information sequentially from one model to another. To apply the same method for passing entity information to one another across many models one must consider synchronisation. If multiple models were running and passing information to each other then these models could be running at different speeds; i.e. the simulation clocks would be different in each. Thus when Model A receives an event from Model B and Model C, it would need to determine which event to process first. Using a spreadsheet package to facilitate the passing of entities may provide some limited mechanism for reading and writing time-stamped information, event list information and even synchronisation logic (time-management). However it is suggested that such a mechanism would require some middleware logic (program instructions) to give the required functionality. It can then be argued that the spreadsheet package is no longer acting as a simple data passing mechanism, more as a time management component. A spreadsheet package like Microsoft Excel might not be the best tool for this task. Spreadsheet is not a solution for all projects but the simplest interoperations approach.

In the research, two major simulation modelling packages have been investigated: Witness and Simul8. The simulation model created for the case studies are mostly by Witness. The Lanner WITNESS solution is widely acknowledged as flexible, scalable solution available for business transformation, business process management and process engineering. With its simulation suite, enhancement modules, development modules, and other plug-in components, the simulation package is extendable and scalable to fulfil the requirement of this research and to go beyond the conventional approach of applying simulation modelling.

5.4 Modelling perspectives for the manufacturing system

A manufacturing system can be modelled in different ways by modelling focus and purpose so that the significant attributes of the system can be represented adequately as suggested by Kang et al. (1998). They had proposed a rather complete modelling perspective illustrating the directions or goals for a simulation project:

5.4.1 Physical Material Focus vs. Control Data Focus

In manufacturing systems, physical materials and control data are the fundamental objects to be processed. Depending on the types of objects a modeller focuses on, the system can be modelled in different fashions.

Physical material focus is for understanding or analysing the manufacturing system, efforts must be undertaken to represent the product/part flow through the facilities network. The complexity of the product flow is evident in inbound/outbound logistics and physical materials flows within a plant. Considering that a large manufacturing plants could have tens of manufacturing entities. There can be several versions of the process model, depending on the level of abstraction regional. For such system materials routes and states of resources are necessarily highlighted in modelling with a physical materials focus.

For Control data focus, there exist several levels of control in manufacturing systems. The work order generation process is represented as an order module or machine control that starts the physical activities of the machine. A weekly production schedule is used to control the capacity utilisation ratio and the inventory. These relationships and flows of control data and the data processing logic are treated primarily in modelling with a control data focus.

5.4.2 Better Information Management vs. Operations Improvement

The purpose of manufacturing systems modelling can be generally classified into two categories: better information management and operations improvement.

For better information management, information plays several supporting roles in efforts to make processes more efficient and effective. For example, order confirmation for delivery date and production scheduling is a representative activity for information management. Considering that most manufacturers have large investments in information systems that consist of innumerable software applications for CIM, development of an integrated information system is keys to better information management, to support information flows across the functions and applications seamlessly and a variety of decision support requirements arising. Various models are required to represent the information system in manufacturing environments; static to dynamic models, structural to functional models, and procedural to mathematical models.

For operations improvement, many modelling projects put emphasis on the dynamics of a manufacturing system to improve its operational performance in terms of cost efficiency, speed, and quality. Modellers identify many opportunities to eliminate waste in the process by simplifying it. The process based modelling approach focuses on the sequence and value-added aspects of operations. However the automation of a manufacturing system is linked to the information system that controls the operations of physical components and it sometimes difficult to separate both views.

5.5 Generic Simulation Modelling

As introduced in the literature review (Section 2.7.2), generic simulation modelling is a better solution than the conventional approach of simulation modelling approach. Traditional approaches of having the data fixed and hard coded by the simulation packages makes building and maintaining a larger and more complex simulation models difficult when different scenarios are investigated with different layout and resource requirements.. A better approach is to simplify the process through modularisation, i.e., the creation of re-usable simulation model building blocks. Simulations would be built by assembling or configuring, modular building blocks. The use of modules and components makes it possible to provide a great variety of design for the system under study. Similarly, neutral interface formats for transferring data between the simulation and other manufacturing and administration applications are also needed. Data should be imported directly into the simulators without translation using standard data input formats.

Simulation software vendors offer a small set of sample models in the simulation packages when bought to help customers get started using their tools. These basic models seldom are sufficient to meet the needs and requirement. Unfortunately, these vendors do not appear to have either the staff resources or access to proprietary technical data that would allow them to build extensive model libraries to meet actual user needs. In some cases, simulation vendors provide consulting services charging by hours where they build custom models with the technical assistance of their clients. Unfortunately, these models usually become the proprietary property of the client to answer the specific problems and are never made available to other customers nor it could be re-use in another problem. According to Mclean and Leong (2002), the development of neutral, vendor-independent data formats for storing simulation models could greatly improve the accessibility of simulation technology to industry by enabling the development of reusable models. Such neutral, simulation-model formats would enable the development of reusable models by individual companies, simulation vendors, equipment and resource manufacturers, consultants, and service providers. Model libraries could be potentially marketed as stand-alone products or distributed as shareware.

McLean and Leong (2002) also stated that neutral model formats would help enlarge the market for simulation models and make their development a more viable business enterprise. Standard formats for models would make it possible for simulation developers to sell model libraries much the same way clip art libraries are sold for graphics software packages today. Simulation model libraries could be expected to increase the value of manufacturing simulators for industrial users much the same way graphics libraries increase the value of photo processing, paint, and graphics illustration software packages to their users. In the absence of standard formats, the development of simulation model libraries is probably not a viable independent business proposition.

Currently, the modeller would have to code the simulation models in perhaps a dozen different formats to cover as many manufacturing simulators as possible. Furthermore, the developer would probably have to provide multiple language front-ends to be successful internationally. As each of the target simulators evolved, the model library would require constant revisions to maintain compatibility with each vendor's product. These findings from literature review and observation of current simulation modelling practices commercially, modular design of manufacturing system element is one area which need more work and collaboration.

5.6 Object oriented Simulation Modelling

The modular design of manufacturing system element in this research has followed the object-oriented approach. Object-oriented simulation is the most powerful when the user follows a consistent design pattern for object-oriented modelling in which each 'intelligent' component is modelled as an independent entity class. Experience with this design continues to create better opportunities for reusability through production of the simulation 'code' that is more readable by other developers and engineers participating in the development according to Gamma et al. (1995).

Object oriented programming (OOP), a paradigm in which all program variables are represented as objects which communicate by means of message passing, is a significant advancement toward the development of multiple use, general purpose, and plug-compatible models. OOP possesses four key concepts which facilitate this advancement: encapsulation, message passing, late binding, and inheritance (Budd, 1991). A key consequence of the reusability emphasis is the implementation of the separation concept (Pratt et al., 1994).The implementation of separation involves the creation of separate and distinct modelling for physical elements, information flow, and control decisions. Traditional modelling approaches have not considered the separation of physical, information, and control elements. For example, in many simulation languages, the constructs that are provided for information and control are frequently hard coded and dispersed into the model. This results in difficulties to modify and use for multiple purposes.

Another advantage of the separation of physical, information and control objects is that it allows the system modeller to think of these elements independently during model development. The process involves selecting the appropriate physical components without being constrained by concerns regarding how to model information flow. Similarly, information flow is considered without regard to physical objects. This independence facilitates the creation of models with a higher degree of integrity and greater flexibility relative to experimentation with the model. Bhuskhute et al. (1992) proposed a framework with reusability features for modelling and simulation of discrete part manufacturing systems. As suggested therein a modeller can visualize each modelling object in terms of its physical, information, and control aspects. Visualizing physical and information components of a system as distinct elements is straightforward. In most cases, these elements are tangible and easily defined; for a manufacturing system, a mould, a drill press, or a trolley is a physical component whereas a bill of material or a routing plan is an information component. Control components are potentially more difficult to grasp. When a control element interacts with the physical element it controls, it evaluates the state of the system on the basis of physical system status and other available information. Then an action is taken (i.e., a decision is made) based on an algorithm or a decision process. The decision is then communicated to physical, information or other control/decision components. This framework by Bhuskute et al. (1992) was designed for creating models of discrete part manufacturing systems which were to be exercised by a specific simulation tool only. A prototype modelling environment was developed in which the models created were highly reusable within a simulation context in the specific simulation package. The design concepts were not 'reusable' except specifically for simulation project. While this was a major limitation, the richness of the models created and the ease with which the models could be changed opened up new possibilities. The separation idea of physical entities, information and control flow has influenced this research.

5.7 Modular Design Simulation Components

From the literature review and the case studies from previous chapter, it is apparent that the modular design of manufacturing elements for simulation modelling packages is critical to enhance the applicability of simulation modelling. With the modular design, a generic modelling approach is introduced. From this modular deign, a library of Best-Practices design of manufacturing systems can be developed and collected from industries and from various observations and findings. These generic configurable cells are stored and customised according to individual needs of the problem. These configurations and collections of best practise templates are based on various process optimisation philosophies for example, Visual management, Just-In-Time, Lean Manufacturing, Agile manufacturing, Business Process Re-engineering and Total Quality Management.

5.7.1 Kanban System

The Kanban system is one of the key means to realising the philosophy of just-in-time (JIT) manufacturing by retrieving the required amount items at the right time. The development of the concepts utilises a simple card system called Kanban. The application studies of the Kanban system to Toyota Production System (TPS) have been introduced to manufacturers worldwide (Sugimori et al., 1977). Since then, various aspects on TPS such as Kanban system, total quality control, and total preventive maintenance have been studied and explored in depth. As for Kanban system, it has attracted international attention because it differs completely from the traditional production-control system. Materials Requirements Planning (MRP) is almost the opposite of Kanban and JIT from the standpoint of preferred environment. The push system controlled by planning with MRP had been adopted widely in a large number of manufacturers. On the other hand, the Kanban system adopts the pull production system where items are processed at the upstream process, by receiving instructions from the downstream process. Understanding the concepts and variations of Kanban is important in designing any manufacturing cell.

5.7.2 Use case scenarios

According to McLean and Leong (2002) a number of different types of simulation studies may be associated with each level in the manufacturing hierarchy. A particular study may apply to several levels, but not necessarily all levels. Mapping case studies into specific levels is dependant on the objectives and scope of the simulation project aims. Individual case studies should be used as modular building blocks and templates to solve more complex manufacturing problems. For example, a real manufacturing problem might involve issues of site selection and plant layout. The resulting simulation case study may be constructed by assembling models and data from two different case study types. Ideally, case study areas identified in the framework should be "atomic," i.e., unique, indivisible, and non-overlapping. A rigorous analysis should be used to ensure that each case study forms a clean, basic building block. The analysis should aim to assign any objective or question to only one type of case study. On the other hand, different case studies may be used in the same models, input, and output data. This can be demonstrated by an example. Scheduling and plant layout might be two unique, non-overlapping case study areas. The same simulation output metric, e.g., system throughput, might be used as a performance metric to evaluate layout and scheduling changes. McLean and Leong (2002) also identify an initial sampling of simulation case study types in Appendix C.

The set of simulation case study definitions by McLean and Leong (2002) is not necessarily complete or comprehensive. Some of these case study types can be subdivided further. The list is intended to illustrate the wide variety of different reasons for performing simulation case studies and provide a unique study area as the basis for the modular design of manufacturing system in this research.

The following manufacturing processes have been modelled in this research as modular simulation components corresponding to the concept proposed by McLean and Leong (2002) explained above:

a) **Order processing-** models the arrival of customer order, splitting of the order into required number of batches and release the schedule for production;

b) **Output monitoring-** models the orders completed by the system;

c) **Downtime influence-** models the effects of downtimes activities in reduction of resources utilisation;

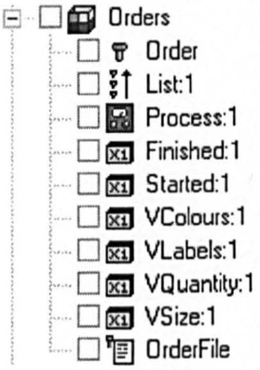
d) **Material handling-** models the trigger of material handling procedures to fetch and dispatch;

e) **Routes planning-** models the routes and process plans of all products;

f) **Shifts patterns-** models the shift pattern and work time of the system.

a) Order processing

Incoming orders are stored in a buffer. When the order required a sorting algorithm or a case specific decision making policy, a process machine is created to do so. Alternatively a sorting algorithm can be trigger to arrange them in the buffer. For the following example from case study 3 in Chapter 4 Figure 5.2), the order process machine also carries the attributes of colours, quantity, size and labels for changeover purposes.

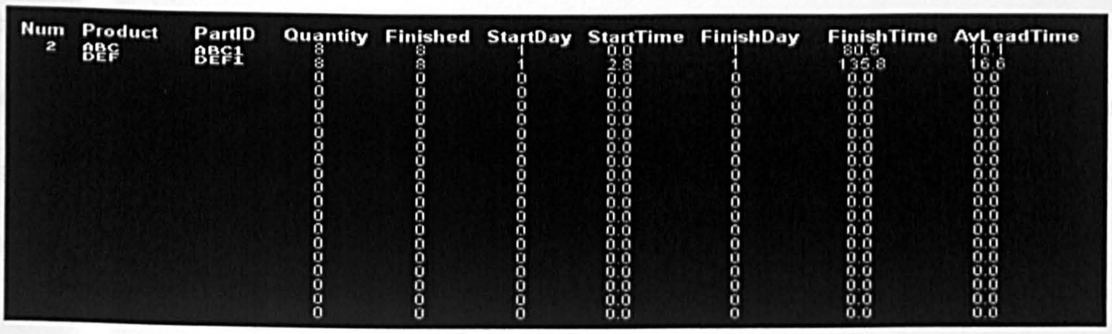


☐ Orders
- ☐ Order
- ☐ List:1
- ☐ Process:1
- ☐ Finished:1
- ☐ Started:1
- ☐ VColours:1
- ☐ VLabels:1
- ☐ VQuantity:1
- ☐ VSize:1
- ☐ OrderFile

Figure 5.2 Order Processing Witness Example

b) Output Monitoring

A set of monitored variables for representing available stock, completed orders, work in progress (WIP), and current stock can be created. Functions like update available stock, update current stock, and update WIP are programmed in the module to capture the required information and status of the variables. An example from case study 2 is shown in Figure 5.3 which monitors order completed.

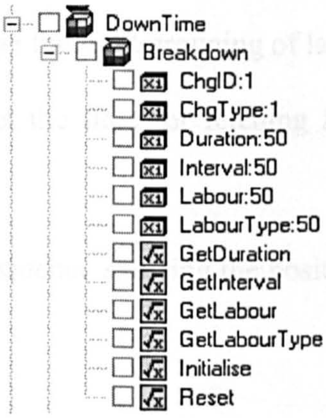


```
Num  Product   PartID   Quantity  Finished  StartDay  StartTime  FinishDay  FinishTime  AvLeadTime
 2   ABC       ABC1        8         8         1        0.0         1          80.5        10.1
     DEF       DEF1        8         8         1        2.8         1         135.8        16.6
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
                           0         0         0        0.0         0           0.0         0.0
```

Figure 5.3 Example of Monitoring Tables on the Simulation Model

c) Downtimes influence

The example of the downtime module in Figure 5.4 consists of the breakdown activities. The trigger of changes is the ID of the downtime, indicating the changes of different type of downtimes, for example, machine break-down, cleaning and drying, etc. Functions like getting the duration of the break down, the interval between activities, the labour type grouping in-charge and the number of labour involved are represented. Each of these modules has their individual initialisation function. The reset function in this module is to set the value back to zero when the simulation model is restarted again shown in Figure 5.4.

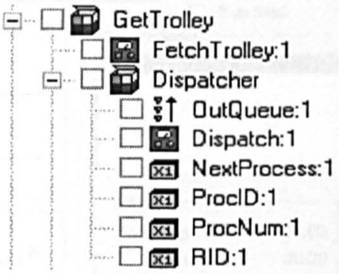


- ☐ DownTime
  - ☐ Breakdown
    - ☐ ChgID:1
    - ☐ ChgType:1
    - ☐ Duration:50
    - ☐ Interval:50
    - ☐ Labour:50
    - ☐ LabourType:50
    - ☐ GetDuration
    - ☐ GetInterval
    - ☐ GetLabour
    - ☐ GetLabourType
    - ☐ Initialise
    - ☐ Reset

Figure 5.4 Downtime Example

d) Materials Handling

Fetching and dispatching to a machine are common material handling features in most manufacturing systems. Sometimes, they are part of a machine, sometimes an operator and sometimes a separate device. These two types of activities exist as fetching and despatching machine in the simulation model. The example shown in Figure 5.5 describes the getting trolleys function to start the operations with trolleys. Accurate number of parts for each product mix is set from a spreadsheet and the actual numbers are fetched accordingly for a batch.



- ☐ GetTrolley
  - ☐ FetchTrolley:1
  - ☐ Dispatcher
    - ☐ OutQueue:1
    - ☐ Dispatch:1
    - ☐ NextProcess:1
    - ☐ ProcID:1
    - ☐ ProcNum:1
    - ☐ RID:1

Figure 5.5 Material Handling Example

e) Routes and Process Planning

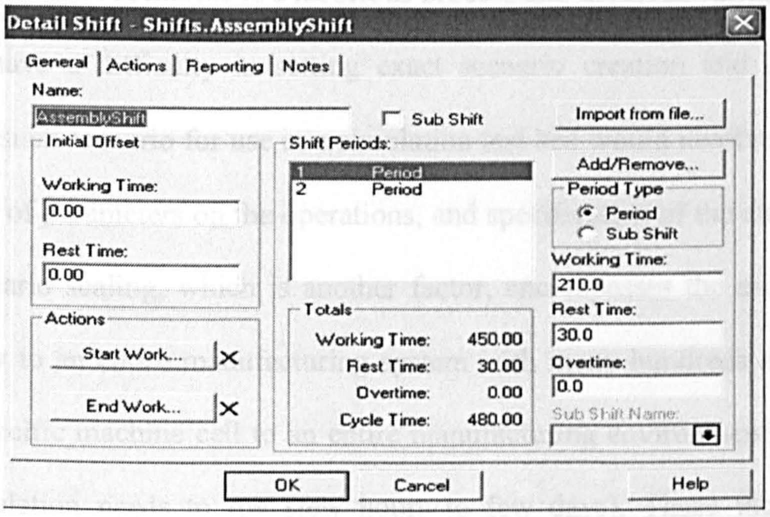
The functions that are repeated in most of the routes and process planning modules:

- Get cycle time- get the cycle time of the processes
- Get dispatch labour- get the right grouping of labour to perform dispatch
- Get dispatch time- get the time for dispatching from one point to the next
- Get fetch labour- get the right grouping of labour to perform fetch
- Get fetch time- get the time for fetching from the previous point to subsequent point
- Get step ID- the sequence showing the position of the part in the route and process plans

- Check buffers- check if it's an intermediate process with buffer to deliver or pull from or a final process
- Next Process Pull– check if the process uses a pull rule
- Next Process Push- check if the process uses a push rule

f) Shift patterns

Most simulation packages include function to manage shift patterns which dictate how machine operates. Shift patterns describe the time for working and breaks to be set. An example of setting the shift pattern in Witness Package is shown in Figure 5.6.



Detail Shift - Shifts.AssemblyShift

Name: AssemblyShift

☐ Sub Shift

Initial Offset
Working Time: 0.00
Rest Time: 0.00

Shift Periods:
1 Period
2 Period

Totals
Working Time: 450.00
Rest Time: 30.00
Overtime: 0.00
Cycle Time: 480.00

Period Type
● Period
○ Sub Shift

Working Time: 210.0
Rest Time: 30.0
Overtime: 0.0
Sub Shift Name:

Figure 5.6 Example of the Details of a Shift Pattern

Figure 5.6 shows there are two different types of shift pattern: period 1 and period 2. The working time for period 1 is 450 minutes and the rest time is 30 minutes. The total cycle time for one shift is 480 minutes. In the next example in Figure 5.7, some shop floor runs more shifts on Monday to Thursday and fewer shifts on Friday. The working time for weekday and weekend might also be different. Hence the various shift patterns can be set in the shift clock module to provide this flexibility.

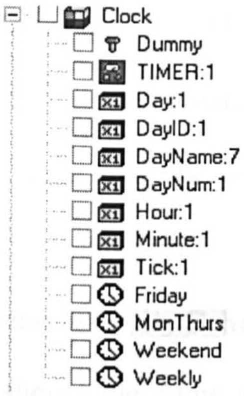


Figure 5.7 Example of a Shift Clock Module

5.8 Experimentation with scenario generation and Output

The creation of realistic scenarios is a laborious process and involves various problems and experts often have a difficulty in setting exact scenario creation and conditions. The creation of one such scenario for use in a simulation test bed would involve placement of a range of targets of parameters on the operations, and specification of the attributes of these processes. Scenario scaling, which is another factor, encompasses the number of targets parameters (few to an entire manufacturing system with many hundreds of them), model size (from a specific machine cell to an entire manufacturing environment) and time over which the simulation needs to run (few hours to few days). These factors led to the development of a dedicated scenario generation module with the aim of reducing the drudgery of scenario creation while creating best possible data for the simulation test bed. The following aspects should be considered in designing the experimentation process user interface:

5.8.1 Interactive Scenario Creation

The creation of a scenario should be easy, interactive and intuitive. The scenario creation process should involve least possible steps from start to end, while giving the user easy access to all associated data through a user interface.

The user should have the option of entering the scenario in an automated or manual process. In the automated case, the scenarios will be generated by simply selecting certain parameters, while in the latter case the user would create the scenario one parameter or target at a time through a user interface.

5.8.2 Definition of Scenario/Entity Behaviour

The scenario generator should the allow selection of entity or platform models from an existing source and should also support the creation and definition of new types of models. In addition to there should be means for defining data, the behaviour, i.e. behaviour for a demand order, or machine performance. Prior to the creation of the scenario the user should be able to define simulation variables like simulation time of the scenario, the time step interval, and statistical distributions to be used. When completed, the scenario created should provide all possible data that may be required to run the simulation successfully.

5.8.3 Scenario Size and Re-Usability

There is a great monetary and time investment involved in the development of scenarios; hence there is a sound reason for providing a provision for the reuse of scenarios. This means that the scenario generated should be saved and made available for later reuse and editing. The size of the scenario should not be a limiting factor during the creation of scenarios. In most situations due to the large amount of data generated during the process of scenario generation entails that database support must be provided for effective storage and maintenance of the scenario data. The database support should allow: (i) storage of entity behaviour and model information and (ii) storage of data generated during the simulation itself. Although version control, data security and access-level might be a further challenge to the developer and users.

5.8.4 Visualization and Representation of Information

The scenario generator should provide the user with a capability to navigate and interact with the scenario easily. The scenario representation should cater to both two and three dimensional information representation. The scenario generator should provide the user with information both in real time and historical at a rate that is easy for the user to absorb. The scenario generator should provide the flow of information in an easy to understand fashion.

5.8.5 Output Results

The major components that affect the output results or report generation for users are Input Value Setting, Objective result, Variance generated and the Confidence Tables & Graphs. All these elements trigger a better feedback and system improvement. Functions can be created to collect specific and customise results from the simulation models. The accuracy of the details of input data is reflected on the output results.

Expected benefits from these improved decisions in a manufacturing example include:

- Increased throughput
- Reduced inventories
- Reduced lead time
- Greater customer satisfaction

5.8.6 Performance measure

Broad stakeholder objectives form the backdrop to operations decision making, but operations requires a more tightly defined set of objectives that relate specifically to its basic task of satisfying customer requirements. Performance measure can be used to measure benefits of the output result. There are five basic 'performance objectives' that apply to all types of operation (Slack et al., 2004):

- Quality which reduces cost and increases dependability

- Speed to reduce inventories, and risk
- Dependability which saves time, money, and gives stability
- Flexibility which speeds up response, saves time, and maintains dependability
- Cost which is affected by other performance objectives
- Other measures of operation performance are agility and productivity.

According to Slack et al. (2004) competitive factors that customers valued are:

- Low price
- High quality
- Fast delivery
- Reliable delivery
- Innovative products and services
- Wide range of products and services
- The ability to change the timing or quantity of products and services

These performance objectives and competitive factors contribute to order-winning factors or qualifying factors that the business needs to meet to compete in the current turbulent environment. Hence the output results generated from the simulation model can be validated through these performance measures. Besides performance objectives, other factors like strategic decisions on new product/service development, supply network, facilities strategy and technology on structural decisions area plays a vital role in the business plan. These also affect the manufacturing system. Infrastructure strategic decision impact on workforce and organisation, capacity adjustment, supplier development, inventory, planning and control systems, improvement and failure prevention and recovery are also area where strategic plans could encourage competitiveness of a company.

5.9 Data Classification and Collection

In a manufacturing environment, the elements that comprise the whole system are often similar and repetitive. Each system has both operational and characteristic attributes. For example, each system has machines, components and labour to start of with. Each of these elements has characteristic attributes like single or assembly machine, operational or maintenance labour and so on. The system requires operational data like machine time, breakdown time, and shift pattern to start the working process. In most simulation studies or projects, the bottleneck activity holding the project back and most time-consuming is data collection. In many cases, to collect accurate values for the study is very difficult as certain values are taken as an approximation or average, especially in new system where historical data is not available. The reliability of these approximations will determine the accuracy of the output result in the later stage.

After data is collected, data classification sometimes proved to be a difficult task as often no standard approach is adopted across the team involved in the simulation modelling project. In this research a Case Research approach has been carried out with a list of case studies presented in Chapter 4. These case studies have contributed generating to a list of elements or attributes required for the simulation modelling project (summarised in Table 5.3). Although the elements stated are important for data input but if data are not available, dummy values can be entered as temporary measure to continue the project. After the data is analysed, the manufacturing system elements are classified according to the class diagram proposed in Chapter 3 and the behaviours described with sequence diagrams as a standard communication tool. In this research, a data-collection questionnaire has been proposed to collect all necessary data to cover all elements of manufacturing system based on the object-oriented approach classification of manufacturing system element.

Manufacturing Areas	Variables

Process	Cycle time	Critical Level (1-100)
	Deviation (SML)	Process Variability
	Changeover Affects (SML)	Labour Dependent (%)
	Dedication Level	Mean Time to Failure
	Mean Time to Repair	Replaceable Machines
Process Details	Process Routes	Frequency of routes changes
	Pattern of routes changes	Replenishment system
	Spaces for marketplace	Changes in marketplace
	Changes in marketplace's spaces	
Process Performance	Machine Utilisation	Tool Utilisation
	People Utilisation	Material Handling Utilisation
	Throughput Time	Capacity
Management Policies	Use of Visual management	Number of Kanban
	Kanban Zones	Use of SMED
	Use of 5S	Use of 5 Zeros
	Use of Analytical Tool	
Material Handling	Total Time	Impact on Lead Time
	% on Lead Time	Changes of Routes
	Other Tools	System Re-configurability
	Labour Intensive	% Automatic
	% Labour	Automatic Handling devices
Labour	Skill Level	Ease of Training
	Time to Train	Skill Replace-ability
	Labour Type	Number of Shifts
	Breakdown of Shift	Changes in Labour Number
	No. Labour in Processes	Total Labour Number
	Labour Cost	
Downtimes	Historical Data (Y/N)	New Data (Y/N)
	Activities	Time Required
	Frequency	Labour Type
	Labour Requirement	Processes Involved
	Tools Involved	Replaceable Tools
Quality Issues	Measurement Systems	% of Scrap
	% Rework	Priority of Parts
	Priority of Reworks	Rework Procedures
	Tooling Quality control	Labour Quality control
	Material Handling quality control	Machine Quality control
Product	Product range	% of Bespoke product
	% of Reconfigurable product	Product Similarity

	Component replace-ability	Component replace-ability by other supplier
	Product Variation	% of Product Mix
	Future Introduction of New product	Product Termination
	Prioritise Product Policy	Core Component
	Volume of Finished Inventory	Volume of Work in Progress
	Inventory Carrying Cost	Inventory Ordering Cost
	Inventory Stock out Cost	Safety Stock
Demand	Demand Stability	Demand Fluctuation
	Demand Source	Demand Pattern
	Availability of Historical data	Demand direct from Customer
	Demand from Sales	Planning Tools
	Split Order	Material Ordering Policy
	Shop floor Ordering Policy	Calculation of Lead Time

Table 5.3 Common Manufacturing System Elements

The common characteristic and similarities of manufacturing system (Table 5.4) from the case studies has validated the common manufacturing elements in Table 5.3 are sufficient to cover all areas in the manufacturing environment. Process can be divided into pre-processes, machining processes, assembly processes, and post processes. It's a classification of types of process and not exactly the attributes of the process. A general questionnaire to enable data collection of all required data for a manufacturing study or to start a simulation modelling project is developed based on the manufacturing system elements. Data is categorised to describe the entities, the material flow, and the control mechanism. All the elements suggested in the questionnaire is a collection of elements from various simulation modelling projects, prompting more information than any one particular simulation modelling project. This questionnaire is used and validated in Case Study 4.

Properties	Case Study 1	Case Study 2	Case Study 3
Process			
Pre-processes		√	√
Machining processes	√	√	√
Assembly processes		√	√
Post-processes		√	

Cycle time	√	√	√
Process Deviation			
Dedication Level			
Changeover Effects	√		√
Process Variability			
Mean Time to Repair			
Mean Time to Failure			
Labour Dependent		√	
Critical Level			
Replaceable Machines			
Process Details			
Process Routes		√	
Pattern of routes changes		√	
Spaces for marketplace			
Changes in marketplace's spaces			
Frequency of routes changes			
Replenishment system			
Changes in marketplace			
Process Performance			
Machine Utilisation	√	√	
People Utilisation		√	√
Tool Utilisation		√	
Material Handling Utilisation			
Throughput Time		√	√
Capacity			√
Management Policies			
Use of Visual management			
Kanban Zones			
Number of Kanban			
Use of 5S			
Use of Analytical Tool			
Use of SMED			
Use of 5 Zeros			
Material Handling			
Labour Intensive		√	
System Re-configurability			
Automatic Handling devices			√
Other Tools			
Impact on Lead Time		√	√
Changes of Routes		√	
Labour			
Various Skill Level			√
Labour Type		√	√
Training Issues			
Skill Replace-ability			
Breakdown of Shift		√	√
Number of Shifts		√	√
Labour Cost			√
Changes in Labour Number			
Downtimes			
Historical Data	√		√
New Data			
Various Activities	√		√
High Frequency	√		√
Labour Requirement	√		√
Tools Involved			√
Labour Type			√

Multiple Processes Involved			√
Replaceable Tools			
Quality Issues			
Measurement Systems			
Rework			
Priority of Reworks			
Tooling Quality control			
Material Handling quality control			
Scrap			
Priority of Parts			
Rework Procedures			
Labour Quality control			
Machine Quality control			
Product			
Product range	√	√	√
Bespoke product			
Reconfigurable product			
Product Variation	√	√	√
High Product Mix	√	√	√
Product Similarity	√		√
Core Component			
Component replace-ability			
Work in Progress	√	√	√
Safety Stock			
Future Introduction of New product	√		
Product Termination	√		
Prioritise Product Policy	√		
High Finished Inventory	√		
Component replace-ability by other supplier			
Inventory Carrying Cost			
Inventory Stock out Cost			
Inventory Ordering Cost			
Demand			
Demand Stability			
Demand Source			
Availability of Historical data	√	√	
Demand from Sales			
Split Order	√		
Shop floor Ordering Policy			
Demand Fluctuation	√		√
Demand Pattern	√	√	√
Demand direct from Customer			
Planning Tools			
Material Ordering Policy			
Calculation of Lead Time		√	√

Table 5.4 Common Features of Case Studies.

The questionnaire collects different type of data:

- some are just logical yes or no,

- some require a qualitative answer (e.g. small, medium, large) reflecting the effect on the whole system or the problem being studied,
- some require description of the activities involved such as rules for selecting the routes, and
- others require quantitative values.

Like most data collection technique, how accurate the results will depend on how accurate and detailed the data are entered at the beginning. Some of the questions can merely ask for an approximate value to start the study while others need accurate values such as process plan.

The person who is filling the questionnaires have to list main processes in the system, replace-able machines, downtime activities, labour/process/tools/replace-able tool related to downtime activities, the shift patterns and labour types. The breakdown of calculation has to done manually without any options to choose from. Certain questions provide a list to choose from but if the answer is not on the list then the user have to specify. Elements like process deviation, labour skill level, ease of labour training, time to train labour, labour skill replace-ability, changes in labour requirement, frequency of changes on routes, spaces of marketplace, changes of marketplace, changes of spaces in marketplace, material handling time, impact of material handling time on lead time, changes of material handling routes, material handling system re-configurability, product range, product similarity, product variation, volume of finished inventory, and volume in work in progress have the option of answering just 3 different level S, M, L, which stands for Small, Medium or Large effect. These are qualitative answers to give an indication whether the element will be a potential problem area that require further study. The full questionnaires are in Appendix D.

5.10 Structured Methodology

As the market becomes more competitive, manufacturers will have to re-design or modify existing plants as well as designing new facilities to cope with the ever-changing demand. The manufacturing system being modelled can be a concept design for a new plant, or an existing layout of a factory. The data collected are different for each of these two different scenarios. The assumptions made are different. For example, if the manufacturing system is an existing system, to model the process, historical data are collected and the operations are classed as the process class diagram. The control mechanisms of the processes or machines need to be identified. Constant monitoring and changes play an important consideration in whether the control actions are housed in the process class or in the dynamic control section as a global controlling module. If it's a new system, data from vendors are used as approximation, and classification of the manufacturing elements and the design of the system need to be investigated further for maximum benefit. The design methodology suggested by Rao and Gu (1997) in section 5.2.1 and modelling perspectives suggested by Kang at al. (1998) that are mentioned in the section 5.4 are considered. The comprehensive use case scenarios suggested by Mclean and Leong (2002) in the earlier section 5.7.2 are used as a basis to identify the problem in the simulation project. Objectives identification and problem formulation of the simulation project are performed. At the start of a simulation project, data collection plays an important role with the accuracy of the system representation. From the case studies in this research and observations in the manufacturing environment, manufacturing elements are compiled and a questionnaire is developed for a structured and complete data collection. The data collected are then translated and classified according to the proposed Object-oriented UML approach.

The Object-Oriented UML approach to classify the manufacturing element proposed in chapter 3 demonstrated a structured and standardised method. The classification of the manufacturing element in class structures provides the basis for design of modularity. The manufacturing elements in the system are classified according to the general class diagram proposed in chapter 3 shown in Figure 5.8. Classes are highlighted to activate the class in used.

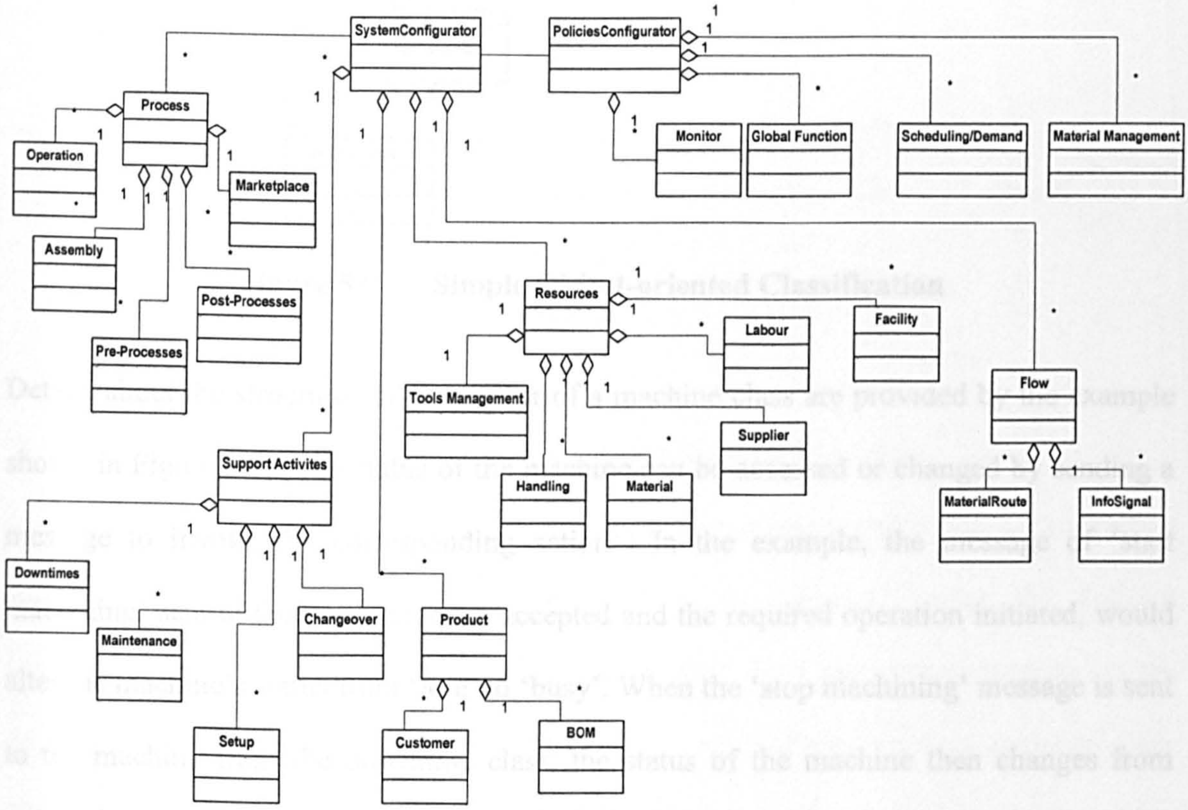


Figure 5.8 General Class Diagram in a Manufacturing Environment

From the general class diagram, the classes are detailed further with instances specified to the project. An example of a process class to the machine class is provided in Figure 5.9. The manufacturing class consists of process class among other classes (e.g. resources, product, etc.). The process consists of many different activities (e.g. operation, assembly, pre-processes, etc.). The operation may consist of different types of machines (e.g. general machine, continuous machine, etc.). The machines in the operation share the same structure and behaviours.

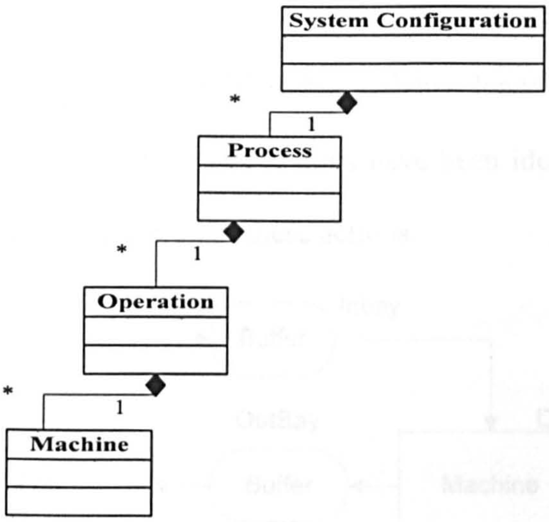


Figure 5.9 Simple Object-oriented Classification

Details about the structure and behaviour of a machine class are provided by the example shown in Figure 5.1. The status of the machine can be accessed or changed by sending a message to invoke the corresponding action. In the example, the message of 'start machining' sent to the machine, once accepted and the required operation initiated, would alter the machine's status from 'idle' to 'busy'. When the 'stop machining' message is sent to the machine from the downtime class, the status of the machine then changes from 'busy' to 'idle'.

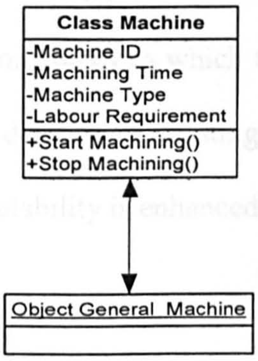


Figure 5.10 A machine viewed as an object

With the Object-Oriented perspective, the structure of a machine class would be conceptualised as shown in Figure 5.11. The process of loading, machining and dispatch are machines that carry out tasks. The buffers are temporary storages and the queues are the temporary wait in front of the machines before being loaded and after completion. The elements in the machines and their own actions have been identified, each possessing its own data necessary for the execution of these actions.

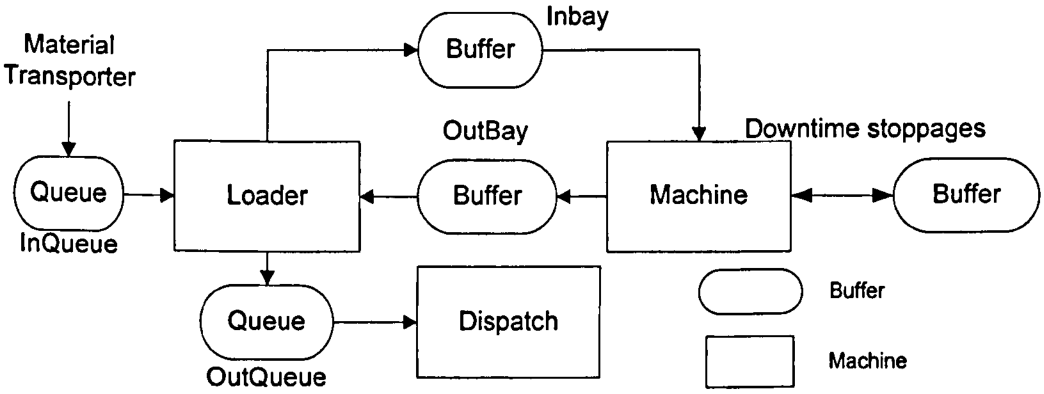


Figure 5.11 Object-Oriented View of a Machine

In the proposed approach, the physical entities are classed under the static system configuration, the information and control flow is classified under the policies configuration. This methodology separates the physical flow and control flow in system design. All elements are individual entities which are self-contained in terms of their operations and the corresponding data. With this approach, a system consists of a collection of classes which are an encapsulation of data, whose functionality is obtained by defining a set of operations or messages to which they respond. Through this method of encapsulation, adding a new or deleting an existing class will have little influence on the system, so that flexibility and scalability is enhanced and modification eased.

5.11 Conclusions and Future Work

The simulation framework outlined in this research provides a basis for initiating discussions on generic simulation modelling and development of the manufacturing system simulation component library. At this point in time, the goal of the framework has been to identify the potential of modular design in simulation modelling. The boundaries of manufacturing simulation must be defined and offers an initial skeleton that can be used to organise requirements for simulation models and data standards. The analysis using the simulation model provides a more realistic assessment of the impact of design and policy decisions. Object-oriented approach is widely recognised as an excellent approach to manage and describing large complex systems through encapsulation and inheritance. Modular design of manufacturing systems is necessary to enhance the simulation modelling project, and a set of general manufacturing system questionnaire provide a more structured approach for data collection and classification. The questionnaire allows experts in a company to get a better view of the type of data required and the level of detail involved for a successful simulation modelling project. The structure methodology proposed an approach of classifying the manufacturing elements with object-oriented approach which later forms the design in the simulation model. From the IDEF diagram-Layer A1-Defining and Structuring the Problem in Figure 1.5 in Chapter 1, the following IDEF diagram detailing layer A12 describing data and model definition is shown in Figure 5.12.

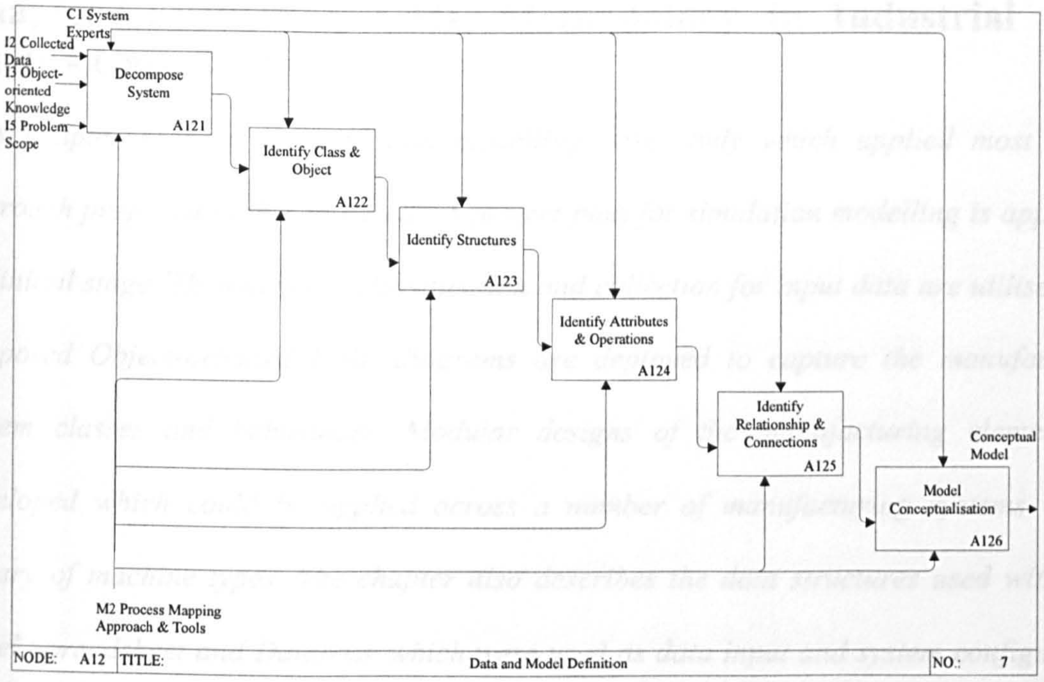


Figure 5.12 Layer A12 –Data and Model Definition

This IDEF diagram illustrates the steps of the data and model definition proposed in the structure methodology in section 5.10. The manufacturing system is decomposed, and the classes and objects are identified with the object-oriented approach. The structure is then identified and followed by identifying the attributes and operations. The relationships and connections between the manufacturing elements are identified with the UML sequence diagram. A conceptual model is subsequently created from the object-oriented process description from the previous steps.

Chapter 6 Evaluating UML Methodology in Industrial Case Study - Case Study 4

This chapter presents a simulation modelling case study which applied most of the approach proposed in this research. A project plan for simulation modelling is applied at the initial stage. Then the data classification and collection for input data are utilised. The Proposed Object-oriented UML diagrams are deployed to capture the manufacturing system classes and behaviours. Modular designs of the manufacturing element are developed which could be applied across a number of manufacturing systems with a library of machine types. The chapter also describes the data structures used within an Excel Spreadsheet and Database which were used as data input and system configuration interfaces to the developed model. The output results generated are briefly discussed and future work is recommended.

6.1 Case Study Background

The case study company is a large manufacturing supplier of complex assembled automotives parts. The company is planning to modernise and expand its manufacturing facilities through acquiring a large number of purpose-built highly automated machining centres. The product range is also to be expanded introducing a degree of flexibility and variety. The project is to be implemented over a number of stages by expanding to deliver different capacity requirements over two years. The proposed manufacturing system consists of 120 machining cells grouped into three divisions covering the three key types of components and further grouped into functional units each representing a number of highly automated machining centres of a similar type. The machines feed an assembly line which was not detailed in this model but represented a demand source pulling components from the machining sections. The proposed manufacturing system is to utilise visual management techniques with a flexible routing approach adding to the complexity of managing the day-to-day management of the system. The size and the complex nature of the project provided an ideal example to apply the techniques proposed in this research. An object orient approach was applied to define the system entities, behaviour and requirements and was then utilised to develop a data driven modular approach to construct the model. A reconfigurable modular approach was critical as the complex nature of the project requirements and duration meant that a large number of experiments were to be conducted and documentation of system configurations and results became more critical. Since the model was to be operated and modified by the company it was also critical to provide a structured approach for data entry and operating the model.

6.2 System Overviews

Based on the information provided by the company, the manufacturing system covers a range of machining centres, marketplaces and an assembly line; a diagram is devised to describe the system shown in Figure 6.1. The assembly line is a simple representation to generate demand to assemble and not the actual assembling unit in the manufacturing system. The raw material or stock arrived at the decant machine, and are fed into the start marketplace. There are three marketplaces in the manufacturing system where materials are stored and queued. Machine centres in the manufacturing system are grouped as

- decanting machines for transferring stock into material handling units,
- machining centres which are processes that may include a number of the same machines,
- manual work centre for example the inspection centre,
- and other types of process which include delay operation like heat treatment, continuous operations like cleaning and chemical treatment machine.

The wide range of components can be dedicated to a particular machine line or the component could go to any open shared-machine. The names for the components, processes, and marketplaces for the manufacturing system are renamed due to confidentiality of company data.

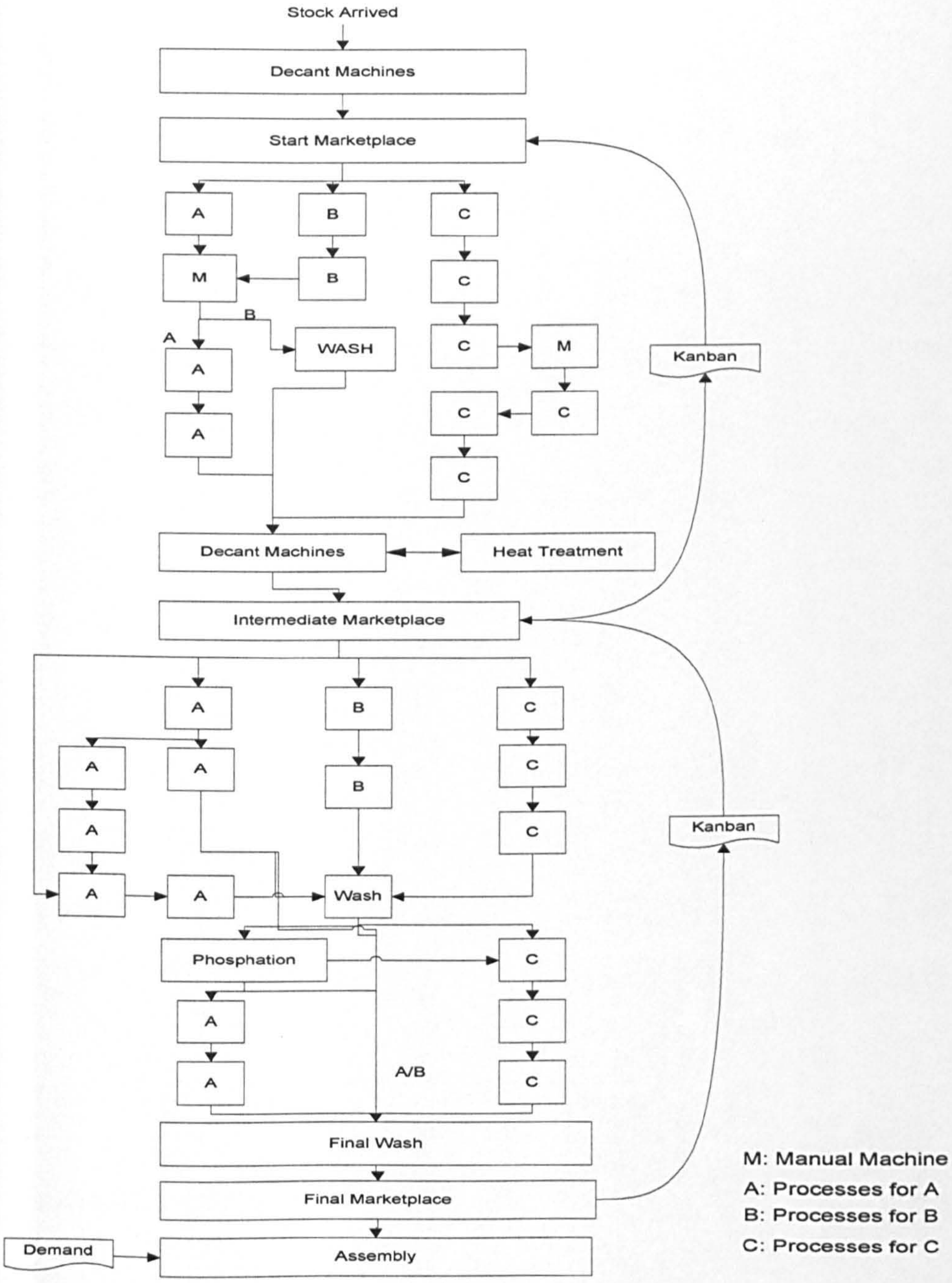


Figure 6.1 Overall System Structure

The assembly line pulls components to assembled dictate by the demand file. The final marketplace sent signals to the intermediate marketplace to release batches to downstream process. And another signal is sent to the start marketplace to release batches to the downstream process. Detail of the system elements and rules are given below.

6.2.1 Products Configuration

The product configuration in this manufacturing system consists of 3 different components type (A, B and C). An assembled product consist of a set of 11 different A components, 1 B component, and 3 different C components shown in Figure 6.2, as well as a large number of bought in components not considered in this model. Variants for each component are termed as derivatives. These derivatives are set as AA and BA. The derivatives could grow or be terminated depending on the design of the product and customers requirement. Hence the number of configurations can be high.

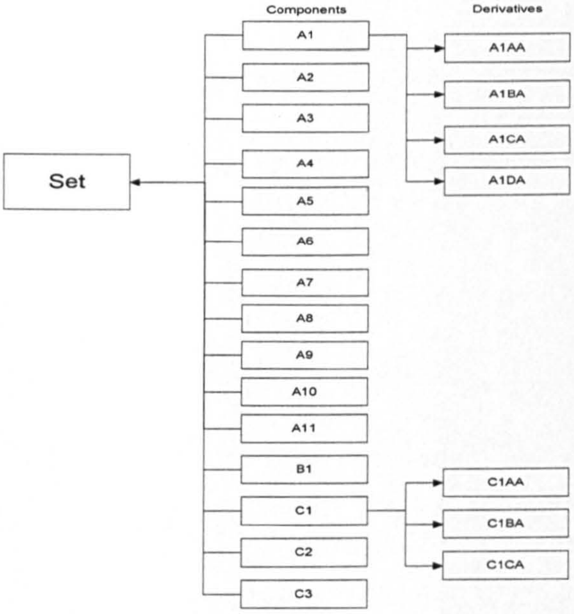


Figure 6.2 Composition of Product

6.2.2 Material Handling

As the manufacturing system is to produce 400000 assembled units per year, material handling plays a critical part in the management of this system. In effect material handling issues in this case study can be viewed as a study of its own, but is briefly summarised in this project. Components are stored in purposely design baskets, each component is a different size hence the number in the baskets are different. Baskets are placed on trolleys that are specially design to be able to fit the automated loading system of the machines. The baskets are transport around by trolleys where each trolley has different quantities of components, therefore for each component the batch size is different and consequently different numbers of trolleys are required. This complicates the simple visual management in use. The operator has to know the batch size for each component for control and planning purpose.

As all components are heat treated before placing in the intermediate marketplace, they have to be removed from the trolleys and baskets to purposely built heat resistant racks and containers. This adds to the complexity of the system.

6.2.3 Material Flow Management

The manufacturing system has three marketplaces: Start, Intermediate and Final. The final marketplace sends finished components to the assembly machine according to the rate of production, which can be set by the demand. The system uses a visual management through a kanban approach and the marketplaces for intermediate storage. The Start marketplace is placed after decant for Part C and Part A /Part B. The Intermediate marketplace is placed after the Heat Treatment. The Final marketplace is at the end of the processes before the Assembly Machine. The Assembly Line pulls rate from the Marketplace Final is constant. When the quantity of any component goes below a batch size's quantity, a signal is sent to the upstream marketplace to release a batch to be processed by the subsequent machining operation as shown in Figure 6.3. Each marketplace contains a number of batches for each component type and variant.

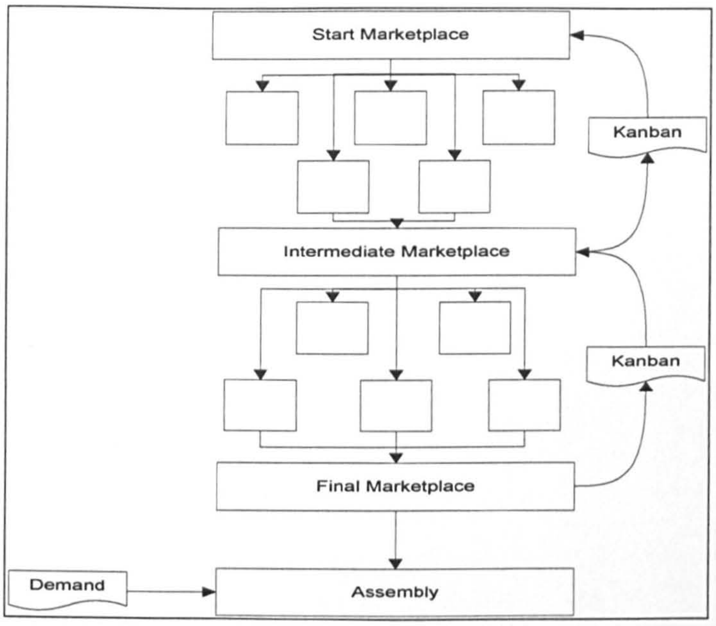


Figure 6.3 Order Mechanism

6.2.4 Downtimes

In this case study, many other activities are carried out in the machining centres. Some affecting the actual machine by stopping production like maintenance, while others happen on the side lines while production still carried out on the machine but where labour resources are required (e.g. cleaning). Both of these activities are termed as downtimes in this case study. Downtimes activities in the manufacturing system are classified into downtimes that are triggered by the number of operations carried out (e.g. tool change) after a number of parts have been machined; by frequency dictated through either number of shifts or time (e.g. cleaning per shift); changeover that happen when there is a change of parts or derivatives; and by routine activities like weekly maintenance. These downtimes activities have great effect on the utilisation of the machines, and resources, and it is important for planning and control of the shop floor to consider these activities when optimising the system.

6.3 Objectives of Case Study 4

The model is to be developed in a number of stages at various levels of detail providing a number of deliverables at key decision making points. These are listed as follows:

1. Initial Model (Provides a quick overview of system requirements)
    - Visualisation of capacity effects
    - Indication of effect of uptime/downtime of machines/on the operation of the system
    - Identification of process bottlenecks
    - Indication of material handling (basket and trolleys) requirements
    - Identification of optimum WIP values and position
    - Identification of labour requirements and utilisation
2. Detailed Model (More detailed representation of operations and tooling)
    - Detailed representation of downtimes
    - Detailed material handling and material flow
    - Layout and graphical representation
    - Labour grouping
3. Operational Model (Decision support system for assessing changes)
    - Demand patterns & product mix
    - Planned downtimes etc.
    - Rapid reconfiguring of routes and allocation of resources
    - Individual Tooling requirements
4. Model requirement
    - Speed of generating results
    - Configurability and expandability of the system
    - Ease of use

6.4 Assumptions

The building of simulation models requires making many assumptions. These assumptions fall into different categories such as:

- system assumptions which are assumptions of the operations on the shop floor,
- model assumption which is assumption made in the simulation model,
- and data assumption which is approximation of data and values for the system.

Actual material handling, replenishment, assembly and strategies had to be defined before simulation development. The following are some of the initial assumptions before model development:

- Rough stock is available on request at decant operations, hence raw materials are always available
- There are two types of operators, general and maintenance and they are not linked to shifts in the initial model
- Demand is generated by a request from the assembly line
- Heat Treatment process is treated as a Variable Delay in the process
- Tool details (wears and changeover) are fixed and not linked to the component or part type but number of operations
- Single tool change per machine (ignore multiple tools) with average time
- Transport times are fixed and operator movement times are ignored
- Assembly pulls the exact required quantity of parts, residuals are sent back to final marketplace but the Intermediate marketplace pulls by a batch
- The ratios from basket to container; and from trolleys to racks for heat treatment are assumed as one to one but in more detail study, this ratio will be different.
- The scrap rate is assumed to be 2% of the overall production and taken out in the final marketplace. The value of the scrap rate can be changed.

6.5 Data Classification and Collection

The data-collection questionnaire was used by the project engineers to collect all necessary data to cover all elements of manufacturing system. The common characteristics of manufacturing system are shown in Table 6.1. Although the system is a complex, not all elements given in Chapter 5 are studied.

Due to the fact that the project is to develop a new plant, a large proportion of the data collected was provisional and subject to continual changes. Some of the detailed process data such as cycle time downtime etc was available in tabular excel sheet which was filtered by extracting those that are required for the project. The data collected using the questionnaire in Appendix E was arranged and presented in an Excel spreadsheet shown in Appendix F. As the project moved into a more stable stage, a database was created to store the data with a user interface to provide more flexibility and control over the data. The database is used to generate the various spreadsheets to feed into the simulation model, discussed in detail in Chapter 7.

Properties	**Case Study 4**
Process	
Pre-processes	√
Machining processes	√
Assembly processes	√
Post-processes	
Cycle time	√
Process Deviation	
Dedication Level	
Changeover Effects	√
Process Variability	
Mean Time to Repair	
Mean Time to Failure	
Labour Dependent	√
Critical Level	
Replaceable Machines	
Process Details	
Process Routes	√
Pattern of routes changes	
Spaces for marketplace	√
Changes in marketplace's spaces	√
Frequency of routes changes	
Replenishment system	√
Changes in marketplace	
Process Performance	

Machine Utilisation	√
People Utilisation	√
Tool Utilisation	√
Material Handling Utilisation	√
Throughput Time	√
Capacity	√
Management Policies	
Use of Visual management	√
Kanban Zones	√
Number of Kanban	√
Use of 5S	
Use of Analytical Tool	
Use of SMED	
Use of 5 Zeros	
Material Handling	
Labour Intensive	√
System Re-configurability	
Automatic Handling devices	
Other Tools	√
Impact on Lead Time	√
Changes of Routes	
Labour	
Various Skill Level	√
Labour Type	√
Training Issues	
Skill Replace-ability	
Breakdown of Shift	
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Historical Data	√
New Data	√
Various Activities	√
High Frequency	√
Labour Requirement	√
Tools Involved	√
Labour Type	√
Multiple Processes Involved	√
Replaceable Tools	
Quality Issues	
Measurement Systems	
Rework	
Priority of Reworks	
Tooling Quality control	
Material Handling quality control	
Scrap	√
Priority of Parts	
Rework Procedures	
Labour Quality control	
Machine Quality control	
Product	
Product range	√
Bespoke product	
Reconfigurable product	
Product Variation	√
High Product Mix	√
Product Similarity	√

Core Component	
Component replace-ability	
Work in Progress	√
Safety Stock	√
Future Introduction of New product	√
Product Termination	√
Prioritise Product Policy	
High Finished Inventory	
Component replace-ability by other supplier	
Inventory Carrying Cost	
Inventory Stock out Cost	
Inventory Ordering Cost	
Demand	
Demand Stability	
Demand Source	
Availability of Historical data	
Demand from Sales	
Split Order	√
Shop floor Ordering Policy	
Demand Fluctuation	√
Demand Pattern	√
Demand direct from Customer	
Planning Tools	
Material Ordering Policy	
Calculation of Lead Time	√

Table 6.1 Manufacturing Elements in the Case Study 4

6.6 UML Representation of the manufacturing system

UML process mapping approach proposed in chapter 3 is used in this case study. The elements in the manufacturing system collected from the questionnaire and compiled from Table 6.1, formed the basis to generate a class diagram specific for this case study from the general class diagram proposed. The behaviours of the manufacturing system are described with UML sequence diagram and activity diagram.

6.6.1 Class Diagram

The components in this manufacturing system are classified according to the class diagram proposed in Chapter 3 in Figure 6.4.

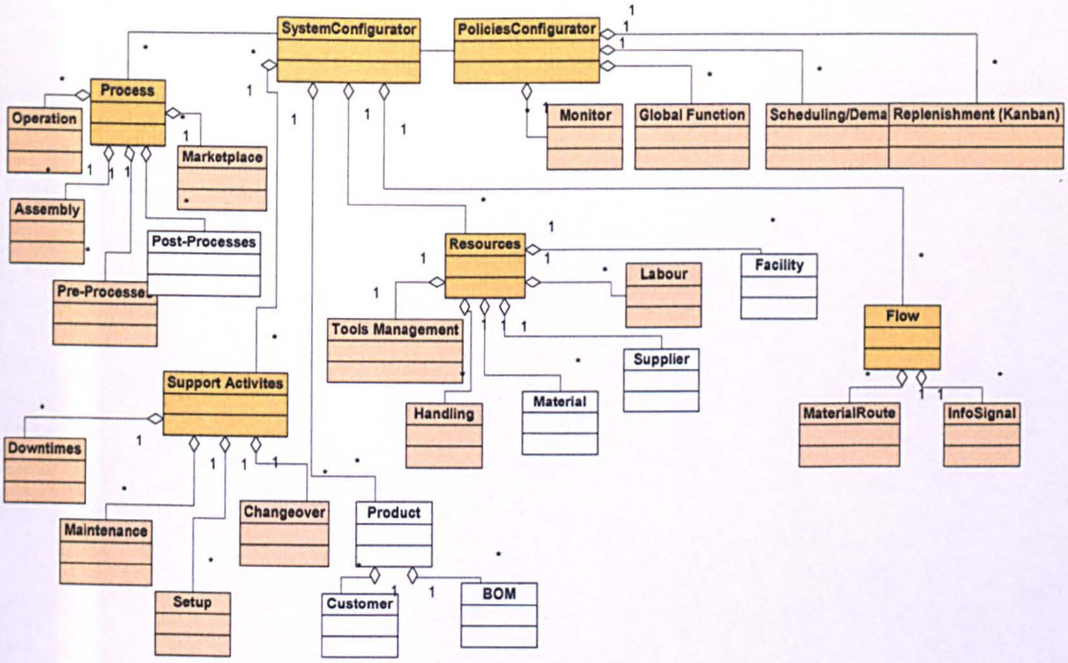


Figure 6.4 Case study 4 Main Class Diagram

Due to the size and complexity of the case study, more classes are used in the general class diagram. Although product configuration was discussed in the earlier section, and is a large combination of several families, the purpose of the project is to find out whether the system could produce the capacity predicted with the number of machines proposed by the company and not testing the product mix effect. Hence the product issue with the bill of material and customer are not activated as a study point. This case study exploits all other classes proposed in this research. Both the static and the dynamic side of the system are fully utilised in this case study. As listed in the assumption section a detailed study of utilisation of individual tools for each process or machines is not carried out in this case study. The tool management data are average tool use and tool change for the process is independent of component type.

6.6.2 From Flowchart to Sequence diagram

This case study explores various tools and techniques to process map the activities. The flowchart shows the flow and classes involved, and the sequence diagram shows the interaction and timeline of the process. A feature of this manufacturing system is the process of replenishment and the large number of different machines/processes. Having a system which each machines runs at a different pace, synchronisation is a large and complicated task. To determine the batch sizes and optimum safety stock for the system to run smoothly and produce the targeted capacity in the time allocated is critical. Figure 6.5 shows a brief flowchart of the how the system triggers a make request and the components involved in a marketplace. In the marketplace, a variety of operations happens, sometimes not sequential but parallel. The sequence diagram in Figure 6.6 provides a more detail plan to present the classes involved and the interaction between them. These diagrams help to explain and present the replenishment system and the components involved. The start of each operation and these operations that are performed in parallel are illustrated in the sequence diagram.

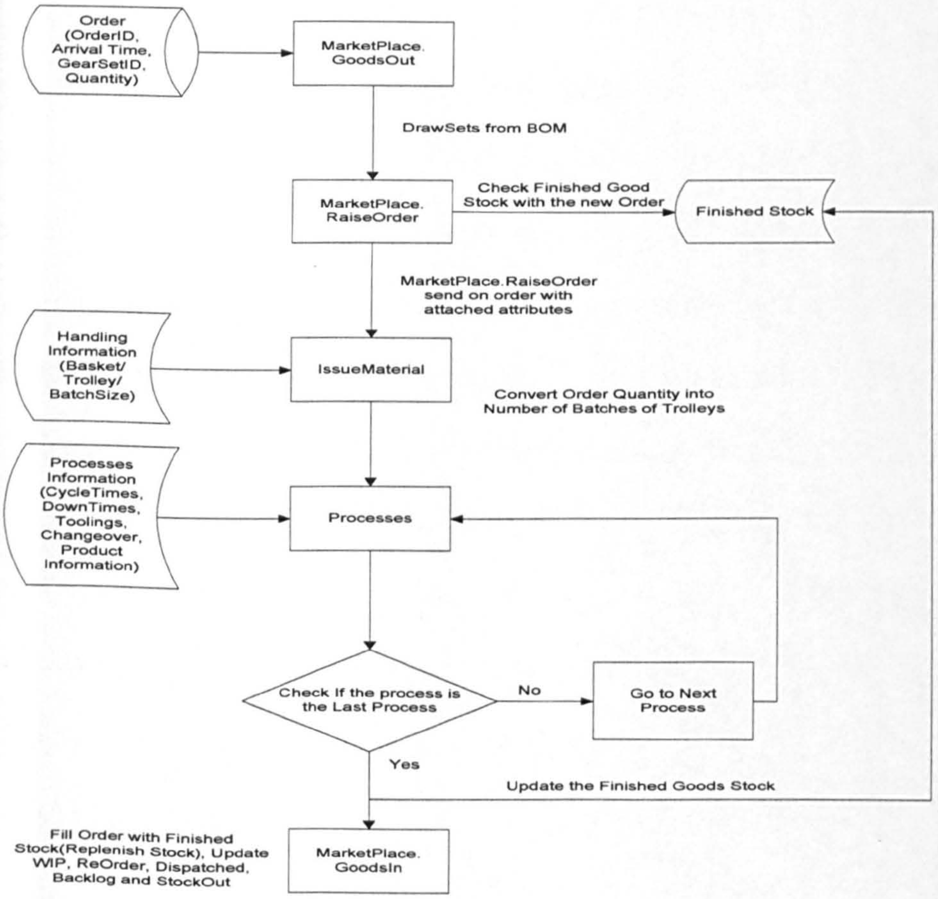
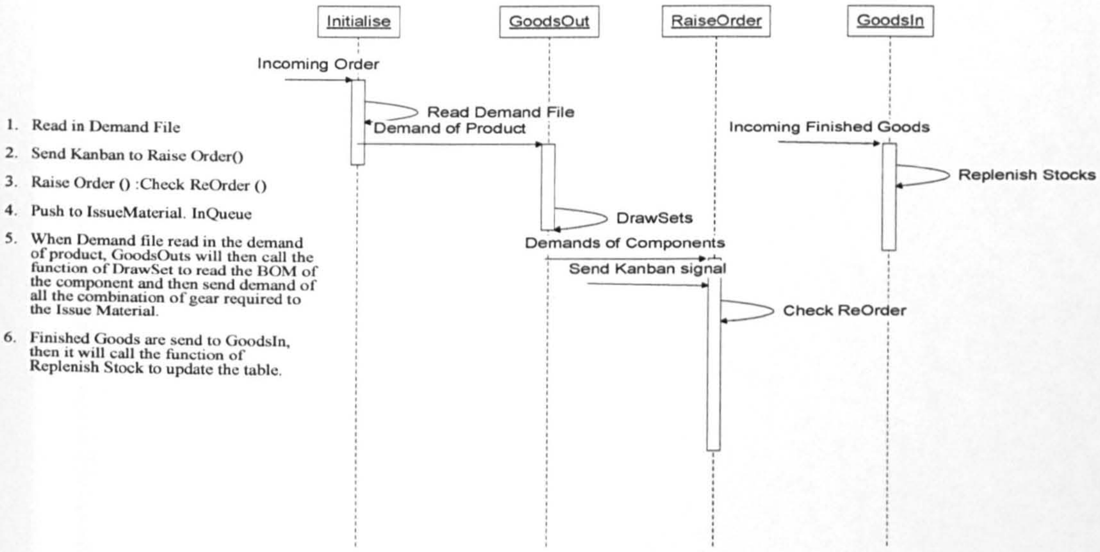


Figure 6.5 Flowchart of a General Kanban Call



1. Read in Demand File
2. Send Kanban to Raise Order()
3. Raise Order () :Check ReOrder ()
4. Push to IssueMaterial. InQueue
5. When Demand file read in the demand of product, GoodsOuts will then call the function of DrawSet to read the BOM of the component and then send demand of all the combination of gear required to the Issue Material.
6. Finished Goods are send to GoodsIn, then it will call the function of Replenish Stock to update the table.

Figure 6.6 Sequence Diagram of the General Kanban Call

6.6.3 Swimlane Diagram

The interaction between each class in each module is complicated and therefore the documentation of these interactions with the swimlane diagram using the UML activity diagram is useful for communicating between all involved in this project. The modelling package used in this project is data driven and for simple systems that does not require so many programming routines. However in this case study a high degree of programming is required. The process mapping technique allows the developer to trace each step easily and to validate the programming logic. An example of the swimlane diagram is illustrated in Figures 7.7 and 7.8. These figures show the swimlane diagrams representing the key machining centre type used by the system. The diagram describes the logic employed to represent the operation selecting a trolley, loading mechanism, and the start of machining process. The rules of loading and dispatching are pre-programmed by the developer when constructing the design.

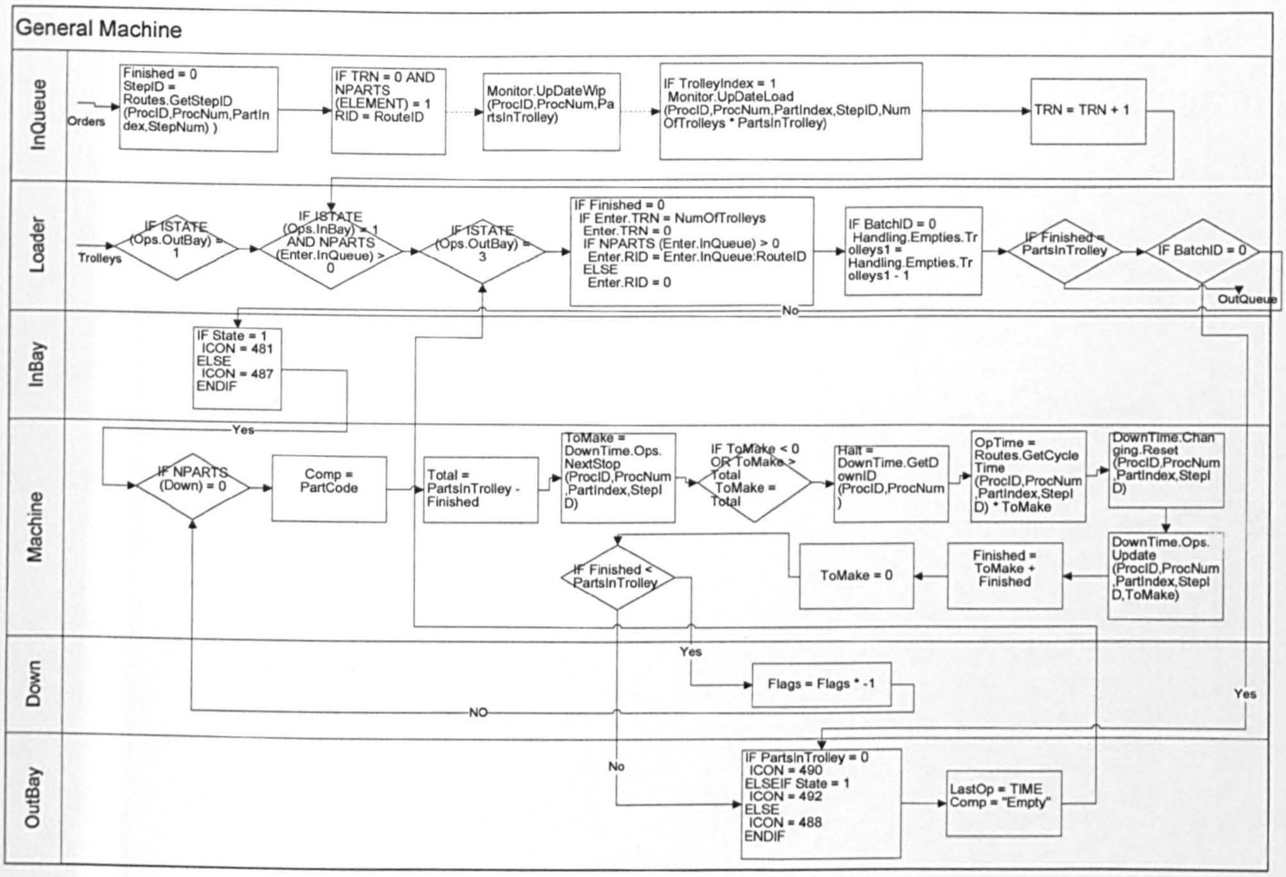


Figure 6.7 Page 1 of General Machine Swimlanes Diagram

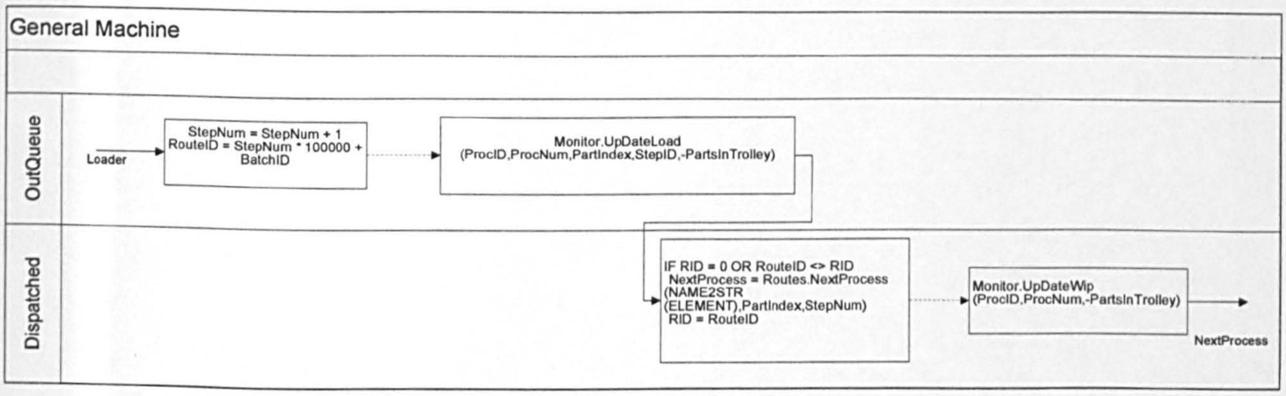


Figure 6.8 Page 2 of General Machine Swimlanes Diagram

6.7 Modular Simulation Modelling Approach

From classes activated in the general class diagram, a number of modules are defined in the simulation model. As the modelling tool used is not fully object oriented in structure, a degree of conversion is required to represent classes and behaviour. This is also necessary as a direct mapping from class to the model module could result in model inefficiencies in terms of speed or reconfigurability. For example, if a class or a particular function appears in all modules, it is taken out and placed in the Global function module. The Global function modules control the data input and result generation process. This function contains pre-programmed operations or functions that all class can access. Hence, repetition is minimised and changes can easily be made as the control of this is centralised.

6.7.1 Simulation Model Overview

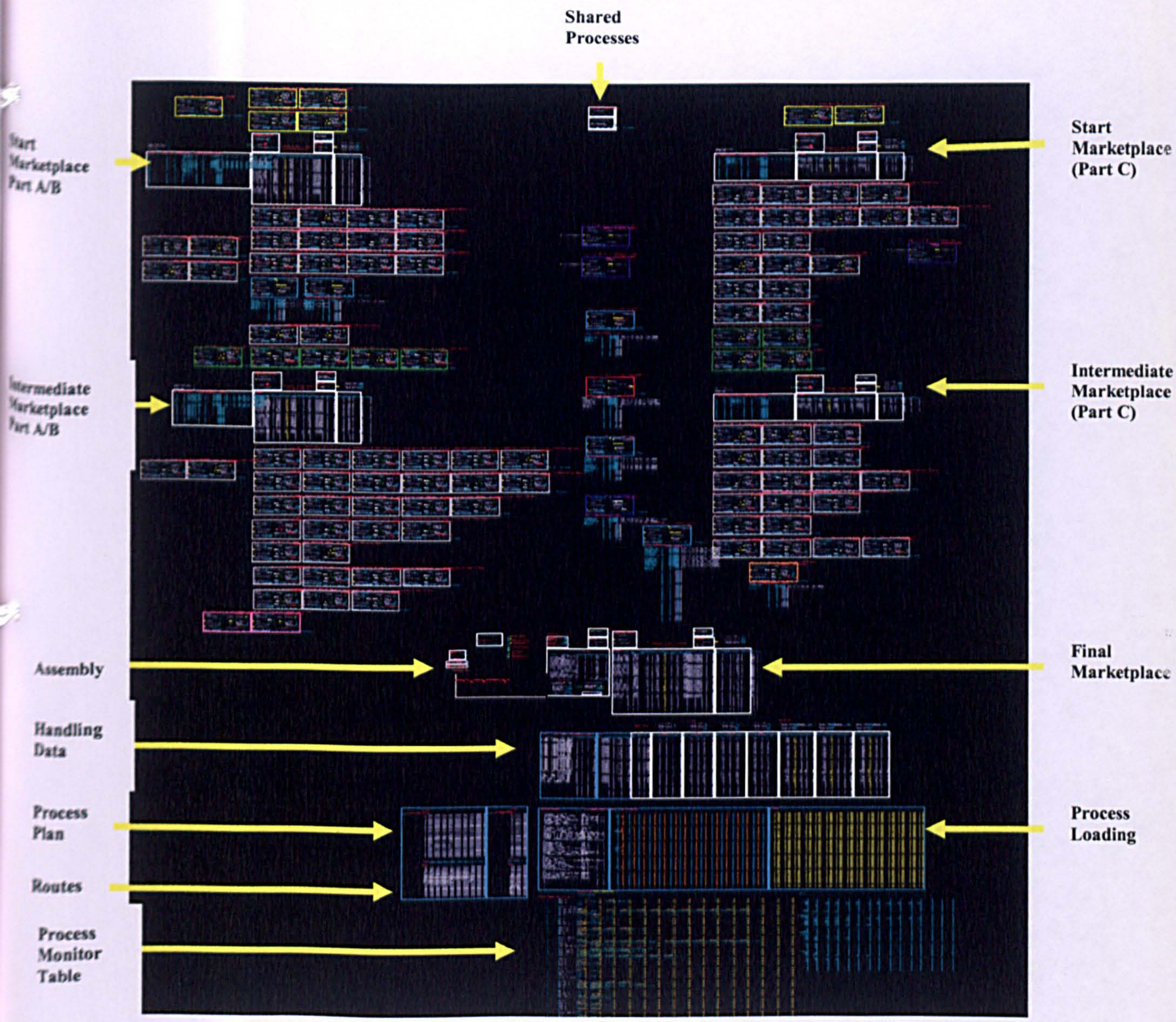


Figure 6.9 Snapshot of Simulation Model (Case Study 4)

The layout presented in Figure 6.9 in the simulation model is not the actual layout in the factory but for the purpose of ease of monitoring and display. The model displays a graphical representation of the flow of material, indication of needs of the labour, and indication of number of materials required. The bottom part of the simulation model displays the stock in the final marketplace and the current work load in each machine and several monitoring tables. The tables showing details of batches passing through the marketplaces are displayed in three sections in the simulation model displayed. The coloured small boxes shown in Figure 6.9 represent one machine centre. Each colour indicates a different machine type and the machine details are explained in a later section. Each box contains various operations to represent the activities carried out on that machine.

6.7.2 Elements in the simulation model

Due to the large number of components in the manufacturing system, many components are modularly designed and created individually, the general elements are carefully created to be used by most modules. The general elements are illustrated in Table 6.2.

Parts	**LabourType**	**Attributes**	
• Basket	• Assembler	• Baskets	• PartsInTrolley
• Card	• PartA/BStart	• BatchID	• RouteID
• Product	• PartA/BIntermediate	• BatchSize	• State
• Container	• General	• Finished	• StepID
• Kanban	• Maintenance	• MktIndex	• StepNum
• Order	• PartCStart	• NumOfTrolleys	• TimeStamp
• Trolley	• PartCIntermediate	• PartCode	• TrolleyIndex
		• PartIndex	• NextName
		• PartType	• Priority

Table 6.2 Elements Defined for the simulation model

In Table 6.2, the parts defined may not necessary be a physical part, it may be a signal or control. For example, the basket and trolley are physical entities that are moved around in the manufacturing system, and order and kanban are signal to trigger an action or a control signal. The labour types created here are operators for each area pre-defined like Start, Intermediate and Assembly area. Besides the operators for each specific area, there are general and maintenance operator who service all three areas. Attributes are attached to each basket and trolley to represent batch ID, component type etc just to name a few for data collection. The attributes are important elements or characteristic to enable accurate and easy monitoring and traceability. The machine centres and supporting operations like downtimes are created as modules. The two categories of modules are explained in the following section. Each modules has it own set of machines, buffer, variables, attributes and functions.

6.7.3 Libraries of Machines Type

Manufacturing operations types are numerous and diverse. In each type there are basic activities like loading, unloading, actual processing, temporary storing, batching, assembling, fetching and dispatching, retooling, repair and maintenance. With some of the combination of basic activities, a list of different machines type has been designed and created to represent the various types of machines in the model. There are 9 types of machine centres:

1. General Process machines with automated input
2. General Dedicated Process machine
3. Decant machine 1(Bin to Trolley), Pre-processes machines
4. Decant machine 2 (2-way), Pre-processes machines
5. Continuous machine with batching, wash machine
6. Chemical treatment Continuous machine, Phosphate Machine
7. Waiting/Queuing area, Marketplaces (Start, Intermediate and Final)
8. Delayed machine, (Heat Treatment or Oven)

9. Manual machines (inspection and cleaning)

6.7.3.1 General Process machines with automated input

Activities in a general machine shown in Figure 6.10:

1. Trolleys arrive and are push into Inqueue.
2. The Operator loads trolley into the Loader if the bay(s) is free or available.
3. Loader pushes trolley to WIP area (InBay) waiting to be process
4. Operation/Machine will check if any auxiliary activities (setups, maintenance, tooling, changeover, etc) need to be carried out. The activities call functions to identify the type of auxiliary activities to trigger and to calculate the time to stop and time require.
5. Machine/Operation will run with cycle time of the specific parts it is working on.
6. When parts are finished, they are pushed to WIP Area (OutBay) till the Unloader is available.
7. Unloader will check if the process is the last operation, if yes, it will push to marketplace, else it will push to the next process in the route/path.

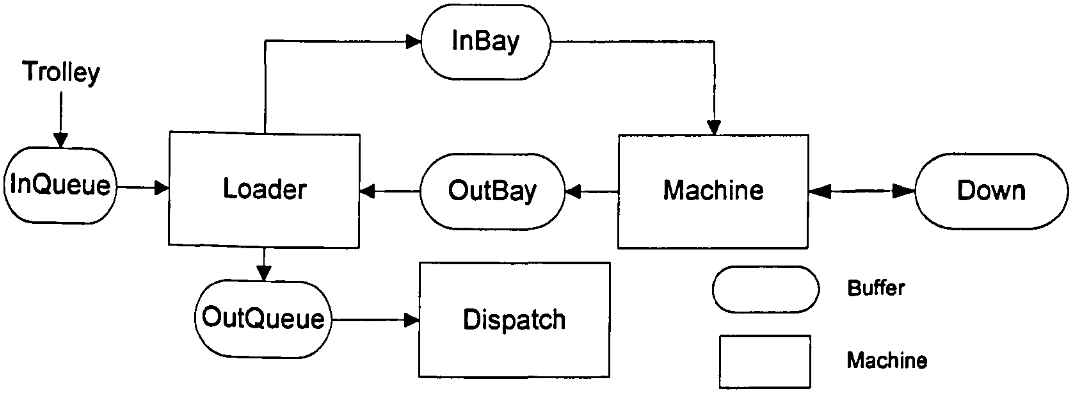
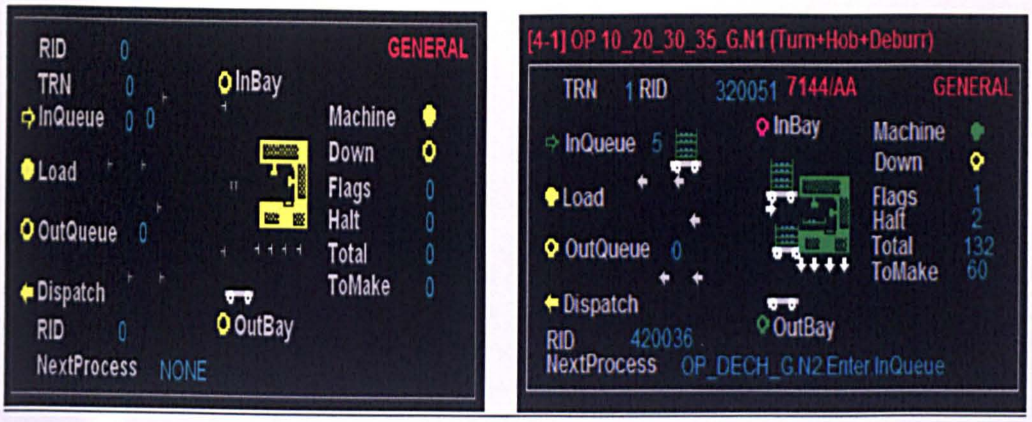


Figure 6.10 Process Map of General Machine

An example of a general machine layout and display in the simulation model is shown in Figure 6.11(a) and (b).

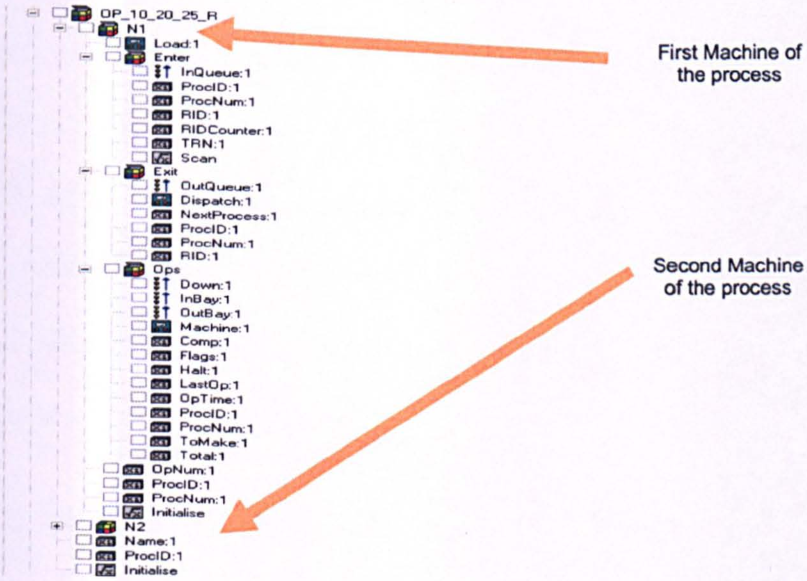


RID 0
TRN 0
InQueue 0 0
Load
OutQueue 0
Dispatch
RID 0
NextProcess NONE
GENERAL
InBay
Machine
Down
Flags 0
Halt 0
Total 0
ToMake 0
OutBay

[4-1] OP 10_20_30_35_G.N1 (Turn+Hob+Deburr)
TRN 1 RID 320051 7144/AA
GENERAL
InQueue 5
Load
OutQueue 0
Dispatch
RID 420036
NextProcess OP_DECH_G.N2.Enter.InQueue
InBay
Machine
Down
Flags 1
Halt 2
Total 132
ToMake 60
OutBay

Figure 6.11 (a)Layout of a General Machine Cell with Automated Handling Before and (b) After the Start of the Simulation

The elements used in a general machine are illustrated in Figure 6.12 showing the load machine with three modules: 'Enter', 'Exit', and 'Ops' to carry out all the functionality of the general machine. There are two machines allocated for the Op_10_20_25_R process in the example named as N1 and N2 in Figure 6.12.



- OP_10_20_25_R
  - N1
    - Load:1
    - Enter
      - InQueue:1
      - ProcID:1
      - ProcNum:1
      - RID:1
      - RIDCounter:1
      - TRN:1
      - Scan
    - Exit
      - OutQueue:1
      - Dispatch:1
      - NextProcess:1
      - ProcID:1
      - ProcNum:1
      - RID:1
    - Ops
      - Down:1
      - InBay:1
      - OutBay:1
      - Machine:1
      - Comp:1
      - Flags:1
      - Halt:1
      - LastOp:1
      - OpTime:1
      - ProcID:1
      - ProcNum:1
      - ToMake:1
      - Total:1
    - OpNum:1
    - ProcID:1
    - ProcNum:1
    - Initialise
  - N2
  - Name:1
  - ProcID:1
  - Initialise

Figure 6.12 Elements in a General Machine

The features of the general machine:

- Flexible allowing for additional stoppage and tooling information without a redefinition
- Machines work on completed trolleys. The total cycle time to finish a trolley is used.

- Operating times are determined by the number of components per trolley
- Stoppage are calculated from a central module which identifies how long to run before a stoppage
- Stoppage within a trolley cycle is allowed and represented by a shorter cycle time with a temporary exit and return of the trolley
- Labour is only attached to dispatch, loading and stoppages
- Loader waits for the batch to complete before selecting a new batch, even if there is another trolley waiting in Inqueue.
- Dispatch maintains the same destination for the trolleys in the same batch driven by a central shared function that checks the route table for information.
- Dispatch time is centrally controlled and based on the distance between processes

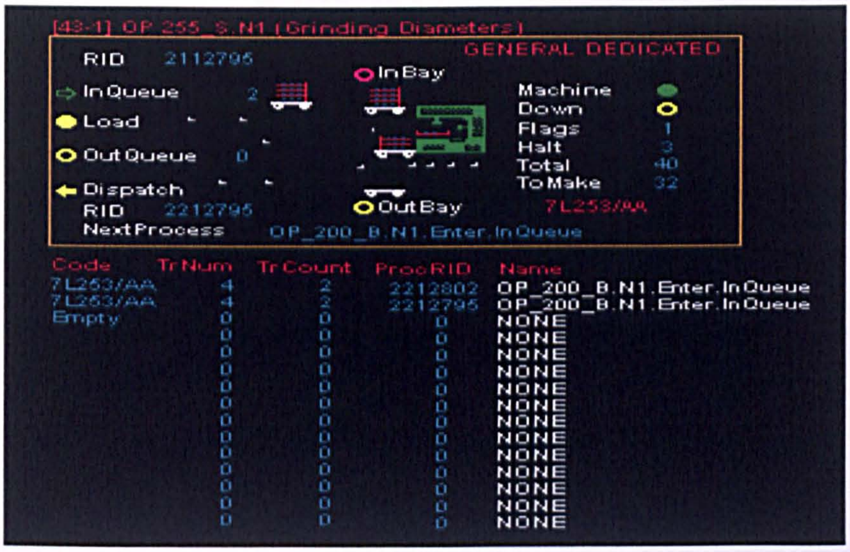
The cell displays most of the important data for easy monitoring and inspection. The process number, process name and machine number are shown on the top of the box. The type of machine is also displayed. If the machine is experiencing some sort of down times, the down icon will change status to indicate the downtimes, the type of downtime is also indicated with a number defined in the programme. If the machine broke down, the status of the machine changes to red to indicate this. The batch number and trolley number is also on display for traceability.

6.7.3.2 General Dedicated Machines

Features of the general dedicated machine shown in Figure 6.13:

- A similar machine function as the general machine
- Passive machine dedicated to a particular product families waiting for parts to enter, does not wait for full batch of trolleys to complete to start another batch

- Dispatch keeps a record of where each live batch was sent which is erased once a complete batch has passed through

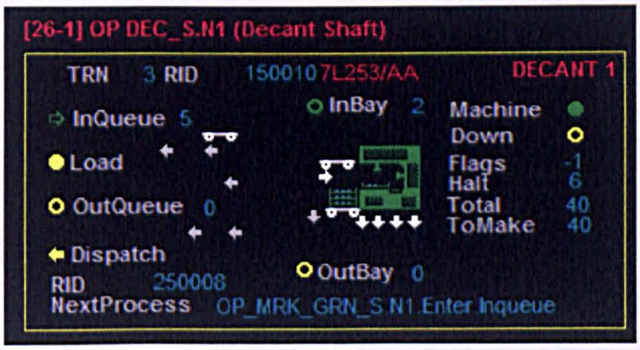


```
[43-1] OP 255_S.N1 (Grinding Diameters)
                                              GENERAL DEDICATED
  RID         2112795
                              InBay
  InQueue          2                          Machine
  Load                                        Down
                                              Flags        1
  Out Queue        0                          Halt         3
                                              Total       40
  Dispatch                                    To Make     32
  RID         2212795         OutBay             7L253/AA
  NextProcess     OP_200_B.N1.Enter.InQueue
Code        TrNum    TrCount    ProcRID   Name
7L263/AA      4         2       2212802   OP_200_B.N1.Enter.InQueue
7L263/AA      4         2       2212795   OP_200_B.N1.Enter.InQueue
Empty         0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
              0         0             0   NONE
```

Figure 6.13 Example of General Dedicated Machine

6.7.3.3 Decant Machine Type 1 (Bin to Trolley)

The decant machine type one shown in Figure 6.14 transfers from a material storage place like a bin to a material handling/transportation for example a basket/trolley. The decant machine is designed with the same flexibility and functionality like other machines. Downtimes and traceability of the products can easily be monitored.



```
[26-1] OP DEC_S.N1 (Decant Shaft)
  TRN    3 RID     1500107L253/AA                DECANT 1
                            InBay   2   Machine
  InQueue  5                            Down
  Load                                  Flags      -1
                                        Halt        6
  OutQueue  0                           Total      40
                                        ToMake     40
  Dispatch
  RID          250008       OutBay  0
  NextProcess   OP_MRK_GRN_S.N1.Enter.Inqueue
```

Figure 6.14 Decant Machine Type 1

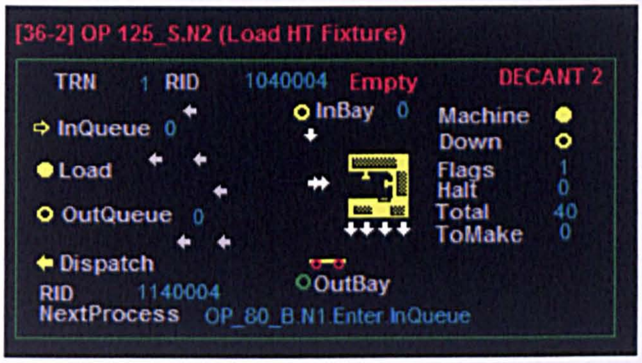
Features of the machine are:

- Same batch and trolley "in and out" control as general machines

- Accepts empty trolleys and fills with stock parts

6.7.3.4 Decant Machines Type 2 (2 way decant machine -load and unload)

The decant machine type two shown in Figure 6.15 is for transferring of goods between two different material handling devices. In this case study, the parts are transferred from normal trolley to special racks for heat treatment and vice versa. Hence the decant machine type two can performed the transferring function both ways.



[36-2] OP 125_S.N2 (Load HT Fixture)

TRN 1 RID 1040004 Empty DECANT 2

○ InBay 0

⇨ InQueue 0

● Load

○ OutQueue 0

← Dispatch

○ OutBay

Machine ●

Down ○

Flags 1

Halt 0

Total 40

ToMake 0

RID 1140004

NextProcess OP_80_B.N1.Enter.InQueue

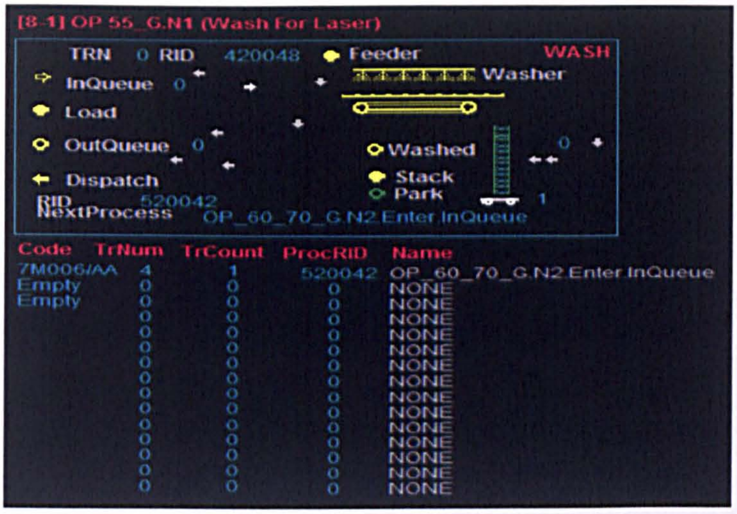
Figure 6.15 Decant Machine Type 2

Features of the machine are:

- Same batch and trolley "in and out" control as general machines
- Transfers parts between trolleys and containers for delay process (i.e. oven and heat treatment)
- Changes the status of the component from before treated/processed to after treated/processed
- One to One ratio of changes of material handling component but can be customised

6.7.3.5 Continuous machine with batching, e.g. wash machine and spraying machine

This type of continuous machine includes a function of batching which means the user can define the number of parts that goes through. For example, the wash machine in Figure 6.16 could handle two trolleys of parts each time, hence the operation will start when two trolleys are present.



```
[8-1] OP 55_G.N1 (Wash For Laser)
    TRN   0 RID   420048    Feeder                    WASH
  InQueue  0                              Washer
  Load
  OutQueue  0                  Washed                0
  Dispatch                     Stack
  RID        520042            Park                  1
  NextProcess     OP_60_70_G.N2.Enter.InQueue
Code       TrNum    TrCount    ProcRID   Name
7M006/AA   4        1          520042    OP_60_70_G.N2.Enter.InQueue
Empty      0        0          0         NONE
Empty      0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
           0        0          0         NONE
```

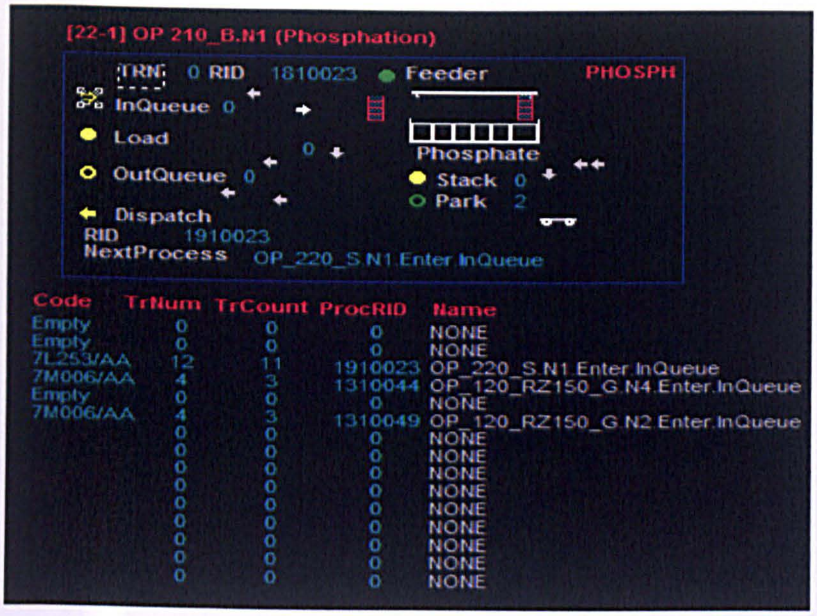
Figure 6.16 Example of Continuous Machine

Features of this type of machine are:

- No control on order of trolleys on loading
- Dispatch keeps a record of where each live batch was sent which is erased once a complete batch has passed through
- Continuous operation represented as a conveyor with an index speed = operation time/size (in material handling unit i.e. baskets)
- The loader splits trolleys into pairs of baskets for feeding to the conveyor
- Downtime are represented on the "STACK" process which in effect blocks the process
- Feeder and stack speed are derived from machine processing speed determined

6.7.3.6 Chemical Treatment Continuous machine, i.e. phosphate machine and curing machine

This type of continuous machine shown in Figure 6.17 has no batching function like the machine type explained above, but is common for chemical treatment operations.



```
[22-1] OP 210_B.N1 (Phosphation)
TRN  0 RID  1810023   Feeder            PHOSPH
InQueue  0
Load                  0
OutQueue  0               Phosphate
                          Stack  0
                          Park   2
Dispatch
RID         1910023
NextProcess   OP_220_S.N1.Enter.InQueue

Code      TrNum  TrCount  ProcRID  Name
Empty       0       0           0  NONE
Empty       0       0           0  NONE
7L253/AA   12      11     1910023  OP_220_S.N1.Enter.InQueue
7M006/AA    4       3     1310044  OP_120_RZ150_G.N4.Enter.InQueue
Empty       0       0           0  NONE
7M006/AA    4       3     1310049  OP_120_RZ150_G.N2.Enter.InQueue
            0       0           0  NONE
            0       0           0  NONE
            0       0           0  NONE
            0       0           0  NONE
            0       0           0  NONE
            0       0           0  NONE
            0       0           0  NONE
            0       0           0  NONE
            0       0           0  NONE
```

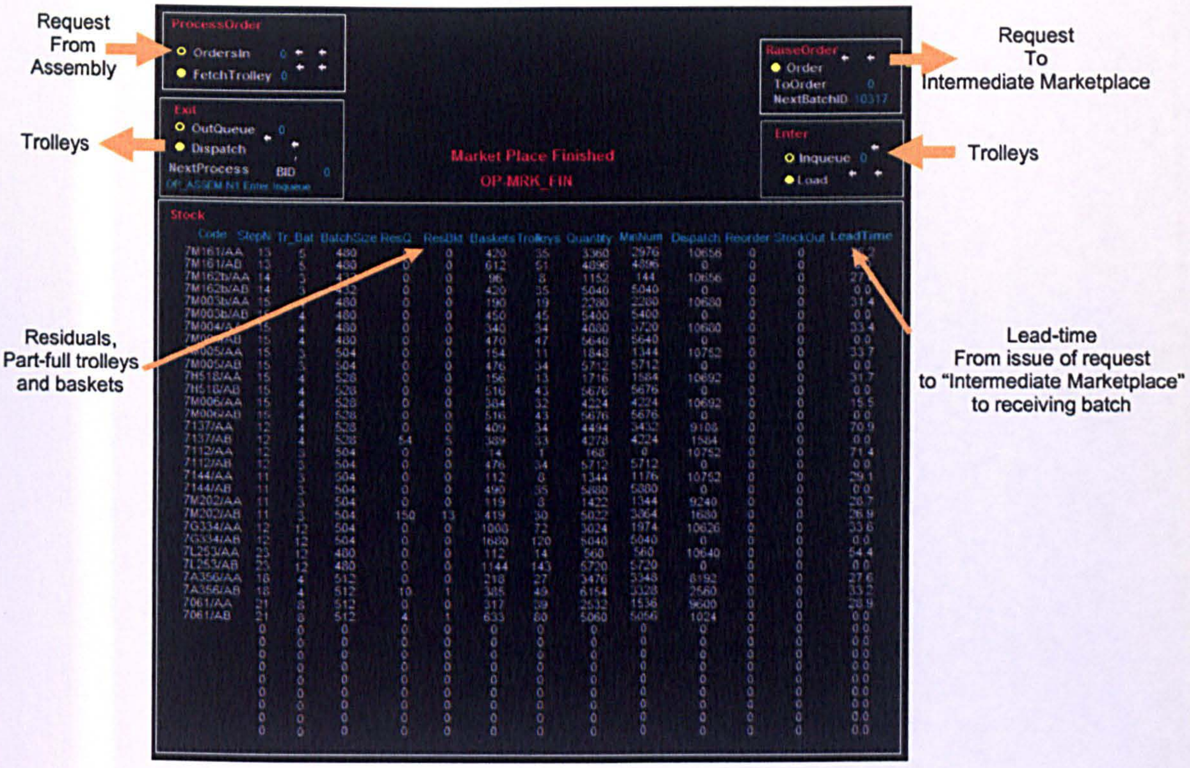
Figure 6.17 Chemical Treatment Continuous Machine

Features of the machine are:

- Similar to a continuous machine in trolley control input and output
- Dispatch keeps a record of where each live batch was sent which is erased once a complete batch has passed through
- Process represented by a buffer that received determined material handling unit for example in this case: can only take three trolleys worth of baskets at a time with a time delay to represent the process.
- Downtime are represented on the "STACK" process which in effect blocks the process

6.7.3.7 Queue Area, Storage Area or Marketplace

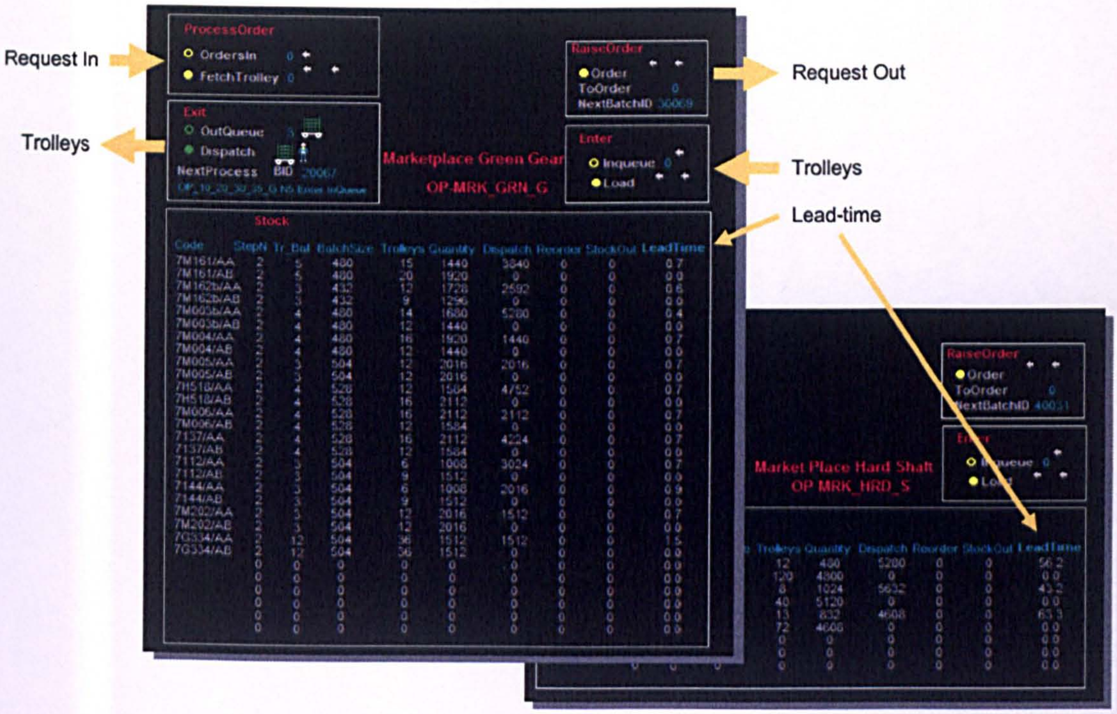
The logic of marketplace is slightly more complicated than the rest of the machine types. A request for a specific set of trolleys representing a specific product configuration is sent to the final marketplace shown in Figure 6.18. As a result a single trolley form the relevant components is released to the assembly line.



Code	StepN	Tr_Bat	BatchSize	ResQ	ResBkt	Baskets	Trolleys	Quantity	MinNum	Dispatch	Reorder	StockOut	LeadTime
7M161/AA	13	5	480	[illegible]	0	420	35	3360	2976	10656	0	0	[illegible]
7M161/AB	13	5	480	0	0	612	51	4896	4896	0	0	0	[illegible]
7M162b/AA	14	3	[illegible]	0	0	96	8	1152	144	10656	0	0	[illegible]
7M162b/AB	14	3	432	0	0	420	35	5040	5040	0	0	0	0.0
7M003b/AA	15	[illegible]	480	0	0	190	19	2280	2280	10680	0	0	31.4
7M003b/AB	15	4	480	0	0	450	45	5400	5400	0	0	0	0.0
[illegible]	15	4	480	0	0	340	34	4080	3720	10600	0	0	33.4
[illegible]	15	4	480	0	0	470	47	5640	5640	0	0	0	0.0
7M005/AA	15	3	504	0	0	154	11	1848	1344	10752	0	0	33.7
7M005/AB	15	3	504	0	0	476	34	5712	5712	0	0	0	0.0
7H518/AA	15	4	528	0	0	156	13	1716	1584	10692	0	0	31.7
7H518/AB	15	4	528	0	0	516	43	5676	5676	0	0	0	0.0
7M006/AA	15	4	528	0	0	384	32	4224	4224	10692	0	0	15.5
7M006/AB	15	4	528	0	0	516	43	5676	5676	0	0	0	0.0
7137/AA	12	4	528	0	0	409	34	4494	3432	9108	0	0	70.9
7137/AB	12	4	528	54	5	389	33	4278	4224	1584	0	0	0.0
7112/AA	12	3	504	0	0	14	1	168	0	10752	0	0	71.4
7112/AB	12	3	504	0	0	476	34	5712	5712	0	0	0	0.0
7144/AA	11	3	504	0	0	112	8	1344	1176	10752	0	0	29.1
7144/AB	11	3	504	0	0	490	35	5880	5880	0	0	0	0.0
7M202/AA	11	3	504	0	0	119	8	1422	1344	9240	0	0	28.7
7M202/AB	11	3	504	150	13	419	30	5022	3864	1680	0	0	26.9
7G334/AA	12	12	504	0	0	1008	72	3024	1974	10626	0	0	33.6
7G334/AB	12	12	504	0	0	1680	120	5040	5040	0	0	0	0.0
7L253/AA	23	12	480	0	0	112	14	560	560	10640	0	0	54.4
7L253/AB	23	12	480	0	0	1144	143	5720	5720	0	0	0	0.0
7A356/AA	18	4	512	0	0	218	27	3476	3348	8192	0	0	27.6
7A356/AB	18	4	512	10	1	385	49	6154	3328	2560	0	0	33.2
7061/AA	21	8	512	0	0	317	39	2532	1536	9600	0	0	28.9
7061/AB	21	8	512	4	1	633	80	5060	5056	1024	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0	0	0	0	0.0

Figure 6.18 Example of the Final Marketplace

If drawing a trolley from any component results in a complete batch being used a trigger is sent to the intermediate market to release a full batch of the component. Since the number of components per trolley is different for each component, the timing of the trigger signals across the marketplace is irregular. Full trolleys from the processes upstream enter the 'Enter Module', and leave from the 'Exit Module'. Actions are attached in each of the modules to replenish the display data. As for residuals in the final marketplace, parts in trolleys that are not fully used to fulfil the demand are sent back. In the case of the Start and Intermediate marketplace shown in Figure 6.19, the movement of trolley in and out are similar to the final marketplace except that there are no trolleys with residuals as component are released in complete batches and are received in complete trolleys. Rejects are considered as scrap and are taken out in the final marketplace. This represents a higher loading on the system as quality checks are carried out at each stages of the process and rejects are removed earlier upstream if found.



Code	StepN	Tr_Bal	BatchSize	Trolleys	Quantity	Dispatch	Reorder	StockOut	LeadTime
7M161/AA	2	5	480	15	1440	3840	0	0	0.7
7M161/AB	2	5	480	20	1920	0	0	0	0.0
7M162b/AA	2	3	432	12	1728	2592	0	0	0.6
7M162b/AB	2	3	432	9	1296	0	0	0	0.0
7M003b/AA	2	4	480	14	1680	5280	0	0	0.4
7M003b/AB	2	4	480	12	1440	0	0	0	0.0
7M004/AA	2	4	480	16	1920	1440	0	0	0.7
7M004/AB	2	4	480	12	1440	0	0	0	0.0
7M005/AA	2	3	504	12	2016	2016	0	0	0.7
7M005/AB	2	3	504	12	2016	0	0	0	0.0
7H518/AA	2	4	528	12	1584	4752	0	0	0.7
7H518/AB	2	4	528	16	2112	0	0	0	0.0
7M006/AA	2	4	528	16	2112	2112	0	0	0.7
7M006/AB	2	4	528	12	1584	0	0	0	0.0
7137/AA	2	4	528	16	2112	4224	0	0	0.7
7137/AB	2	4	528	12	1584	0	0	0	0.0
7112/AA	2	3	504	6	1008	3024	0	0	0.7
7112/AB	2	3	504	9	1512	0	0	0	0.0
7144/AA	2	3	504	6	1008	2016	0	0	0.9
7144/AB	2	3	504	9	1512	0	0	0	0.0
7M202/AA	2	3	504	12	2016	1512	0	0	0.7
7M202/AB	2	3	504	12	2016	0	0	0	0.0
7G334/AA	2	12	504	36	1512	1512	0	0	1.5
7G334/AB	2	12	504	36	1512	0	0	0	0.0
	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0.0
	0	0	0	0	0	0	0	0	0.0

Trolleys	Quantity	Dispatch	Reorder	StockOut	LeadTime
12	480	5280	0	0	56.2
120	4800	0	0	0	0.0
8	1024	5632	0	0	43.2
40	5120	0	0	0	0.0
13	832	4608	0	0	63.3
72	4608	0	0	0	0.0
0	0	0	0	0	0.0
0	0	0	0	0	0.0
0	0	0	0	0	0.0

Figure 6.19 Example of the Start and Intermediate Marketplace

The list below shown in Figure 6.20 shows the extent of details and variables the simulation model could hold and keep track of. The list also displayed the attributes and variables attached to monitor the important performance measure elements in each marketplace. The machines created in the marketplace are operations to perform the marketplace functions and not exactly a physical machine.

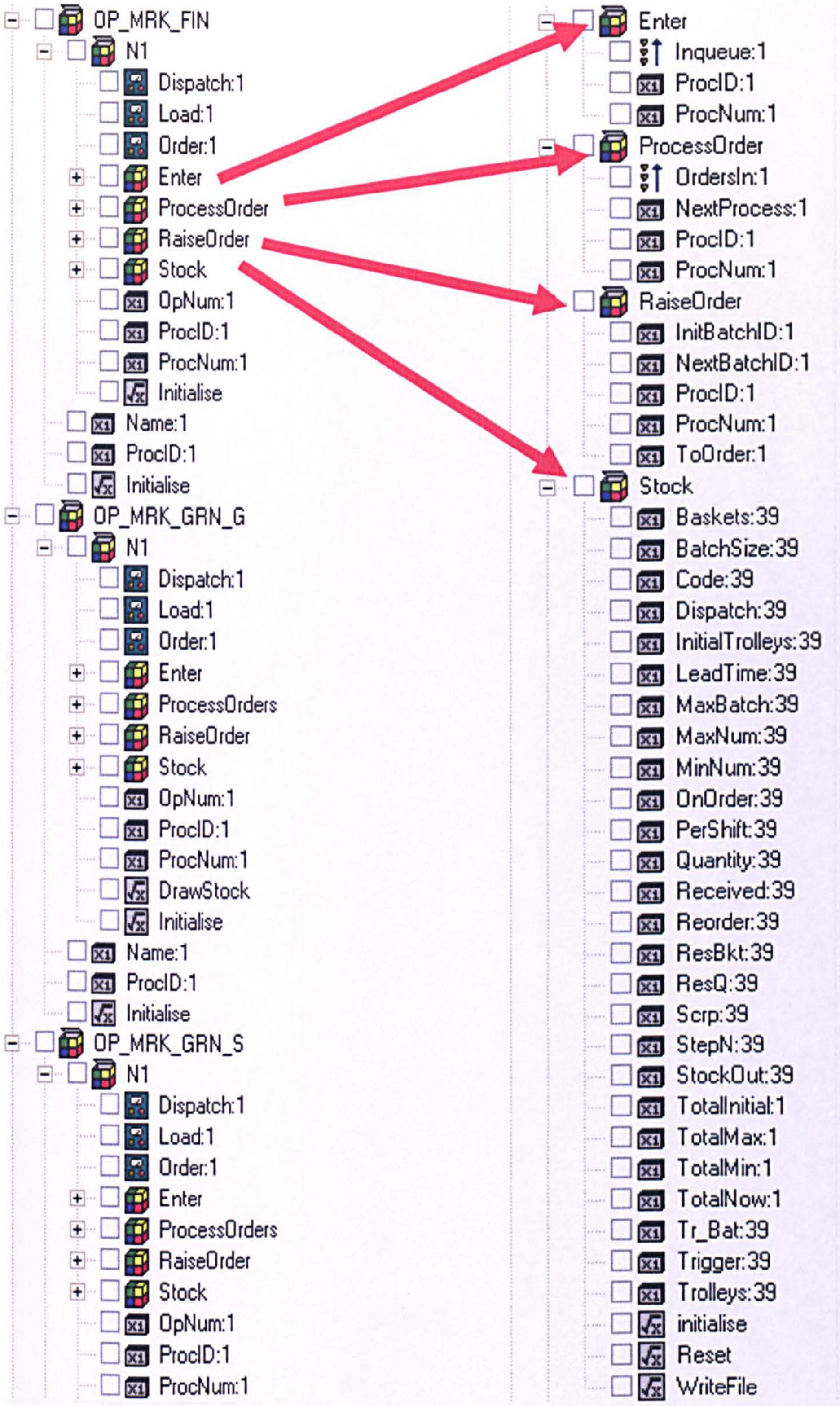
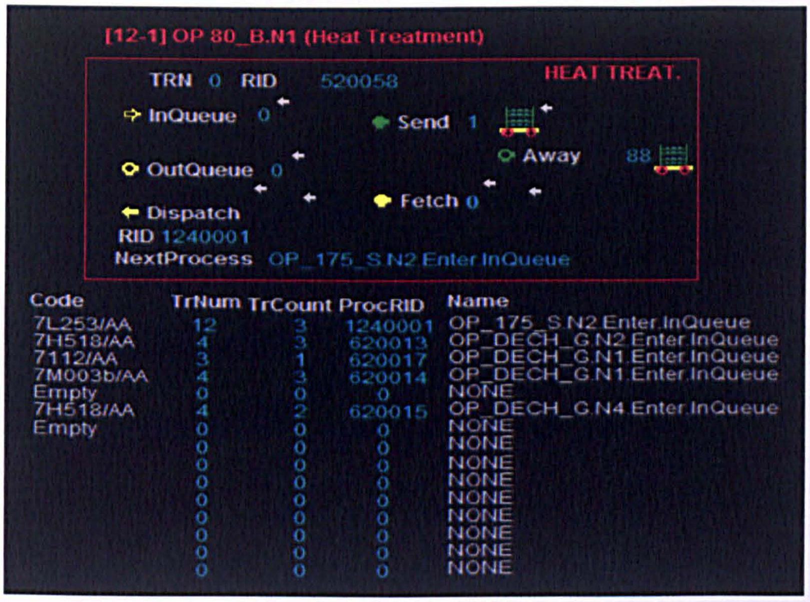


Figure 6.20 **Elements of the marketplace module**

6.7.3.8 Delay Machine (i.e. Oven or Heat Treatment)



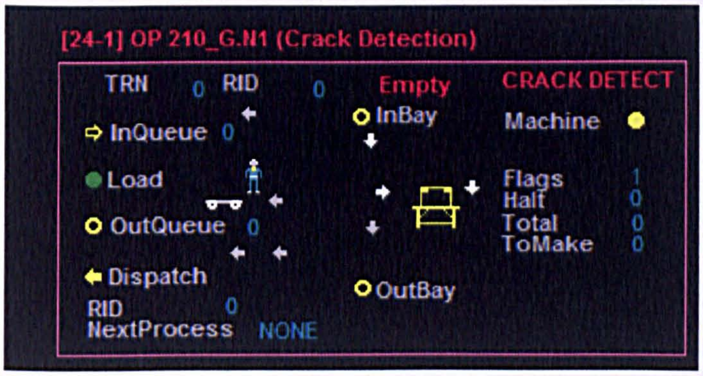
```
[12-1] OP 80_B.N1 (Heat Treatment)
     TRN  0  RID     520058                        HEAT TREAT.
   InQueue   0            Send  1
                                    Away     88
   OutQueue  0
                          Fetch 0
   Dispatch
   RID 1240001
   NextProcess  OP_175_S.N2.Enter.InQueue

Code        TrNum TrCount ProcRID  Name
7L253/AA      12      3   1240001  OP_175_S.N2.Enter.InQueue
7H518/AA      4       3    620013  OP_DECH_G.N2.Enter.InQueue
7112/AA       3       1    620017  OP_DECH_G.N1.Enter.InQueue
7M003b/AA     4       3    620014  OP_DECH_G.N1.Enter.InQueue
Empty         0       0         0  NONE
7H518/AA      4       2    620015  OP_DECH_G.N4.Enter.InQueue
Empty         0       0         0  NONE
              0       0         0  NONE
              0       0         0  NONE
              0       0         0  NONE
              0       0         0  NONE
              0       0         0  NONE
              0       0         0  NONE
              0       0         0  NONE
              0       0         0  NONE
```

Figure 6.21 Example of a Delay Machine (Heat Treatment)

Features of the delay machine shown in Figure 6.21 are:

- Similar to continuous machine in trolley control
- Process represented by a buffer where material handling unit wait for a fixed time pre-determined before they are picked up
- No limit on the facility
- Dispatch keeps a record of where each live batch was sent which is erased once a complete batch has passed through

6.7.3.9 Manual Machines (i.e. Inspection and cleaning)



```
[24-1] OP 210_G.N1 (Crack Detection)
   TRN    0  RID      0     Empty     CRACK DETECT
                            InBay     Machine
 InQueue  0

 Load                                 Flags      1
                                      Half       0
 OutQueue  0                          Total      0
                                      ToMake     0

 Dispatch                   OutBay
 RID          0
 NextProcess   NONE
```

Figure 6.22 Example of Manual Machine

The manual machine shown in Figure 6.22 normally calls operators required to perform the operation. Features of the machine are:

- Same batch and trolley in and out control as general machines
- Uses one in Trolley and one empty trolley for output
- Manually operated process based on the number of components in each trolley

6.8 Proposed Design Modules

Modules are created to represent other activities and operations carried out in the manufacturing system beside the machining processes. The list of modules created for the simulation model of the manufacturing system is as follow:

- Component Module: consist all the data of the components
- Get trolley Module: calling for trolleys and baskets
- Handling Module: information of basket and trolleys in marketplaces
- Monitor Module: update data on the monitoring tables
- OP Module: consist all data on labour details and activities
- Shift Module: shift patterns and the clock for the simulation runs
- Downtimes Module: consist of all downtime activities and details
- Routines Module: the routes and movement rules
- Assembly Module: the assembling procedures and details
- Global Module: data input and result recording and storing

A few of the important modules are discussed in the following section to illustrate the auxiliary operation besides the processing machine centres.

6.8.1 Downtime Module

Downtimes are split into breakdown, changing, load, operations (ops) and routine module in as shown in Figure 6.23 (a). Each module has it owns variables and functions to carry out the retrieval of activities details and data collection function. Activities details retrieval consists of getting the type of downtime with the processing time, and the labour type and requirement.

Breakdown is tested with random distribution of a set time in the simulation model. Elements of breakdown are shown in Figure 6.23(b). Changing is the changeover operation either the change of component type or derivative changeover and elements of the module are shown in Figure 6.23(c).

Loading operations in the downtimes do not refer to the automated loading of parts in a machine centre, but the labour loading the trolleys to the process. The elements of the load module are shown in Figure 6.24(b). Examples of routine activities are checking the work area and simple cleaning near the machines. The elements of routine downtime are shown in Figure 6.24 (b). The last type of downtime is OP which stands for operations. This type of downtime is activities that must carried out after a specific number of operations on the machines. Examples of operational downtimes are gauging and swarfing which are specific to this case study as shown in Figure 6.24 (c).

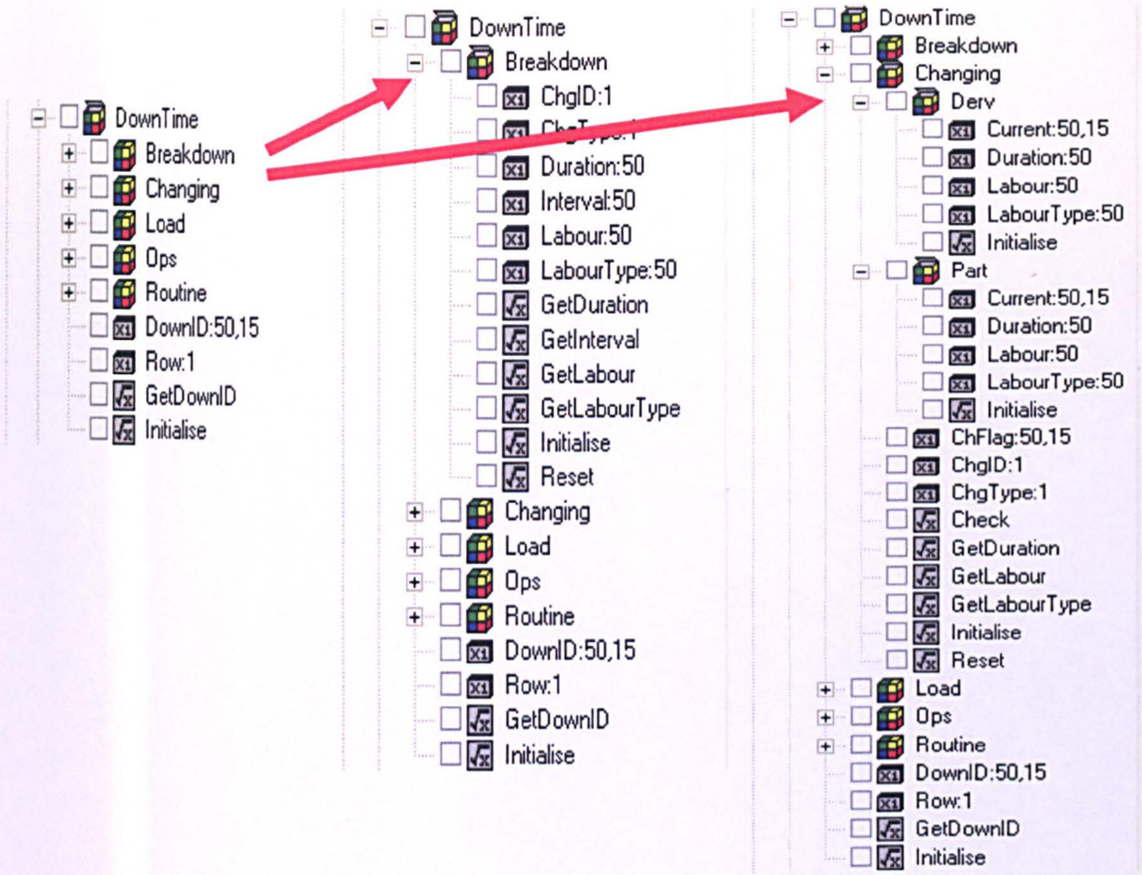


Figure 6.23 **(a) Downtime Module, (b) Breakdown Module and (c) Changing Module**

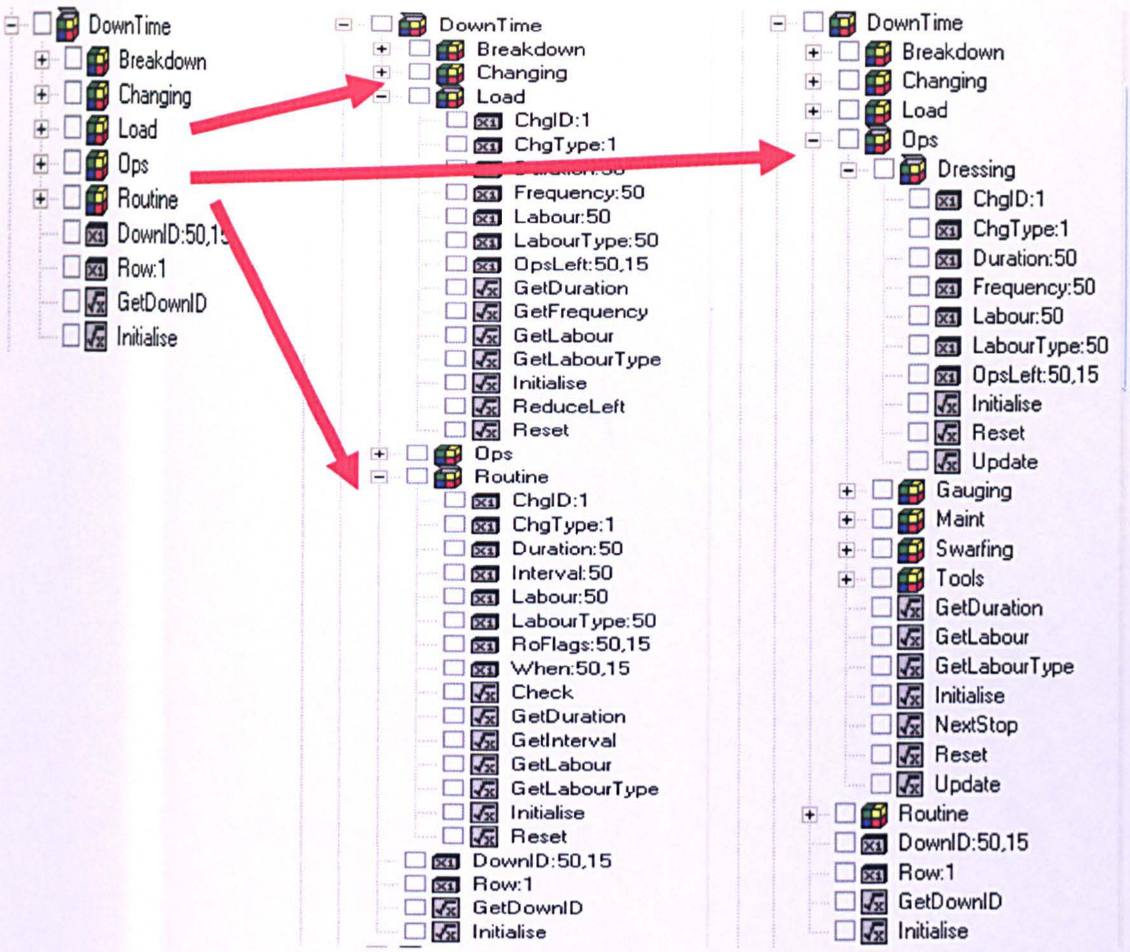
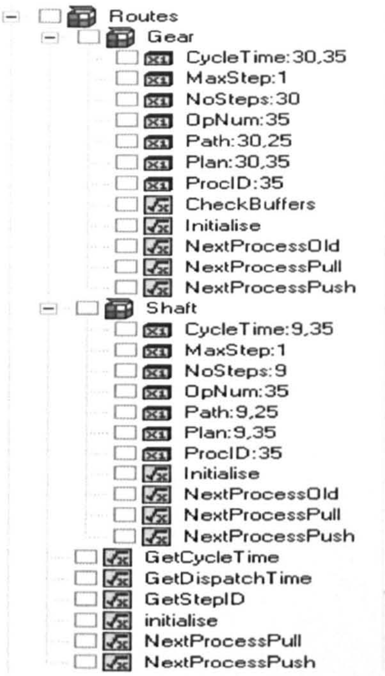


Figure 6.24 (a) Downtime Module, (b) Load Module and Routine Module and (c) Ops Module

6.8.2 Routines Module

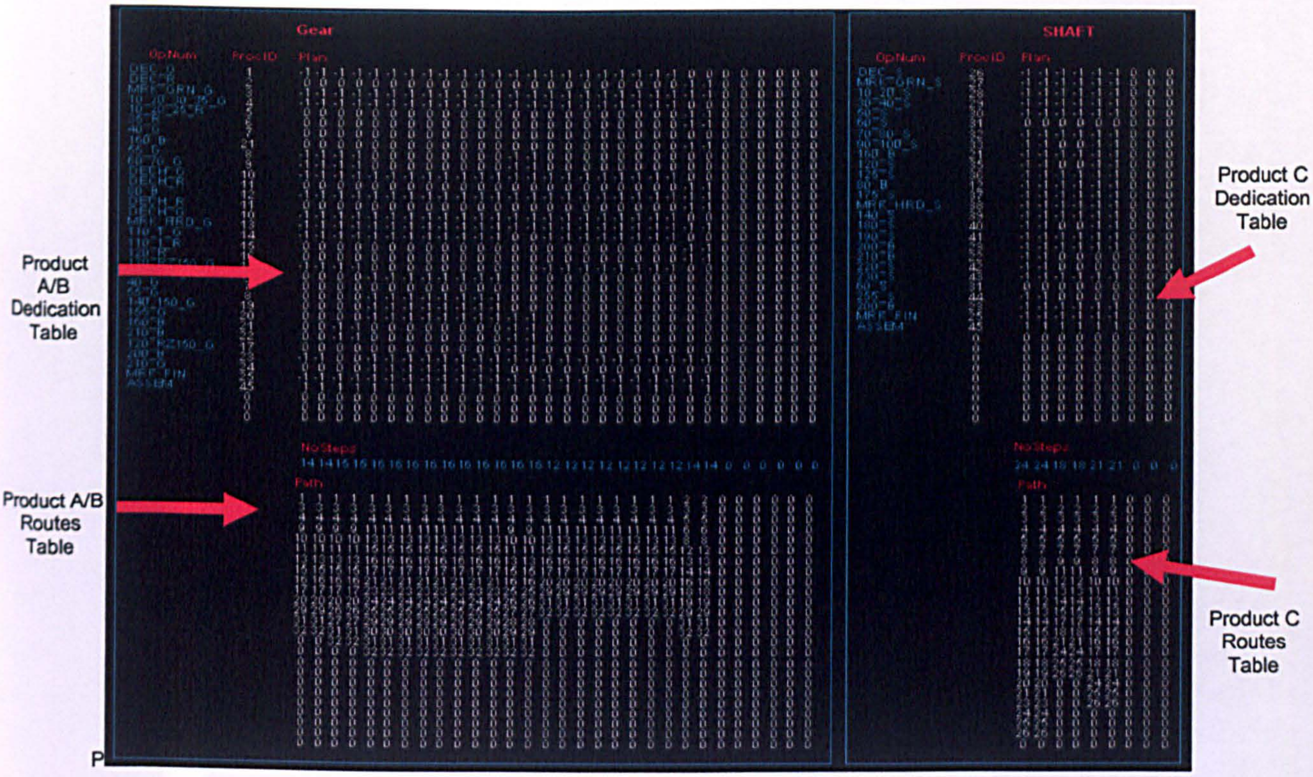
The routing module consists of variables and functions that determine the rules of movement and data to retrieve shown in Figure 6.25. The rules or logic of movement determine whether the process pulls the trolley or trolleys are push to the process. The functions also retrieve route and paths of component from the array of route table from an excel worksheet.



- ☐ Routes
  - ☐ Gear
    - ☐ CycleTime:30,35
    - ☐ MaxStep:1
    - ☐ NoSteps:30
    - ☐ OpNum:35
    - ☐ Path:30,25
    - ☐ Plan:30,35
    - ☐ ProcID:35
    - ☐ CheckBuffers
    - ☐ Initialise
    - ☐ NextProcessOld
    - ☐ NextProcessPull
    - ☐ NextProcessPush
  - ☐ Shaft
    - ☐ CycleTime:9,35
    - ☐ MaxStep:1
    - ☐ NoSteps:9
    - ☐ OpNum:35
    - ☐ Path:9,25
    - ☐ Plan:9,35
    - ☐ ProcID:35
    - ☐ Initialise
    - ☐ NextProcessOld
    - ☐ NextProcessPull
    - ☐ NextProcessPush
  - ☐ GetCycleTime
  - ☐ GetDispatchTime
  - ☐ GetStepID
  - ☐ initialise
  - ☐ NextProcessPull
  - ☐ NextProcessPush

Figure 6.25 Routing Module Elements

Figure 6.26 shows the components' dedication table. In the table, -1 represents that the machine is open to be shared by all products, and 0 indicate the machine is not in used. A positive value will indicate the index of the machine in the process that is dedicated to that component. The components' route table shows the process and the number of processes the part visits. It also shows the number of process (steps) the component goes through before completion.



Product A/B Dedication Table

Product A/B Routes Table

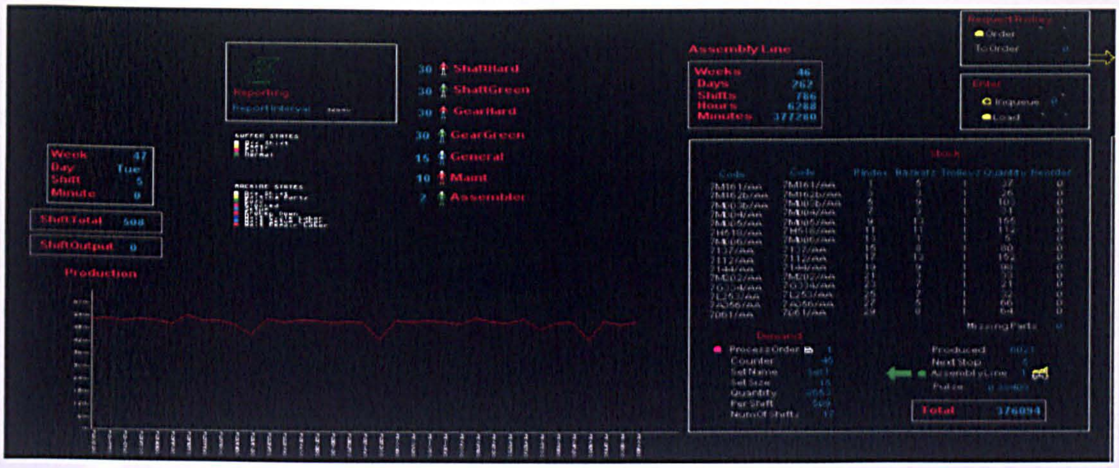
Product C Dedication Table

Product C Routes Table

Figure 6.26 Routing ID Table

6.8.3 Assembly Module

The assembly module shown in Figure 6.27 represents the system demand and operates by pulling trolleys from the marketplace as needed. A demand file indicates the order to the Assembly Line. The number of components per trolley is different; hence the rate of pull for each trolley is different. At changeover the trolleys that are not further required are sent back to the marketplace with residual parts. Monitoring information like the production timeline and current status of the stock in the final marketplace are display in the assembly module also shown in Figure 6.27.



Week 47
Day Tue
Shift 5
Minute 0

ShiftTotal 508

ShiftOutput 0

30 ShaftHard
30 ShaftGreen
30 GearHard
30 GearGreen
15 General
10 Maint
2 Assembler

Weeks 46
Days 262
Shifts 786
Hours 6288
Minutes 377280

To Order 0

Inqueue 0

Counter 46
Set Size 15
Per Shift 509

Total 376094

Figure 6.27 Assembly Module Consisting Output Report Showing Production Timeline and Monitoring Table

An example of a timeline of production for an entire year is shown in Figure 6.28. The X-axis represents of shifts and the Y-axis represents number of products.

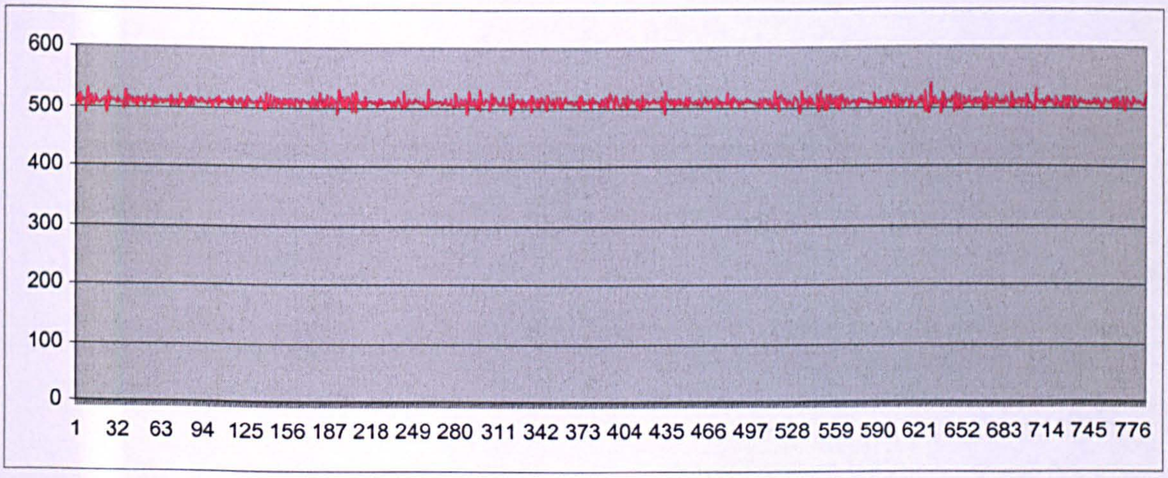


Figure 6.28 An Example of Production Timeline per year

The timeline in Figure 6.28 shows the production rate fluctuation in the time line structure. The reporting interval is a variable where the user can change to give different period reading. The assembly table shows the day and time the current shift and also the total production at the current period.

When an order is received in the Order module, the order with the 15 components that assembled into this product with their derivative details and quantity are draw from the

Final Marketplace in the system. The assembly machine has a production rate, and this depends on the output planned for each shift. This rate can be change in the Excel Information file. It is calculated by the expert of the system. In Figure 6.29, the extent of the attributes and variable to trace and calculate the important performance measure or key element to enhance decision making process is illustrated.

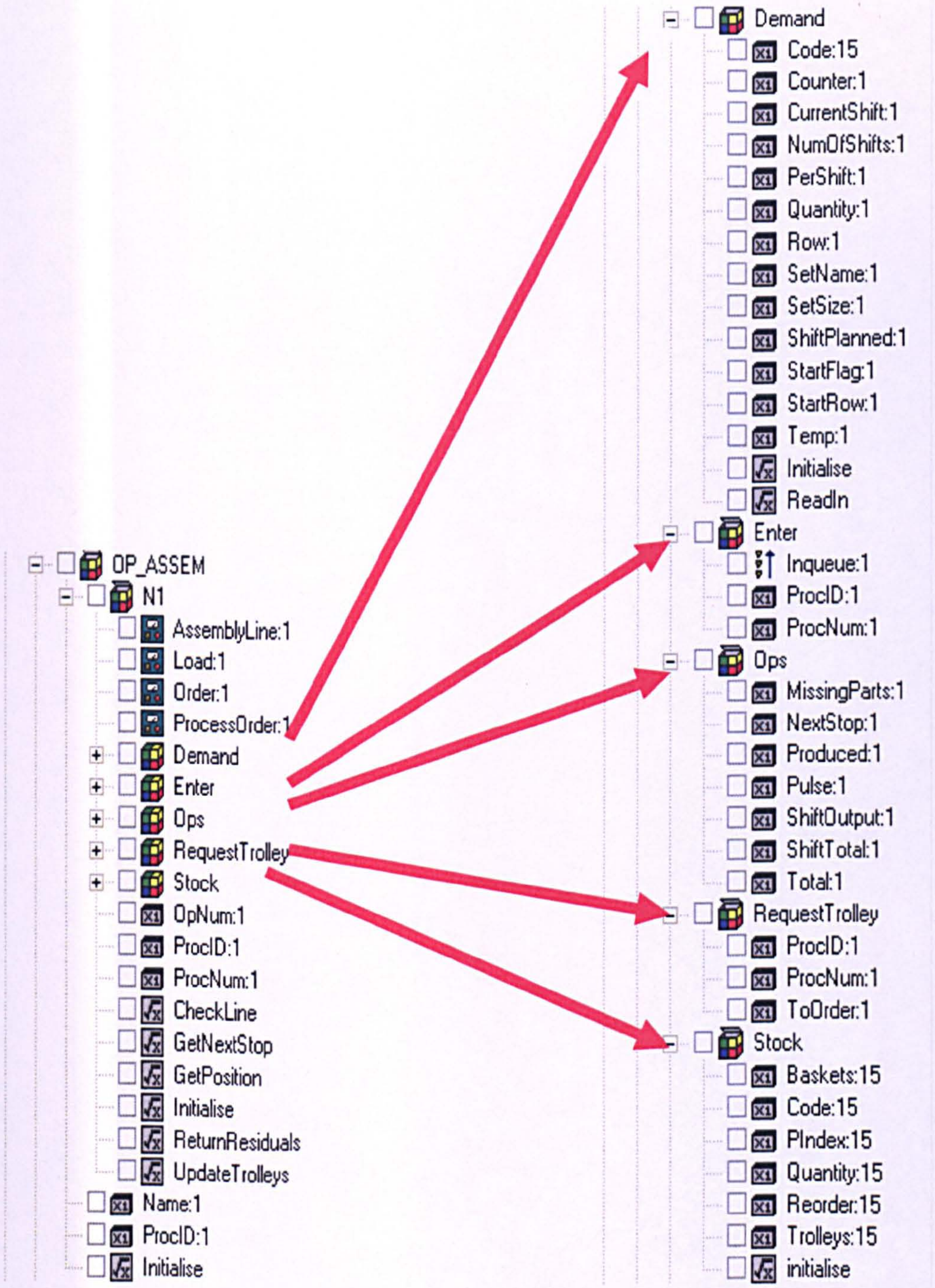
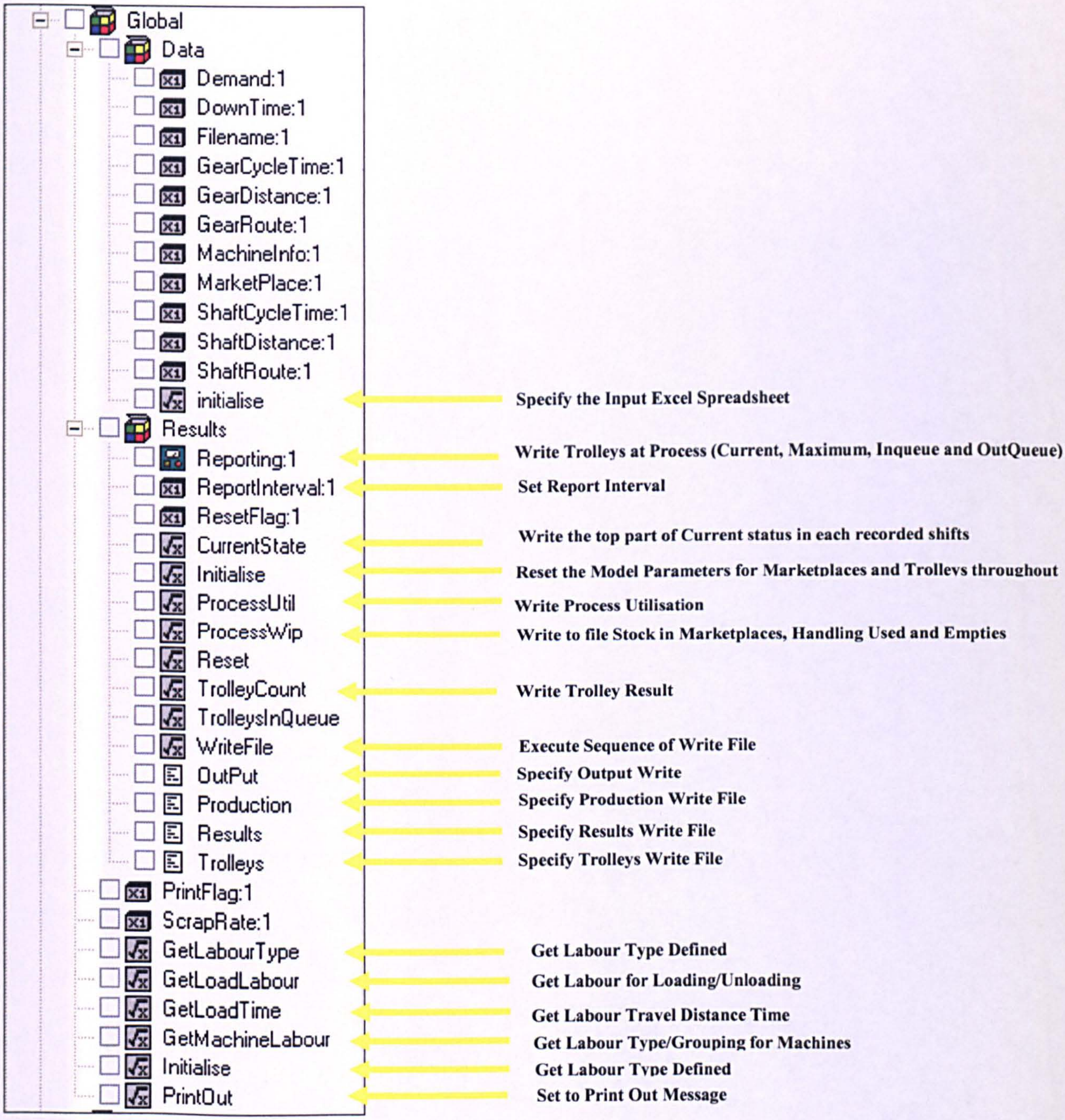


Figure 6.29 Elements of the Assembly Module

6.8.4 Global Module: Data Input and Result Generation

The data input and result generation module consist of a number of smaller modules. The initialisation in the data module shown in Figure 6.30 specify the excel spreadsheet its reading from. All data are read into the variables representing them in the simulation model.



Specify the Input Excel Spreadsheet

Write Trolleys at Process (Current, Maximum, Inqueue and OutQueue)

Set Report Interval

Write the top part of Current status in each recorded shifts

Reset the Model Parameters for Marketplaces and Trolleys throughout

Write Process Utilisation

Write to file Stock in Marketplaces, Handling Used and Empties

Write Trolley Result

Execute Sequence of Write File

Specify Output Write

Specify Production Write File

Specify Results Write File

Specify Trolleys Write File

Get Labour Type Defined

Get Labour for Loading/Unloading

Get Labour Travel Distance Time

Get Labour Type/Grouping for Machines

Get Labour Type Defined

Set to Print Out Message

Figure 6.30 Data Input and Result Generation Module Elements

The report module shown in Figure 6.30 illustrates the functions pre-programmed to collect the needed data and the destination of the output results. A detailed set of system performance and state data are collected every 68 shifts interval (representing 4 weeks of production). Data collected consists of number of assembled units, trolleys usage with maximum and minimum in the marketplace, the trolleys at the machine with current status and the maximum number reached and all machine utilisation. The example the results collected are illustrated in the following section on experimentation.

6.9 Experimentation

Experimentation is carried out on the simulation model to collect various types of data. The following list is the type of data collected:

- Production rate for the interval of 68 shifts (4 weeks)
- Lead time of the each component from decant to final marketplace
- Number of trolleys used in the marketplace, collecting the minimum and maximum value reached within each period
- Number of trolleys in each machine, and collecting the current value at the shift and the maximum value
- Machine utilisation of busy, idle and downtimes in percentage
- Status of stock in each marketplace

Every shift is 480 minutes and there are 17 shifts per week. The system considers 4 weeks of 17 shifts per month, giving 786 shifts per annum considering holidays. The main target is whether the manufacturing system in the simulation model could produce 400,000 units in 786 shifts. The simulation model is programmed to collect result every 4 weeks in a structured format writing out details of number of trolleys and baskets used with its maximum and minimum usage in each shifts, production rate for the month, machine utilisation rate and downtimes ratio.

It is assumed that all derivative of the same component goes through the same processes and same cycle time. And the cycle time for each machine in the same process is the same and no variation due to the machine condition.

Each marketplace has been pre-filled with empty baskets and trolleys, as well as filled basket and trolleys. An optimum safety stock in each marketplace has been studied to prime the system to run smoothly. The number of batches to be allocated in each marketplace is tested and data are collected from a number of experimentations. Breakdown of the process is an estimated value which can be altered by the system administrator according to the actual process. The model is tested with machine breakdown of an average of 120 minutes as provided by the company. The frequency of breakdown is an average value provided by the company.

Scrap of components is assumed to be 2% and is applied at the final marketplace. Hence the overall system capacity takes into account the scrap percentage deduction. Due to this assumption of where scrap is allocated, the impact of scrap is higher than the real situation. Scrap that may occur at an early stage of production does not generate as high impact on production time and machine utilisation further downstream.

6.9.1 Experimentation of the operational parameters: Example with breakdown time and number of machine

The key criteria that the model is testing for is whether the manufacturing system is able to deliver 400, 000 units per year. Different parameters like the breakdown and the number of machine for the bottleneck process are tested in this example. The breakdown time selected are selected: 60 minutes or 120 minutes; and different number of machines available for the grinding machine for Product A/B (named as Machine A)and turning combined machine for Product C (named as Machine B) identified as bottleneck processes on previous analysis. The configuration of demand is on 2 different set configured with totally different derivatives for each component. Hence Set A consists of 14 components of derivative AA and Set B consisting 14 components of derivative BA. Changeover of components and derivatives has a large impact on the production time.

The four different output time-line graphs shown in Figure 6.31-Figure 6.34 show the effect of changes on the system, and demonstrate the instability of the system. The X-axis represents shifts and the Y-axis represents number of products.

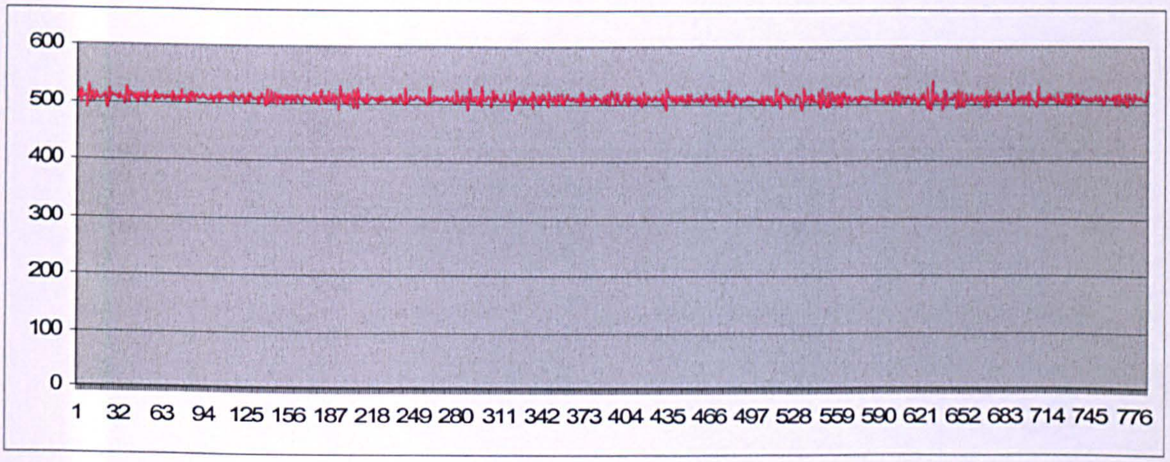


Figure 6.31 Set 1 Results

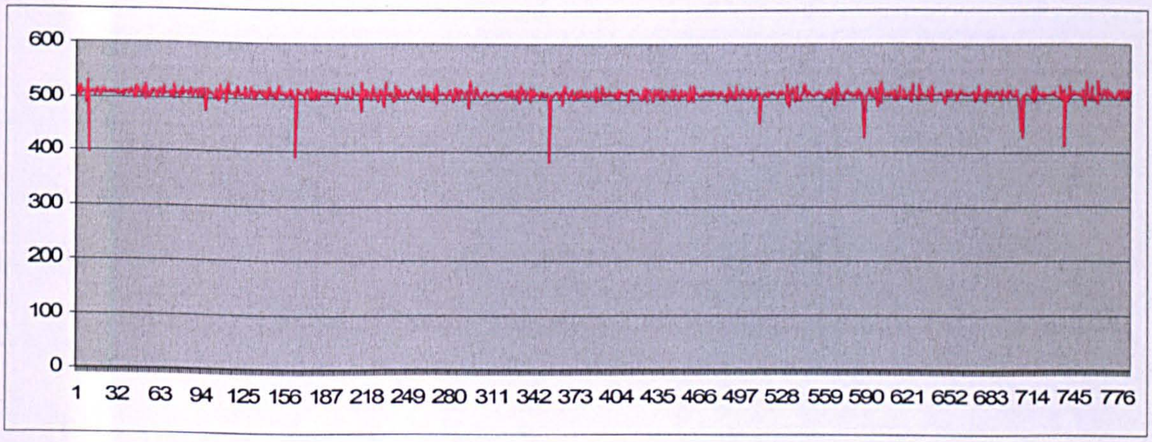


Figure 6.32 Set 2 Results

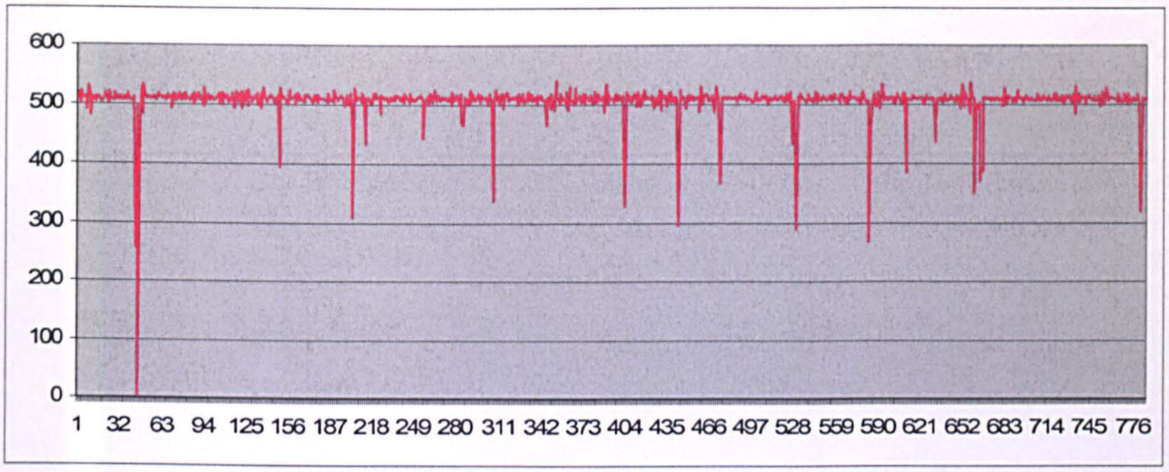


Figure 6.33 Set 3 Results

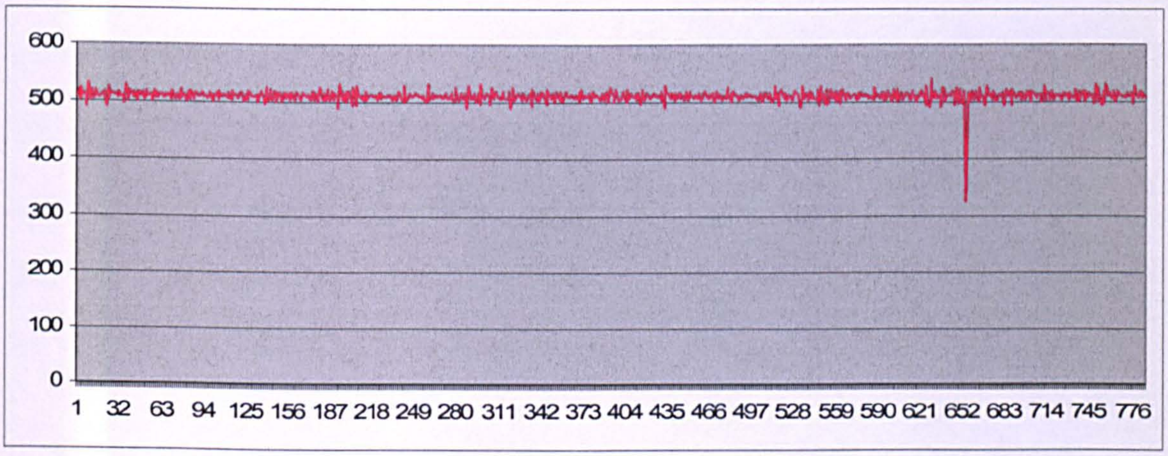


Figure 6.34 Set 4 results

The result in Table 6.3 shows that any changes in the parameter, the overall production output suffers due to delay and blockage in the system. Variation on the output numbers is quite different. The impact of the longer break down is higher than losing one extra machines on each bottleneck processes. From Table 6.3, if all machines have 60 minutes of breakdown time, the end capacity per annum is more than the 400,000 units targeted with 12 bottleneck machine allocate. As the manufacturing system is still under planning, parameters like number of machine to purchase can be analysed and the specification of breakdown time can be improved by the supplier.

Result Set	Demand	Bottleneck Machine A	Bottleneck Machine B	Breakdowns	Production	Short
Set 1	50/50	12	5	60all	400074	-74
Set 2	50/50	12	5	120all	399257	817
Set 3	50/50	11	4	120all	396142	3932
Set 4	50/50	11	4	60all	399891	183

Table 6.3 Summary of Results: Experimentation on Variation of Machine Numbers and Downtimes

6.9.2 Experimentation of Trolleys in Marketplace and in each machine

This is an example of results collected for the intermediate marketplace for product C. In this experiment, the intermediate marketplace of Product C is initially allocated 248 trolleys. And for each interval of 68 shifts, the current number of trolleys, the minimum and maximum number is collected in as shown in Table 6.4 to produce the graph in Figure 6.35. The X-axis represents the shifts, and the Y-axis represents number of trolleys. The graph provides a visual display of the fluctuation of trolley numbers. It also shows the wide gap between the maximum and minimum number of trolleys in the marketplace. The empty trolleys and the racks for heat treatment at each marketplace are also collected and analysed in the same manner.

	Intermediate Market Product C			
Shift	Init	Now	Min	Max
68	248	163	146	248
136	248	158	130	183
204	248	149	124	173
272	248	144	127	181
340	248	142	128	163
408	248	127	120	164
476	248	152	123	167
544	248	139	131	172
612	248	141	127	161
680	248	145	124	157
748	248	137	133	169

Table 6.4 Example of Data Collected for the Intermediate Marketplace for Product C

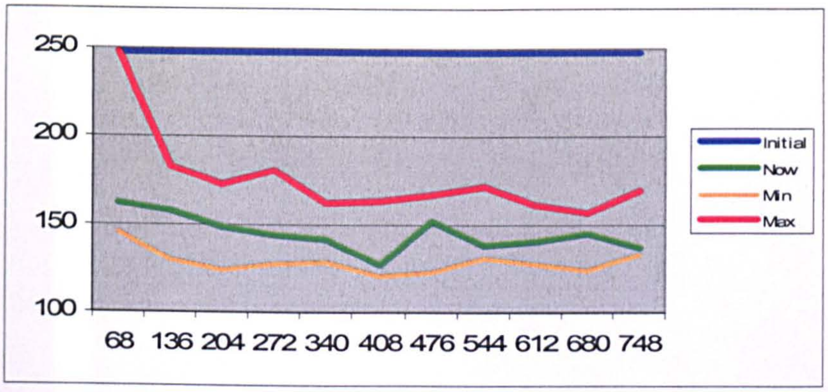


Figure 6.35 Example of Trolley Ranges Graph for an Intermediate Marketplace of Product C

An example of a results table which provides detailed records of trolleys for each component in the intermediate marketplace for product C is shown in Table 6.5. The critical recording of stock out and lead time are important parameters to be studied. The time the data is collected and the number of units produced are also stated.

TIME	391680									
PRODUCED	404685									
CURRENT SHIFT	816									
PLANNED OUTPUT PER SHIFT	509									
C INTERMEDIATE MARKETPLACE										
CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTITY	STKOUT	LEADTIME
C1/AA	4	8	64	20	4	64	60	60	0	30.67
C1/AB	4	8	64	64	0	64	64	64	1	32.07
C2/AA	5	8	20	4	0	20	20	20	0	31.13
C2/AB	5	8	20	20	0	20	20	20	0	32.09
C3/AA	5	8	40	9	3	40	37	37	0	30.15
C3/AB	5	8	40	40	0	40	40	40	1	31.47
TOTALS	-	-	248	157	129	170	41	119		

Table 6.5 Example of Sample of Data Collected at the End of the Year Production at Shift 816

Besides trolley information in marketplace, trolley numbers in each machine are equally important. Build up of trolleys at a machine can have detrimental effect in the space and flow of the process.

Data on the current number of trolleys in each machine, in 'Inqueue' buffer and 'Outqueue' buffers and the maximum it has reached are collected in the table format shown in Table 6.6. The table also records the average time a trolley spends in the queue.

TROLLEYS AT PROCESSES												
Decant Machine x4	Current	0	0	0	0							
	Maximum	1	1	1	1							
	InQueue	0.01	0.01	0.01	0.01							
	OutQueue	0	0	0	0							
Start Marketplace	Current	155										
	Maximum	160										
	InQueue	0										
	OutQueue											
Turning A/B x 12	Current	2	3	3	3	3	3	1	2	2	3	3
	Maximum	3	3	3	3	3	3	3	3	3	3	3
	InQueue	1.34	1.33	1.31	1.35	1.33	1.33	1.38	1.39	1.37	1.31	1.35
	OutQueue	0	0	0	0	0	0	0	0	0	0	0

Table 6.6 Example of Data Collected for Trolley Number at Each Machine

6.9.3 Experimentation with Demand

Experiments were carried out to study the effect of different demand patterns. The demand patterns have a high degree of variation. The model checks for the number of shifts that are allocated to make a set, the configuration of the set, and the number of sets to be make per shift. The model is tested with the following different demand patterns:

- one set with one type of derivatives,
- two sets consisting of totally different derivatives each,
- four different configuration of the sets with 34 shifts, 17 shifts, 10 shifts and 7 shifts (ratio provided by the company)

The model is also tested with a step up from 200 to 509 of units per shift over 3 weeks represents a gradual build up of production. An example of the production timeline with a step up demand is shown in Figure 6.36. The X-axis represents shifts and the Y-axis represents number of products.

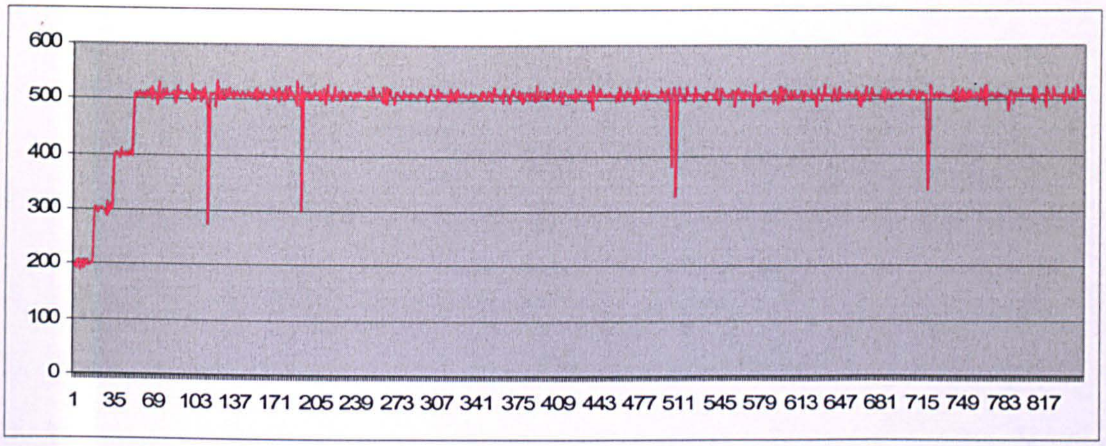


Figure 6.36 Example of Production Timeline with Step Up in Demand

6.9.4 Experimentation on Machine Utilisation

The utilisation of each machine in the process is collected as shown in Table 6.7. The values for the off shift, idle, busy, downtime and breakdown time are in percentage.

PROCESS UTILISATION						
MACHINE						
NAME	OFF-SHIFT	IDLE	BUSY	DOWN	BREAKDOWN	OEE
Assembly Machine(ASSEM) #1	6.25	0.038942	93.7111	0	0	100
Decant #1	0	51.7708	45.8088	2.42034	0	94.9816
Decant #2	0	72.4828	26.1385	1.37868	0	94.9898
Decant #3	0	89.9792	9.5	0.520833	0	94.8025
Decant #4	0	84.2339	14.9695	0.796569	0	94.9476
Turning A #1	0	3.97936	86.2603	7.19844	2.56191	89.8352
Turning A #2	0	7.27802	83.038	8.3027	1.38131	89.5559
Turning A #3	0	8.27393	81.0619	8.51716	2.14702	88.3739
Turning A #4	0	8.00816	81.4559	7.01593	3.52004	88.5468
Turning A #5	0	5.29657	83.6458	7.61905	3.43862	88.3239
Turning A #6	0	7.79118	82.724	8.11887	1.36596	89.7137
Turning A #7	0	9.10071	82.0668	7.3223	1.51021	90.2832
Turning A #8	0	2.285	87.0735	7.95257	2.68892	89.1097
Turning A #9	0	4.91159	81.8457	7.644	5.5987	86.0733
Turning A #10	0	5.90844	83.7137	7.75123	2.62659	88.9705
Turning A #11	0	11.3035	78.6988	8.25674	1.74097	88.7282
Turning A #12	0	7.74374	83.1527	7.90441	1.19912	90.1323
Turn B #1	0	33.0383	62.2166	2.65012	2.09497	92.9137
Turn B #2	0	38.3339	57.7188	2.4663	1.481	93.5989

Table 6.7 Example of Results Collected for Machine Utilisation

The data collected are useful in finding the bottleneck machines. The impact of breakdown time and downtime in ratio to the processing time can be easily looked up. These data help to identify the problematic processes and improvement ideas can be proposed. OEE is the Overall Efficiency Effectiveness of the system without considering the labour factor.

6.10 Excel Spreadsheet

A large amount of data had to be produced at the beginning of the project. If all the data are kept in the simulation model, the processing of data would slow the model processing time. Hence a workbook containing data in separate worksheet was created. Creating an excel spreadsheet was a quick and easy method to start off the project.

The worksheets created are:

- Demand (Product Mix, order per shift)
- Machine Information(Process and Number of Machine, dedication)
- Labour Information (Labour Type and Labour Number)
- Marketplace (Material Handling requirements at each marketplace)
- Downtimes (Types of Downtimes with details)
- Part A/B Cycle Time (Cycle times for component A and B)
- Part A/B Routes (Routes table for component A and B)
- Part A/B Distances (Distances between each process for component A and B)
- Part C Cycle Time (Cycle times for component C)
- Part C Routes (Routes table for component C)
- Part C Distances (Distances between each process for component C)

Part A and Part B are grouped together in this project because they share similarity in processes but not necessarily the same machines. The data regarding cycle time, routes and distances are in the same format for Part A, B, and C. The data are grouped by part types representing cluster of process. A full set of worksheet are provided in Appendix F.

6.11 Discussion and Future Work

6.11.1 Discussion

The simulation model developed in case study 4 achieved its objectives in terms of its technical aims, providing an assessment on the performance of the system, and therefore, achieving the specific aim of the project. Key Model Features are as follow:

- Modular in design utilising a library of bespoke modules
- Scalable to include new processes
- Central control of logic and product routing for ease of change
- Data driven with minimum need to code in witness model for changes and reconfiguration of routes or machines and operating parameters

The simulation model generates and collects large amount of data. Some data collected is straightforward and obvious such as machine utilisation but most data needed further interpretation. Hence, time is required to analyses these for clues to improving the system. The analysis of the results allows management to predict if line-balancing strategies such as batching, set-up reduction, kanban and parts sequencing would be sufficient, or if more fundamental changes such as the dedication of lines or the ordering of more machines is required. The simulation of disturbances such as the machine breakdowns and losing machine availability allows their effects to be quantified which would be difficult by any other means. From this analysis, recommendations can be made regarding the management of the dynamic system. Examples of the recommendations are rules and flow of physical entities movements should be clear; and operational parameters must be monitored carefully. The design of the simulation model is modular, flexible and scalable. Users from the company can easily pick up the simulation model to add, edit, and delete machines or even processes in the simulation model. At the current status of the project, users still need to access the simulation model to make structural changes of the manufacturing system, only minor value changes can be made via the Excel Spreadsheet.

The study predicted chaotic behaviour kicks in if any one element does not run in synchronisation. For visual management with kanban philosophies to be applied, a stable state of the manufacturing system needs to be achieved before any rules could be applied. In this case study, the configuration pattern and quantity of the demand for the manufacturing system is fixed. The marketplace in the system is assumed to have the optimum safety stock from extensive experimentation and analysis. Other elements like breakdown and number of machines in used affect the system greatly. The approach uses the design and philosophies of visual management, but with the analysis from the simulation model, due to the large numbers of trolleys involved, straightforward visual management on the shop floor will not be able to cope without human intervention and more control mechanism with help of technology in place. The number of trolleys from the experiments does not consider trolleys of component which are held due to quality problem or other reasons. Hence the number of trolleys projected should include an extra percentage for unpredicted event that held the trolleys and baskets.

The simulation model generates the route of all the component visits. If the component visits a larger the number of processes, lead time is longer, and chances of delay is higher due to disruptions and queues. Components that visit many shared operations are likely to face queues as well which lead to higher processing time. The route of a component is easily traced through the simulation model and results. Delays and problem areas can be identified through analysing the results and model output.

The entire simulation model has been designed using the modular approach proposed in this research. Although classifying the elements in the system and implementing this design required more time in the initial stage of the project, the overall time saving still out-weights the traditional approach. There is significant reduction of development time and simulation experimentation time. The simulation model can simulated a year production in under 4 hours.

6.11.2 Future Work

Results from the simulation model identifies that the visual management required more attention in terms of human intervention. The complexity and distributed nature of human decision making process is difficult to mimic exactly. The management of trolleys and baskets are not as straightforward and obvious as it seems. Visual management promotes simple and direct control, but due to the constraint of space and the large configuration of different components and quantities, this issue has to be handled properly.

In the existing shop floor, a kanban card consisting information of the batch is attached to each trolley. The kanban card could be designed in different colour to indicate the component family and large font prints for quick and easy visualisation. Areas for designated component family could be marked on the shop floor to differentiate the trolleys.

Order prioritisation is not implemented in the simulation model. The order could be allocated with red or amber flag that machines are pre-programmed to fast track these order. The marketplaces could also use the lead time of the components as an indication to trigger an urgent batch to be process. The users then can test the disruption of prioritise orders going through the system and how quickly can they complete the order.

Automated data collection and tracking of parts are recommended in the new plant of the manufacturing system. Bar code scans, controllers and RFID are among tools that are suggested that would benefit maintaining the accuracy of data collection for better planning and control.

An operational model framework for the plant is proposed in Figure 6.37. The operational model suggests online update and collection of the shop floor material flow status to the computer using intelligent data capture. Bar codes could be attached to trolleys. Receivers or scanners are set up on strategic points in the shop floor to trace the movement of batches. These strategic points could be before each process or before and after a bottleneck process.

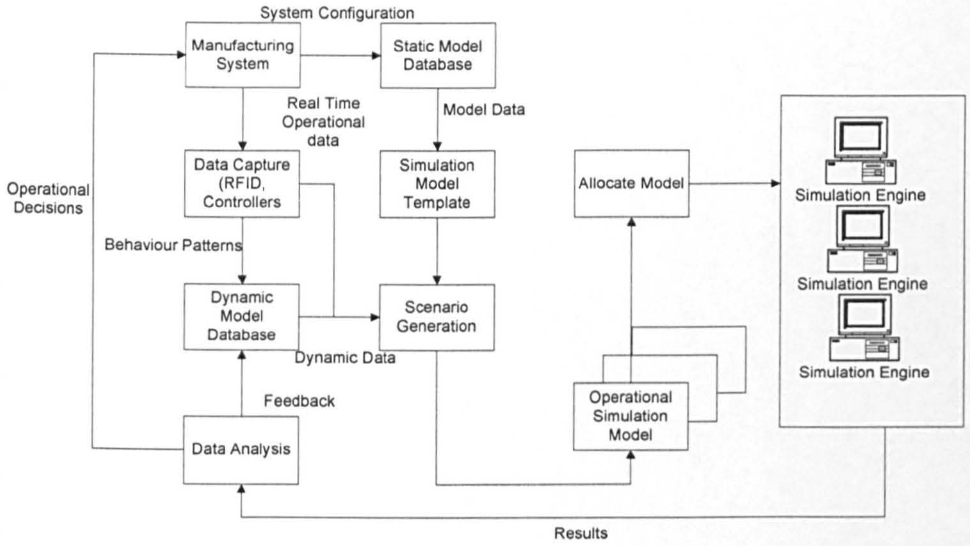


Figure 6.37 Proposed Operational Model Framework

These data are used to update the simulation model operational parameters. The production time line diagram generated from the simulation model implies that any small changes to the demand, product configuration, labour distribution or routes have large effect to the production. The current collection of output result and display with a production timeline format and trolley numbers graph is what the RFID methods will be displaying. The production time line and the ranges of the trolleys number based on the real life system enhance monitoring and planning control. These data updates the changes in machine performances (e.g. cycle times, downtime and breakdown times of the operations) and system performance (e.g. lead time, work in progress and trolleys movements). When these data derailed too much, it prompts the user review the simulation model if the model required to be structural modified.

Due to the size of the model, the speed of getting a wide range of results is limited. This can be solved with distributing the problem to multiple simulation engines. Modern computing hardware with reasonable memory and speed are able to run the simulation model for a year production in 4 hours approximately. Therefore for an operational model, the simulation time would probably be less, (from a shift to a month). With a cluster of computers dedicated for the simulation, a wide range of scenarios can be tested and results generated in a matters of minutes. Results from the experiments can then be used as decision making support tool.

Chapter 7 Data Driven Reconfigurable Model

This chapter starts by detailing the design of a relational database with Object-oriented approach for Chapter 6 Automotive Plant case study (Case Study 4). The use case and user interface, relationship tables, forms and the functionality, tables, macro and queries are explained. The chapter then concludes with using database to reconfigure parameters for the simulation model experiments.

7.1 System Requirement

The main task in the second stage of the case study project is to reconfigure the simulation model data with database and excel integration to enhance the decision support system for handling changes to demand patterns, product mix, planned downtimes, routes and allocation of resources. An overview of how the system components are linked is shown in Figure 7.1. In the initial study the design of Excel spreadsheets are used in Chapter 6 (refer to Appendix F) as the main source of data for the simulation model. In the new design the user input data through the user interface into the database and the database generates the excel spreadsheet to feed into the simulation model.

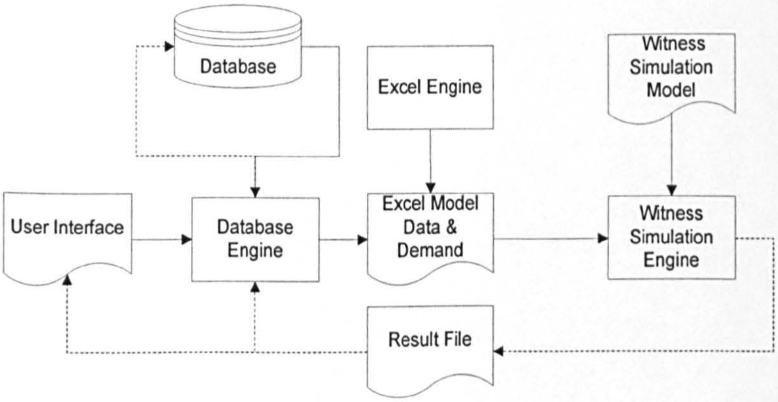


Figure 7.1 System Architecture

The current data structure is based on a Microsoft excel workbook. Microsoft Access is used to create a database to generate the required worksheets in a workbook form to feed into the simulation model. Using OLE(Object Linking and Embedding) objects in Windows and Microsoft Office products (Excel, Word, PowerPoint and Outlook), one can extend Access's ability in incorporate viewable objects of these Microsoft products-without the need to copy the actual data already included in these products without the need to duplicate the information. By using OLE, one can actually change the information in the underlying form object (Excel, Words, etc.). Hence creating the database in Access allows the users to extend the capabilities of their existing data in Microsoft products like words and excel into Access. Access has a complete set of tools for end-user database management. Access has a table creator, a form designer, a query manager, a Data Access page Creator and a Report Writer. Access also offers a powerful environment for developing compete database applications. Hence Access was chosen to house all the data and as the user interface to be integrated as part of the project.

The data structure has to be kept consistent and errors of data input and modification should be minimised. Data integrity plays an important role in ensuring the output results are valid. The database users are identified under three categories with different level of access to the data. They are the developer, who can change the data and the database design; system administrator, who have authority to modify all data but not the database structure; and end users, who use the database to generate the excel spreadsheets.

7.2 Use Cases

A number of tools were used to extend this project. The first step is the use of a mind map to identify and create "use case" scenarios. The main motives of accessing the data are created as the main functions. The two diagrams below: Figure 7.2 and Figure 7.3, each providing different views and information.

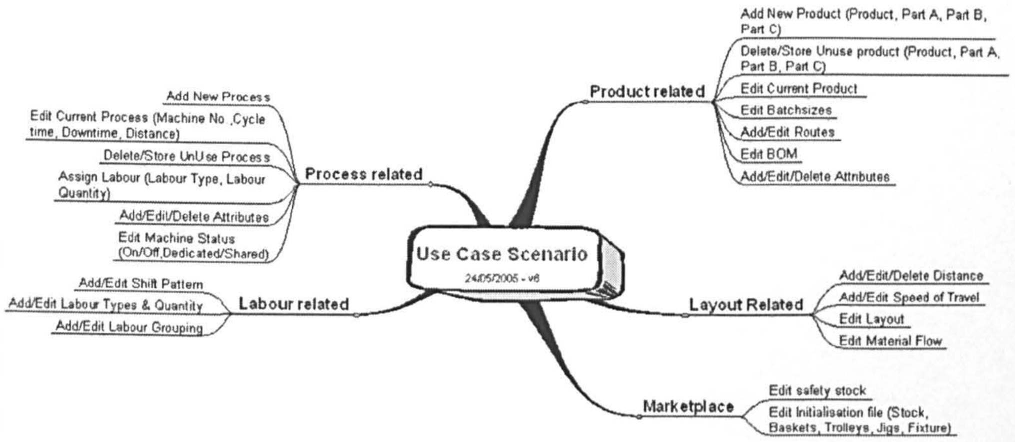


Figure 7.2 Mindmap of the Use Case Scenario for the Database

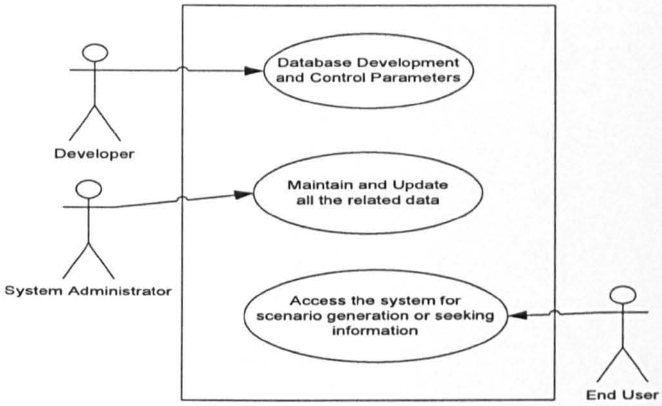


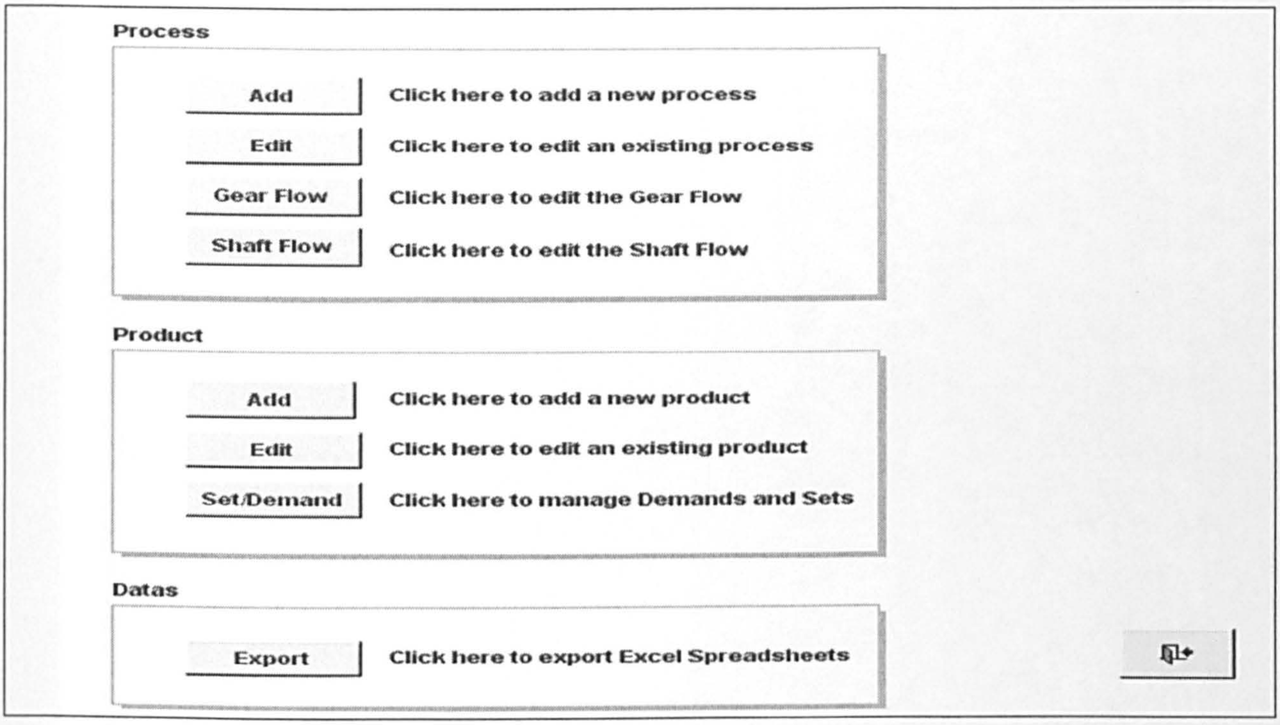
Figure 7.3 Top Level Use Case Diagram of Users

Use case diagrams depict how user uses the system function. Use cases represent the actions carried out by the systems; the actors who represent the users or other systems that interact with the system being modelled. Use case diagrams are supported by behaviour specifications, which define the interactions within a particular use case.

The use case diagram in Figure 7.3 considered all the user of the system. The system developer requires full access to all data and has full abilities to modify the database structure. Other users like managers and engineers have controlled access to the data according to their responsibilities in the project.

7.3 User Interface

The switchboard in Figure 7.4 is the main form of the database. The switchboard is created as the first interface for ease of data control and access to all the functions provided in the database.



Process

Add — Click here to add a new process

Edit — Click here to edit an existing process

Gear Flow — Click here to edit the Gear Flow

Shaft Flow — Click here to edit the Shaft Flow

Product

Add — Click here to add a new product

Edit — Click here to edit an existing product

Set/Demand — Click here to manage Demands and Sets

Datas

Export — Click here to export Excel Spreadsheets

Figure 7.4 Database Switchboard

From this form, the user can access the main functions:

- Add and edit a process,
- Edit the component flow,
- Add and edit a product and Bill Of Material (BOM),
- Edit sets and demands in terms of weekly demand.
- Export the data to Excel spreadsheets for data input to simulation model.

The switchboard is divided in three categories: process, product and export data. The switchboard is the main link to the other forms with associated macros to open and close forms and save data to the database. The buttons on the switchboard create the action pre-programmed with macros. Figure 7.5 shows a tree structure describing the links between the various forms used in the case study. Secondary forms (i.e. add a new downtime, add new machine type, add new derivative, etc.) which can be access only from the main forms are also shown in the tree structure. The details of the switchboard form are shown in Table 7.1.

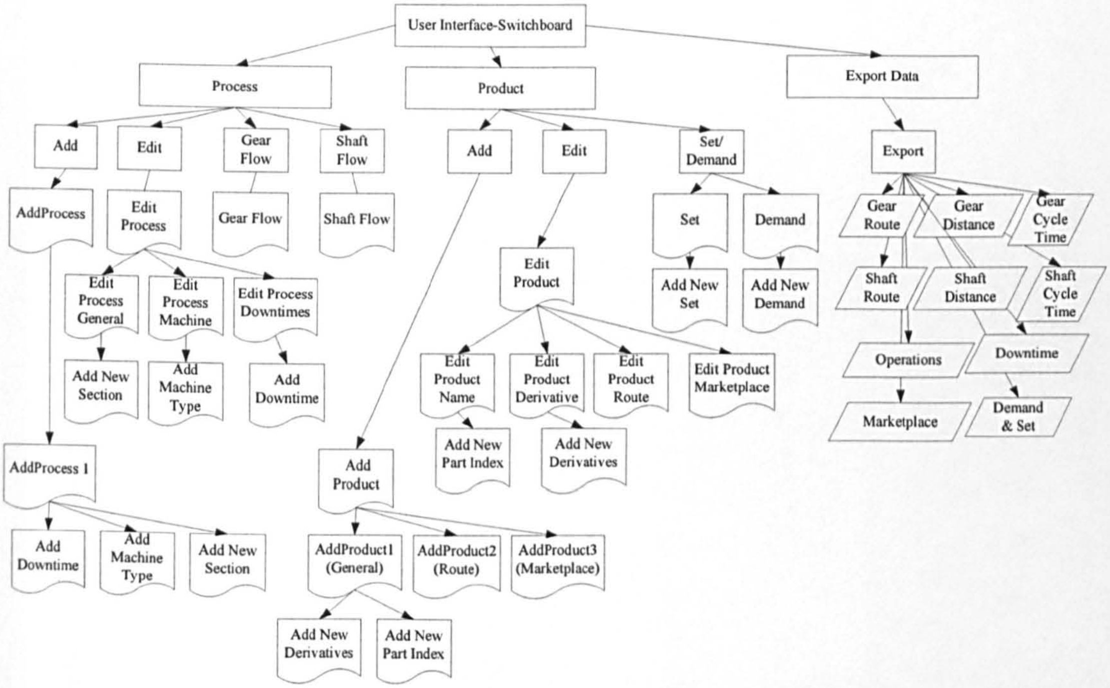


Figure 7.5 **Tree Structure of Connection of Forms for User Interface**

Source	None
Subform	None
Buttons (Macros)	OpenAddProcess, OpenEditProcess, EditGearFlow, EditShaftFlow, OpenAddProduct, OpenEditProduct, OpenDemand/Set, OpenExportSwitchboard, Quit.
Code VBA	None

Table 7.1 **Details of Switchboard Form**

7.4 Relationship

The design of the relational database was influenced by the Object-oriented approach. The tables shown in the relationship table shown in Figure 7.6 are self-contained although all linked with relationship.

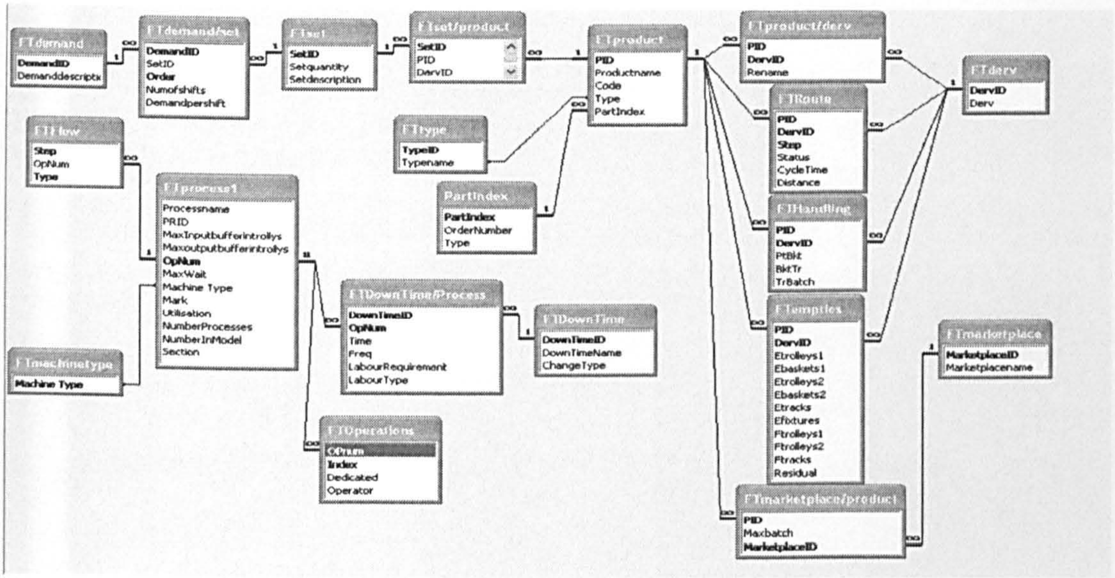


Figure 7.6 Relationship Table

All the tables could easily be modified to suit another application in the same industry though they are not entirely generic. When linked, the tables act as a single table, which one can view and manipulate the data with queries. One can select specific fields, define the sorting orders, created calculated expressions, and enter criteria to select desired records. The results of a query can be displayed and used in a datasheet, form, or report. Primary key is an important parameter that must be designed carefully for data integration and ease of search for compiling the reports and the excel spreadsheet. The details of the table will be illustrated in the following section in 7.5.

7.5 Tables

Tables are created following the functionality of the classes and are shown in Figure 7.7.

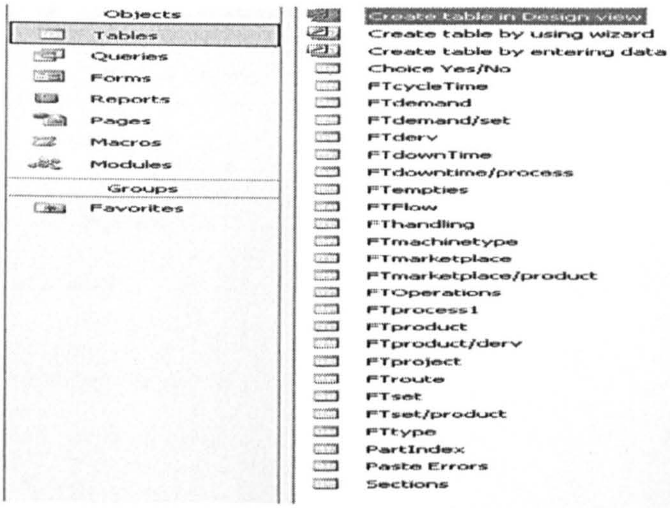


Figure 7.7 Tables Created for this Application

The manufacturing system contains the following categories of data: process, product, set, demand, downtimes, route, marketplace, etc. All data are entered through forms linked to their relevant tables. These tables held all the records of data. Details of tables are described and illustrated in Appendix H.

7.6 Forms and Procedures

Data entry forms including all main forms and sub-forms are shown in Figure 7.8. If the user decides to add a process, besides the process details like name, the other related issues like cycle time, and downtime form are trigger for the user to fill in the relevant information. Labels, text data fields, option buttons, tab controls, check boxes, colours, pictures, graphs, sub-forms, or sub-reports can be added to forms and reports. In addition to that, the developer has complete control over the style and presentation of data in a form or report. Forms can have multiple pages; reports can have many levels of groupings and totals. All forms are explained in Appendix H.

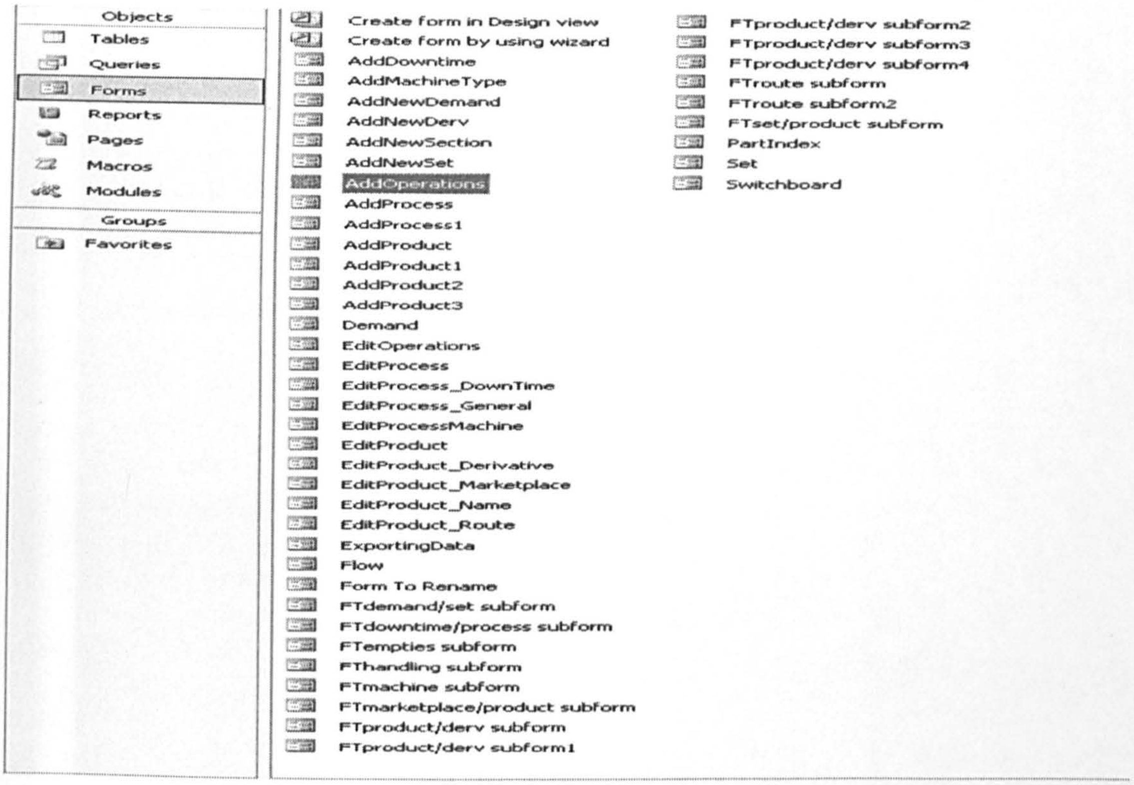
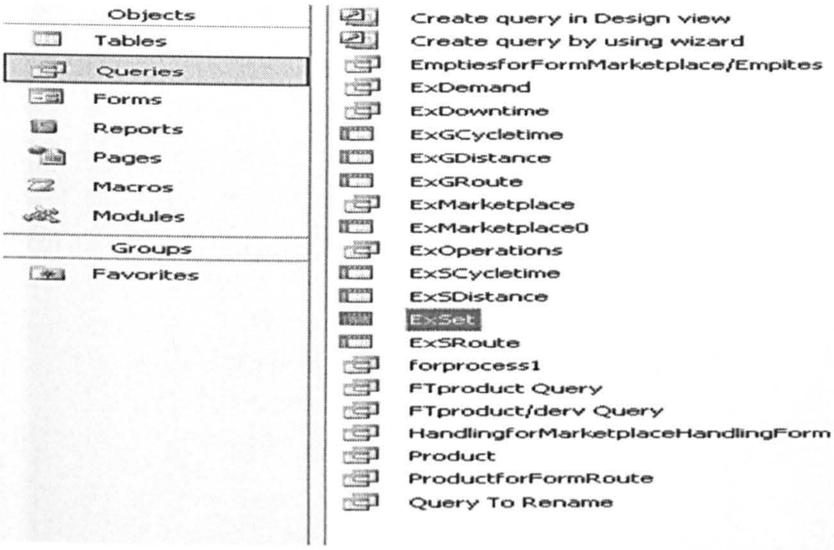


Figure 7.8 Forms Developed for this Application

7.7 Queries

Queries are programmed to do a particular function to request the relevance data. Queries can be created to calculate totals and display cross-tabs and then create new tables from the results. One can also use a query to update data in tables, delete records or append one table. Example of queries for this database is illustrated in 0. In this project, queries are particularly used in compiling the data to be exported to the excel spreadsheets.

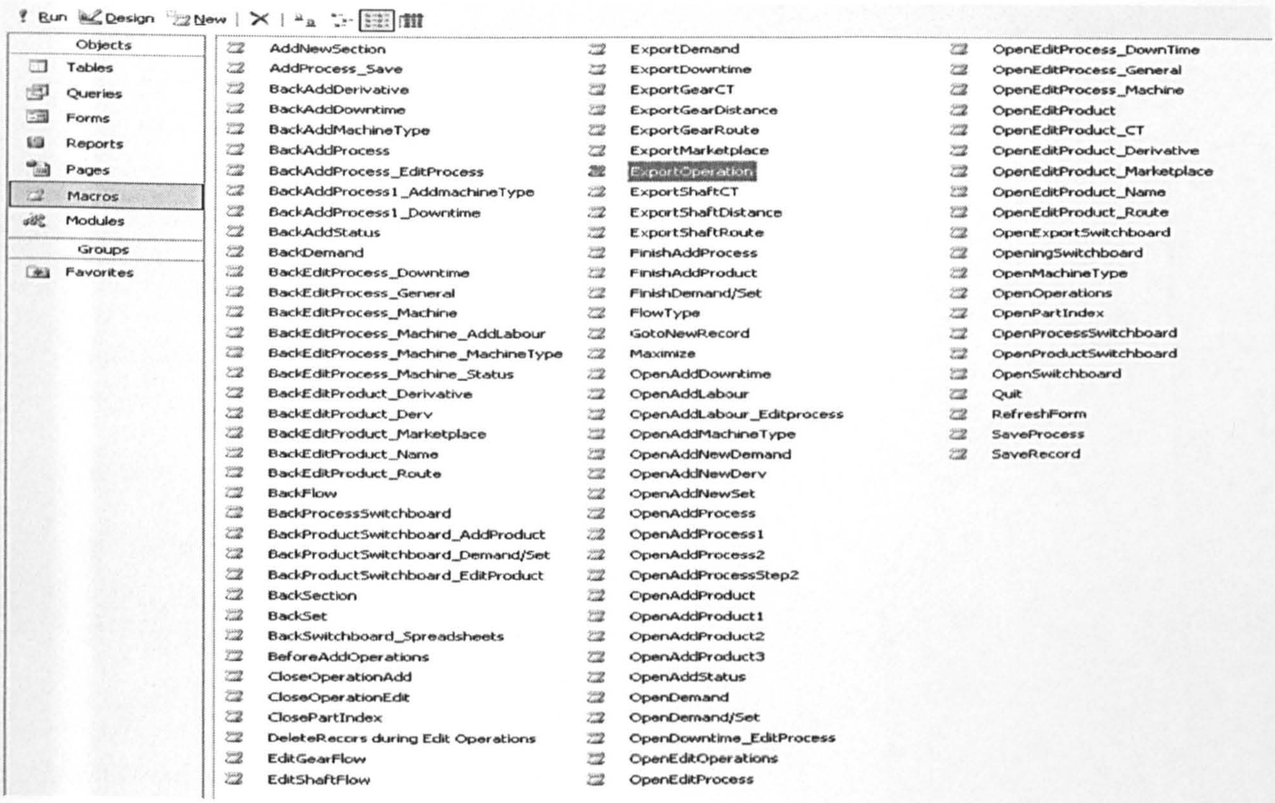


Create query in Design view
Create query by using wizard
EmptiesforFormMarketplace/Empites
ExDemand
ExDowntime
ExGCycletime
ExGDistance
ExGRoute
ExMarketplace
ExMarketplace0
ExOperations
ExSCycletime
ExSDistance
ExSet
ExSRoute
forprocess1
FTproduct Query
FTproduct/derv Query
HandlingforMarketplaceHandlingForm
Product
ProductforFormRoute
Query To Rename

Figure 7.9 List of Queries

7.8 Macros

A number of macros are created to automate many functions. Most frequent used macros are to open and close forms. Macros and VBA codes are used to export the temporary reports generated by queries to the excel spreadsheet. Most of these macros are flexible and can be re-used for other databases with modification. The list in Figure 7.10 shows the extent of pre-programmed macros required even for this database. Detail codes of the macros are displayed in Appendix H.



AddNewSection
AddProcess_Save
BackAddDerivative
BackAddDowntime
BackAddMachineType
BackAddProcess
BackAddProcess_EditProcess
BackAddProcess1_AddmachineType
BackAddProcess1_Downtime
BackAddStatus
BackDemand
BackEditProcess_Downtime
BackEditProcess_General
BackEditProcess_Machine
BackEditProcess_Machine_AddLabour
BackEditProcess_Machine_MachineType
BackEditProcess_Machine_Status
BackEditProduct_Derivative
BackEditProduct_Derv
BackEditProduct_Marketplace
BackEditProduct_Name
BackEditProduct_Route
BackFlow
BackProcessSwitchboard
BackProductSwitchboard_AddProduct
BackProductSwitchboard_Demand/Set
BackProductSwitchboard_EditProduct
BackSection
BackSet
BackSwitchboard_Spreadsheets
BeforeAddOperations
CloseOperationAdd
CloseOperationEdit
ClosePartIndex
DeleteRecors during Edit Operations
EditGearFlow
EditShaftFlow
ExportDemand
ExportDowntime
ExportGearCT
ExportGearDistance
ExportGearRoute
ExportMarketplace
ExportOperation
ExportShaftCT
ExportShaftDistance
ExportShaftRoute
FinishAddProcess
FinishAddProduct
FinishDemand/Set
FlowType
GotoNewRecord
Maximize
OpenAddDowntime
OpenAddLabour
OpenAddLabour_Editprocess
OpenAddMachineType
OpenAddNewDemand
OpenAddNewDerv
OpenAddNewSet
OpenAddProcess
OpenAddProcess1
OpenAddProcess2
OpenAddProcessStep2
OpenAddProduct
OpenAddProduct1
OpenAddProduct2
OpenAddProduct3
OpenAddStatus
OpenDemand
OpenDemand/Set
OpenDowntime_EditProcess
OpenEditOperations
OpenEditProcess
OpenEditProcess_DownTime
OpenEditProcess_General
OpenEditProcess_Machine
OpenEditProduct
OpenEditProduct_CT
OpenEditProduct_Derivative
OpenEditProduct_Marketplace
OpenEditProduct_Name
OpenEditProduct_Route
OpenExportSwitchboard
OpeningSwitchboard
OpenMachineType
OpenOperations
OpenPartIndex
OpenProcessSwitchboard
OpenProductSwitchboard
OpenSwitchboard
Quit
RefreshForm
SaveProcess
SaveRecord

Figure 7.10 List of macros

7.9 Excel Spreadsheets

After the export button is selected by the users, 12 worksheets compiled from various tables are sent to a pre-defined path as one workbook. This process is shown in Figure 7.11.

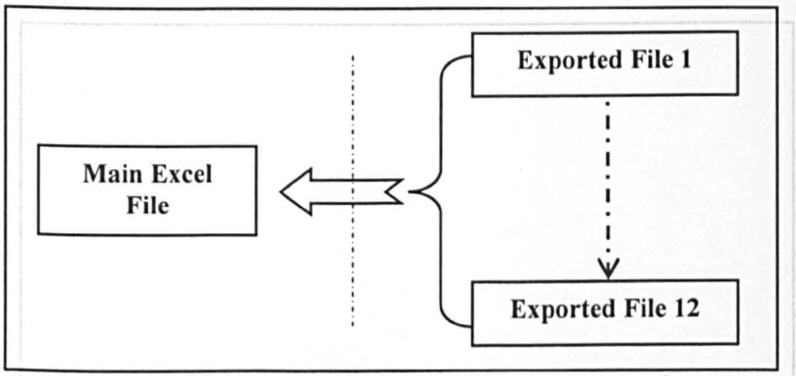


Figure 7.11 Excel Files Framework

The following list is the description of each worksheet:

Name	Description
ExGRoute	Gear Routes
ExGDistance	Gear Distances
ExGCycletime	Gear Cycle Time
ExSRoute	Shaft Routes

ExSDistance	Shaft Distances
ExSCycletime	Shaft Cycle Time
ExOperations	Operations with dedicated machine or not
ExOperations2	Operations with Labour Type
ExSet	Sets details
ExDemand	Demands Pattern and properties
ExDowntime	Downtime Details
Exmarketplace	Marketplace Information

Table 7.2 Excel Spreadsheet List and Description

7.10 Data Driven Modular Design

From the data collection, the manufacturing elements are classified according to the object-oriented UML class diagram approach. These general classes are shown in Figure 7.12. The data collected are entered into the database. The tables and forms in the database are also design with object-oriented approach. The tables which contain the data are design to be self-contained. The relationship of these tables is important to ensure the search of any elements is accurate and easily performed with the primary key defined in each table. The forms are designed to ensure the process of data input is error-proof, user-friendly, simple and quick.

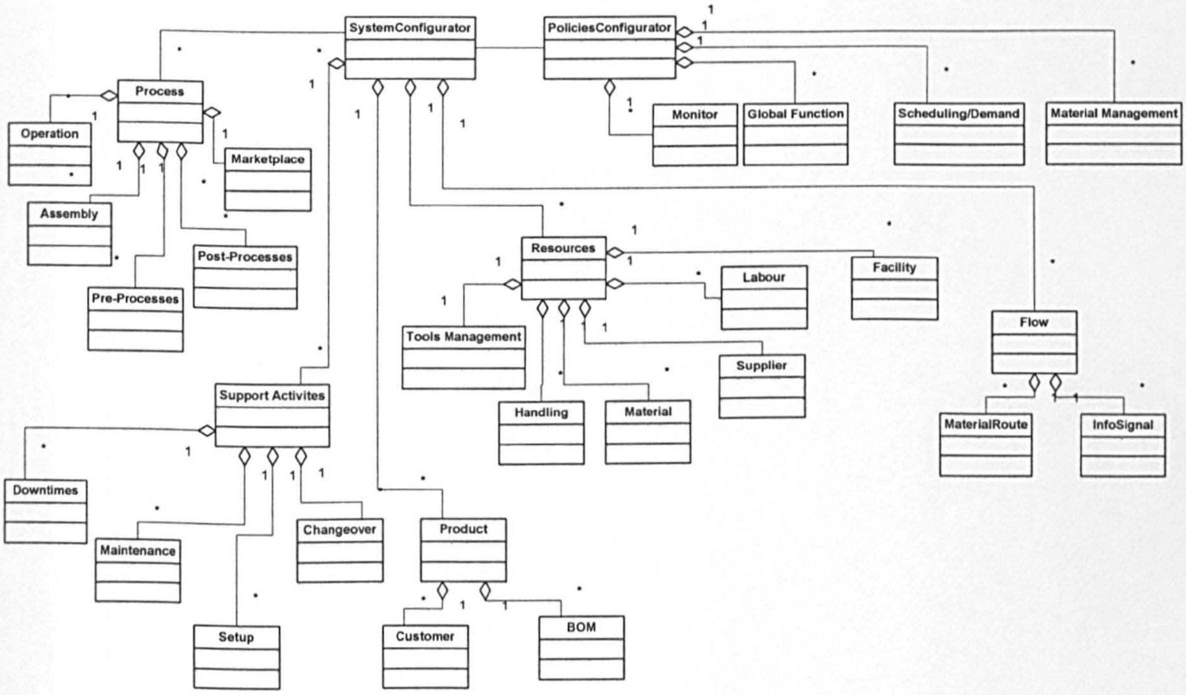


Figure 7.12 General Class Diagram in a Manufacturing Environment

The example of a machine class describe with the object-oriented UML approach is shown in Figure 7.13. An example of the elements and design of a machine in the simulation model is also provided in Figure 7.14.

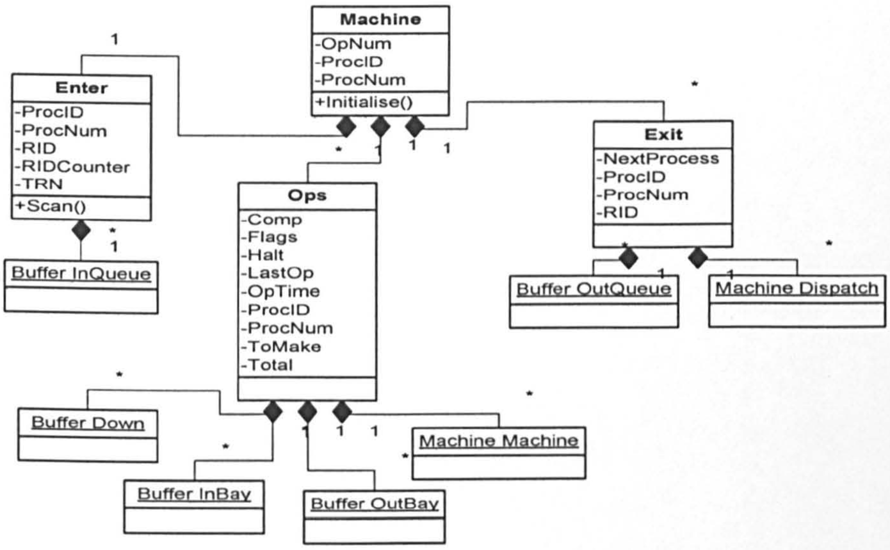


Figure 7.13 UML Class Diagram of A Machine

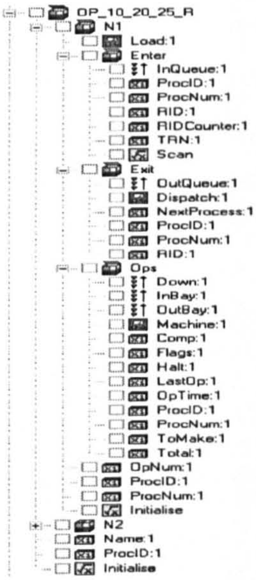


Figure 7.14 Machine Properties in Simulation Model

In the database, the machine data are entered into the FT Process 1 table, FT machine type table, FT flow table and FT operations table as shown in the relationship table in Figure 7.15.

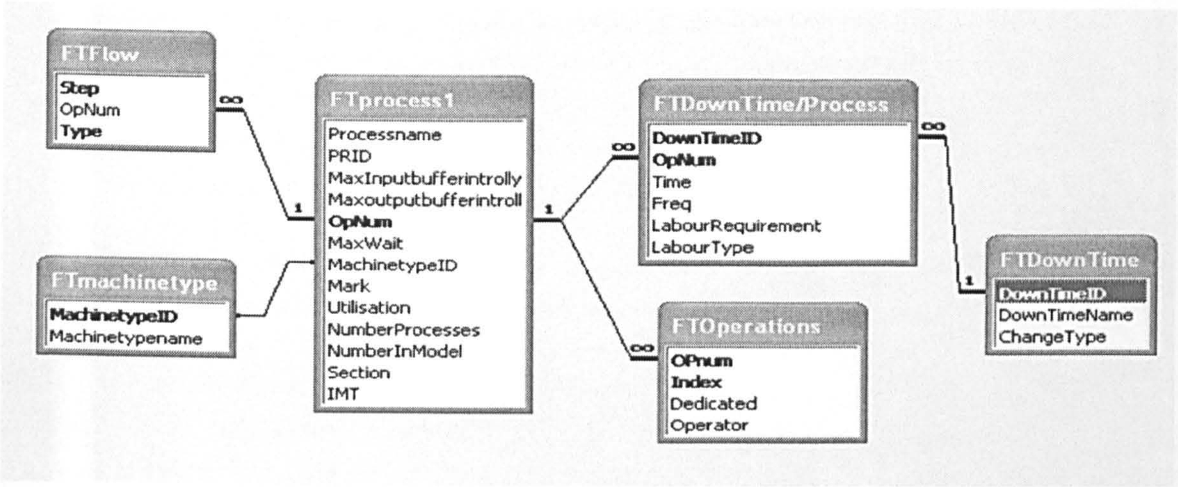


Figure 7.15 Relationship Table

The flow of the process are determined by the process ID (OpNum), the step of the process in the process plan is stored in the route table with the type of the product (i.e. Gear or Shaft).Data entered into FT Process 1 are detail information of the process. Other relevant machine data like downtimes are entered into the FT downtime table. There is a connecting table of FT downtime/Process which shares the connection attributes between processes and downtimes.

Forms are designed using various sub- forms to enter data about machine into a number of tables. For example, for the process section shown in Figure 7.16, the Add Process 1 form is linked to 'add machine type' form, and 'add downtimes' form. The data entered into the 'add machine type' form are entered into 'FT machine type' table. And the data entered into the add downtimes form are entered into 'FT downtime' table.

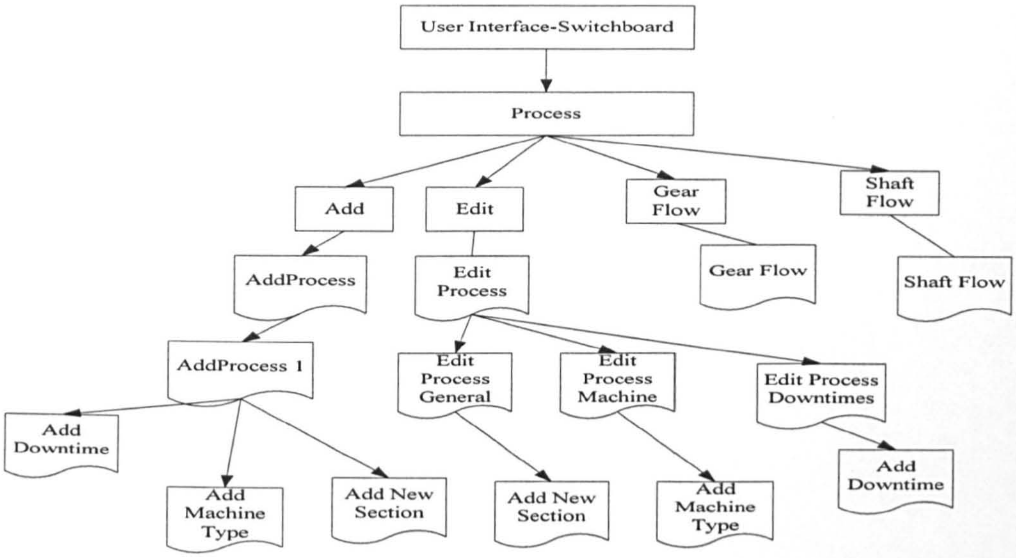


Figure 7.16 Tree Structure of Process Forms and Sub-Forms

As an example, in the gear cycle time Excel spreadsheet, besides the cycle time of each product in each process, there are elements like machine name, the process ID (OpNum), the number of machines for that process, the step of the process in the route table, the product ID, the derivatives for each product, and the total number of steps for each product which are displayed in the spreadsheet to provide a clear understanding of the data structure for the users. Queries are used to combine data from various tables into one worksheet, and a macro is used to provide the data display format.

7.11 Conclusion

Elements of the manufacturing system are classified with object-oriented approach proposed in Chapter 3. The object-oriented classification approach is continued in the database design. The database is created to reduce error in data recording, and unlimited multi-dimensional data can be stored for the case study of Chapter 6. The flexibility and representation of data of the excel spreadsheet is limited. When the simulation model required more complex input data the excel spreadsheet struggle to represent the more than 2 dimensional data. The database design proposed can be easily modified for another simulation modelling project in similar manufacturing environment using the same object-oriented modular approach of classifying the manufacturing system elements. Hence it is reusable and reconfigurable though not entirely generic. Scenarios can be easily reconfigured for experimentation in the simulation model. Developers or system administrator will not need to deal with endless numbers of worksheets to reconfigure the parameters for experimentation.

Chapter 8 Integrated Proposed Framework

Manufacturing environment usually encompass large number of components. The complexities of the manufacturing systems make optimum planning and controlling effort difficult to achieve. This chapter describes an integrated framework which is an extension of the framework proposed in Chapter 1. This framework explores many current and emerging technologies to deliver an integrated platform for developing and implementing manufacturing simulation models. The difference between this integrated framework and the front end framework in Chapter 1 is that this integrated framework aimed to provide realistic possible models that have the potential to be used as an operational tool to support operational decision making.

8.1 Modelling issues of manufacturing systems

The complex nature of manufacturing systems coupled with large number of possible options available to systems designers, increases the effort required to model and improving the system performance. Modelling a manufacturing system with different aims and purposes raises a number of issues:

- Most simulation model are created as a one off model for designing purpose, changes to address dynamic system behaviour is difficult;
- In these one off models, data collection is usually designed as a stand alone or one off process. The data collection is not connected to existing computing system of the company. The simulation model is not embedded with real life or flexible data input. Simulation models easily become obsolete as development continues in the manufacturing system;
- Sometimes, many different individual simulation models are created for different projects in a company. All these models are in the same manufacturing system,

components may be the same, but due to different developers and no communication, reproduction waste enormous time and effort;

- Large complicated simulation model require large processing time for a number of different scenarios to be experiment. Hence the huge experimentation time made the testing prohibitive and impractical;
- Simulation modelling projects require expertise and knowledge that are not easily found in house. Outside consultation involved large investment and time for the project to be successful which made many company reconsider the option.

Besides the reluctance to carry out simulation modelling projects, these problems result in duplicating modelling efforts and mismatches among modelling outputs, which limit manufacturing system integration. These issues motivate the development of an integrated modelling framework, which allows a unified representation of the manufacturing system with a physical material focus as well as a control data focus to support both information management and operations improvement. The proposed concept can be utilised by practitioners for developing large complex simulation model for exploring changes with wide impact on a manufacturing system.

In this manner, the model can serve as a tool for change management. With the current approaches and technologies, simulating a large complex model can take a long time for a single run even with large computing powers. The implementation of large complex simulation model necessitates the development of approaches that exploit current and emerging technologies to allow such simulations to be executed in a reasonable amount of time. Grid technologies seem to provide the answer to seamless computing power to run the models for a given range of scenarios and provide the optimised answer in shorter time span. Exploration of experimenting simulation models of manufacturing system with Grid technologies has yet to happen commercially. And if a company could experiment their simulation model hosted and maintained by a service provider with access to simulation engines and grid based technology with a reasonable fee, the last issue stated above can be addressed.

8.2 Proposed Front End Framework

The review of literature has highlighted the necessity and significance of object oriented approach process mapping techniques especially applying it to the area of manufacturing studies. The use of UML approaches, which are neutral and scalable to describe the complicated system environments for simulation modelling project was also suggested. However, the literature generally does not address adequately 'what should be process mapped?', 'how exactly the process mapping should be carried out?' and to what level of detail they should be mapped. Having recognised these limitations in the literature, a research project has been initiated to address these research questions.

This research developed an approach to process map a manufacturing system to form a set of best practice templates that can easily be reconfigured and expanded to fit different manufacturing system as the front end. It also needs to integrate with simulation modelling tools. The architecture is used to carry out a series of simulations from several perspectives such as resource allocation, material requirement planning and rescheduling. The proposed front end framework is illustrated in Figure 8.1. This framework suggested how a manufacturing system should be represented before translating into a simulation model. The framework enabled object-oriented process mapping approach with UML diagrams to be used to create modular design of simulation model. Experimentation with scenarios generation to achieve desired results is discussed. The proposed front end framework is discussed in detail in Chapter 1.

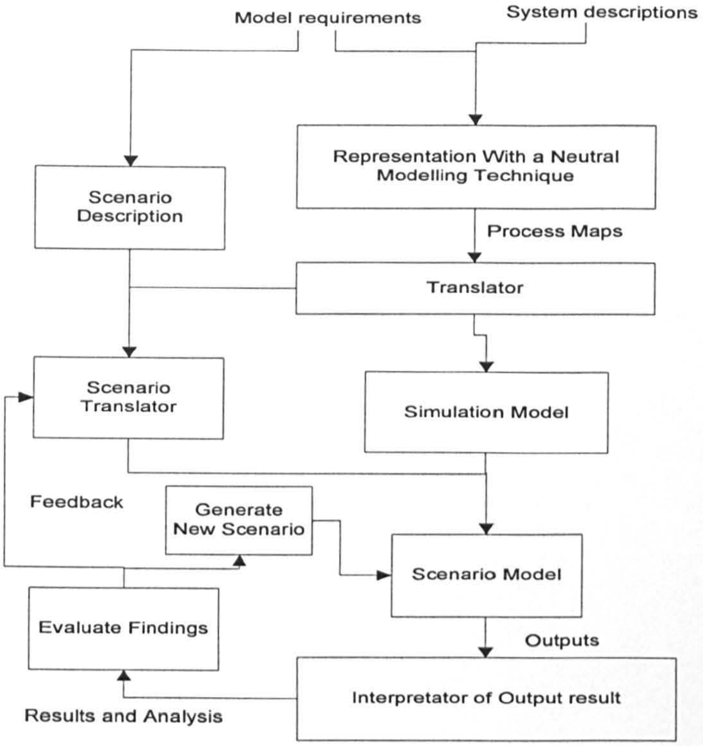


Figure 8.1 Proposed Front End Framework

8.3 Integrated Proposed Framework

Learning from the experiences of the case studies and the knowledge from the research, the development framework proposed from Chapter 1 are extended. Extending from this front end framework, a complete architecture embedding more functions is proposed at the end of this research as the next step to move ahead. The full proposed framework for the development and optimisation of simulation models in manufacturing environments is presented in Figure 8.2. It comprises of a number of components that include UML system developer user interface for process mapping, modular design of simulation model with best practise templates, and a translator from UML diagrams to XML language. This translator then feeds the XML data into simulation models. The translator in a neutral platform enables the user interface to work with various simulation packages, simulation engines/packages. Experimentation with optimisation process and data-processing/accessing/storage are also important areas to be developed and explored.

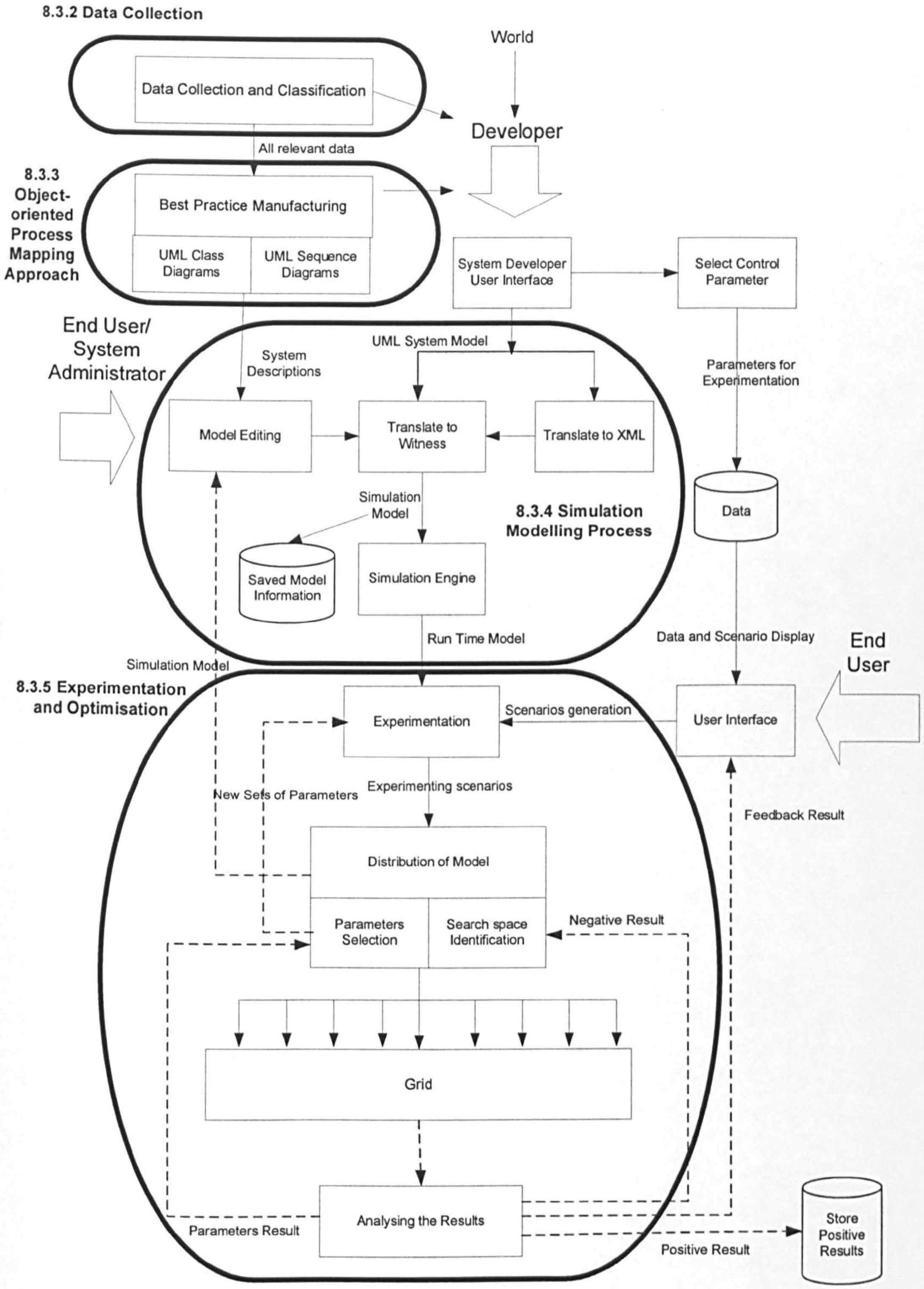


Figure 8.2 Integrated Proposed Framework System Architecture

8.3.1 User Interface and Data Storage

There are a number of entry points in this framework for three different types of users: developer, end user and system administrator. These provide control over the level of access and the amount of information displayed.

- The first type is the developer of the simulation project. He identifies system requirement and develops a detailed model to meet the requirement. The developer selects important control parameters for the user interface to enable the end user to experiment with the model.
- The second type of user is the end users, who have access to experiment with the simulation model and change scenarios and data. He can only test different scenarios with the parameters provided in the database.
- A higher level end user, e.g. managers and system administrators are able to reconfigure the simulation model and have access to modify data, which form the third type of users.

The control parameters are stored and displayed in a database system. The number of the control parameters, the types of the experimentation and the number of end users are important criteria to what type of database system would be suitable. Data could be stored in a local database but if required the system could be implemented with a SQL server and web interface for multi-user access.

8.3.2 Data Collection

Data collection and classification is a stage after identifying the type and boundaries of the model but before the process mapping and simulation modelling work starts. Data collection at the front end is normally the cause of most delays in the simulation modelling projects. The general requirements of information and communication architecture are high accessibility by all involved in the projects, reliability in system and infrastructure, scalability to expand and reconfigure and openness in information and development. In the proposed approach a questionnaire is designed (explained in Chapter 5) that covers a wide range of manufacturing system characteristics and attributes. The data covers both manufacturing entity attributes as well as the rules for material and information flow. The data collected are filtered and classified accordingly. These data are then translated into the UML diagrams. For existing system these will include existing data and future scenarios. For new system these data include concept designs and possible configuration of the systems.

8.3.3 Object Oriented Process Mapping Approach

Object-oriented (O-O) approaches are adopted in defining the manufacturing system with multiple views of UML diagrams. Developers start by conceptually and visually describing the system layouts. One can start designing the system with UML diagrams which are flexible and user friendly. Another easier way would be to define the manufacturing element in the general UML class diagram. This would enable the developer to classify the elements in a structured manner. Best Practice Manufacturing philosophies that influence the design of manufacturing system templates in UML sequence diagram and activity diagram can be pulled out from the library. It covers a collection of template of different systems that can be customised specifically to the system needs. The UML system model is then translated into the simulation package. The library of UML sequence diagram which describes various different manufacturing systems provides the process mapping techniques for users to configure and customise. The library of manufacturing elements proposed in the modular design in simulation modelling for example the machine type, acts like a simulation modelling catalogue. It plays a key role in interactive modelling. It is desirable for modellers to have a centralised catalogue of reusable models' component.

The templates are an ongoing collection of different manufacturing system components or use cases from simulation modelling projects with company from different industries.

8.3.4 Simulation Modelling Process

From the process description in a UML format, the process maps are translates into creating the simulation model. At this stage, an expert carries out the translation work. An automated middleware which could translate the UML diagram to XML and independent of any simulation package would be ideal in future work. Most simulation model can read XML files. And UML can easily be translated into XML. Hence the connection can be performed. Elements are defined and detailed in the simulation model by the experts based on the UML diagrams. After the simulation model is created, many corrections and modification iteration are performed before it reflects the manufacturing system. It is subsequently stored in the database.

Changes to the simulation model can be performed by the system administrator and end users through the database. Model editing can also involve starting from the UML diagrams level as well. The simulation engine of the simulation package runs the experimentation on the simulation model. Version control on the simulation model must be controlled with the various users' access levels.

8.3.5 Experimentation and Optimisation

Simulation models enable system developers to experiments with alternative scenarios to identify optimum parameters and configuration for operating the system. In effect a simulation model is only a test bed for experiments and not an optimiser. The system and complexity of large manufacturing system where the number of possible parameters and configurations are large poses a barrier to model and system development. For modellers, the challenge is to construct a model when all possible parameters and scenarios are accessible and easy to change.

The challenge for the system developer is to develop a series of experiments which can help identifying the optimum system configuration. They are basically two types of experiments.

- The first type involves a change in the value of a system parameter or quantities of system entities. For example cycle time, downtimes, number of machine or operations.
- The second type of experiments involves changes to the model logic such as material flow rules, sequence of operations and prioritisation of processes.

In the first case the optimisation is a process of traversing the search space to identifying the optimum set of parameters. Various optimisation techniques are available for these types of problem. They range from brute force search technique where all possible combinations are tested to evolutionary type techniques that iterate through generations of possible solutions. A range of parameters is tested and the result might contribute to another set of parameter which is fed back into the system. The system iterates until the optimum result that satisfies the user is found. Positive results are kept in a database for future reference. For the second type of experiment, until recently the methods available for finding optimal decisions have been unable to cope with the complexities and uncertainties posed by many real world problems of the form treated by simulation.

The complexities and uncertainties in real systems are the primary reason that simulation is often chosen as a basis for handling the decision problems associated with those systems. Consequently, decision makers must deal with the dilemma that many important types of real world optimization problems can only be treated by the use of simulation models, but once these problems are submitted to simulation there are no optimization methods that can adequately cope with them in a reasonable time frame.

If an objective function can be formulated then the problem can be addressed through iterative optimisation techniques as above. However if it is not possible to define an objective function then technique for reducing the possible number of experiments (e.g. Taguchi) are employed.

As the size and scope of the simulation models increase, the time required to run each experiment increases in turn. To find an optimal solution could involve running a large number of experiments. The time involved could be therefore prohibitive and not practical. For example, case study 4 model takes 4 hours to complete a full year's production. If the model is used as an operational tool for testing scenarios to adopt in a time frame of a week, then each test will require 10 minutes approximately. This limits the possible number of tests the users can carry out before the result are of practical use due to the change in the real life system or the time it takes to get the results.

To address this problem the use of either more powerful computers or to breakdown this experiments into sets that are run simultaneously on a number of computer. The latter involves the use of distributed computing or grid technology. In this case, a level of coordination is required in identifying the required test, allocating them to different computers, collating the results and selecting new parameters for further experimentation. The feasibility of local modelling and remote modelling should be considered in the integration process.

8.4 Proposed operational model framework

The integrated proposed framework illustrated in Figure 8.2 is intended for building a new simulation project or when major changes to the simulation model are required. The operational framework shown in Figure 8.3 is a subset of the full framework which focuses on the use of simulation modelling and experimentation for the purpose of supporting day to day operational decisions.

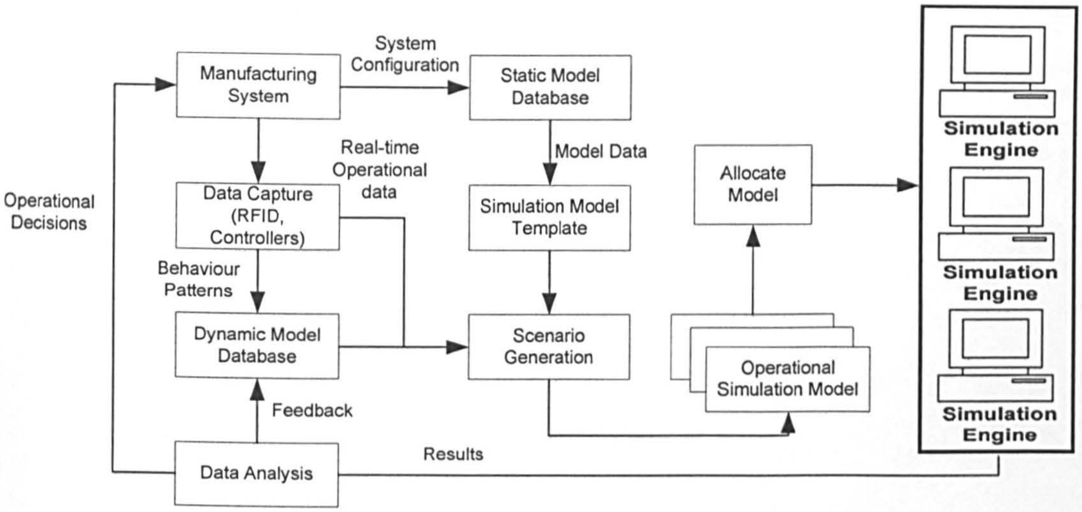


Figure 8.3 Proposed Operational Model Framework

This framework focuses on delivering an experimentation tool for operational personnel like the production managers and shop floor supervisor to test different scenarios and parameters before making any decision when a problem arises in a short span of time. An example of the situation is when a machine breaks down and product might require re-routing. The tool would enable the production manager to test the effect of this on the system over a week or two.

The framework consists the following key sections:

- The first is the simulation model section. It consists of a realistic model representing the real life system and control parameters. The model is supported by a library of best practise templates representing possible actions that a user can select to generate alternative scenarios.
- The second section involves the data capture and update of the simulation model. If the model is to be of any use as operational tool then it has to reflect the real life system. There are various types of data capture techniques in use at the moment. One of the tools that have emerged recently is RFID. Radio-frequency identification (RFID) has generated enormous amount of interest in the supply chain arena in recent years. RFID is an intelligent data capture tools if used appropriately and is feasible to implement in

the manufacturing environment. With RFID technology, inventory can be tracked more accurately in real time resulting in reduced processing time and labour. More significantly, the complete visibility of accurate inventory data throughout the entire manufacturing system, from manufacturer's raw material storage to shop floor and distribution, brings opportunities for improvement and transformation in various areas in a manufacturing system. The data collected can be used to find out patterns of the behaviour of the system. As machine get older, breakdowns and maintenance times can take longer. Collecting such information provides a more accurate representation of new machine behaviour in the model. All these patterns are stored in the dynamic model database for results analysis. If it is just simple system reconfiguration, changes in the parameters, the configuration data are fed into the static simulation model and with the variation of scenarios, experimentation are carried out.

- The third section is the optimiser/simulation engines. This is based on a distributed computing platform where each computer is allocated a subset of experiments to carry out. For larger organisation this could represent existing networks of PCs that are not fully utilised. Alternatively, there could be a cluster of PCs dedicated to the tasks. With the decrease in computing power costs such cluster are now affordable to many companies. A more affordable solution would be to use Grid based technology remotely on demand. This extends to developing a middleware that can submit simulation jobs to remote applications services provider with access to simulation engines as well as collate the results is a structure fashion.

The proposed framework is dependant on a number of technical and computing infrastructures being in place. Never the less, the advantages of real time simulation modelling that can provide timely results for decision support are considerable.

8.5 Summary

This chapter illustrates the integrated proposed framework which provides a more complete framework with the full requirements and services expected in a simulation projects. The research started realising the needs of a process mapping technique to describe manufacturing system for a simulation modelling project. The literature review identifies object-oriented approach using UML diagram a suitable tool. Data collection to feed the process mapping technique is important. Hence a structured data collection questionnaire is developed.

The integrated proposed framework starts with the data collection method proposed, all these data then are fed into the object oriented UML approach to process mapped the manufacturing system. Elements and behaviours of the manufacturing system are mapped with the UML diagrams. These data are then translated into the simulation model by the expert. The design of elements in the simulation model, with influences from the object-oriented UML description is design modularly. A library of modular design components are stored and can be easily customised to the specific needs of different manufacturing simulation models. Optimisation is critical to identify the optimum results, and identifying the suitable optimisation technique shortens the experimentation time and effort. The proposed operational framework is to create an operational simulation model instead of a one-off design and planning tool. Intelligent tools like RFID and controllers are to be explored to collect real life data online to reflect the manufacturing system. Distributed computing and grid based technology are suggested to reduce experimentation time in order to get the results in reasonable and practical time frame. The framework will realise its full potential as all components in the architecture are integrated.

Chapter 9 Conclusions and Future Work

After explaining and verifying the proposed methodologies with a framework and industrial case studies, this chapter discusses what has been achieved and proposed. An extensive literature review and suitable approaches are reviewed. The case studies are briefly summarised and the effects of the proposed methodologies on them is also explained. The last section in the research is the conclusion and some proposals for future research in this area.

9.1 Background

The literature has highlighted the benefits of adopting an object-oriented approach to process mapping. The concept is now slowly being incorporated in business process modelling but is still not that common in manufacturing system analysis. Standardisation of process mapping and modelling in the manufacturing sector is far behind compared to many industries such as software and business process modelling. As large amount of analysis is carried continually to improve the manufacturing system to produce high quality products with quick response to demand, a structured and standardised approach to process map the manufacturing system is needed. Simulation modelling is a valuable tool for studying the dynamic behaviour of manufacturing systems. In the literature review, many researchers have commented that the low usage of simulation modelling in the manufacturing sector are due to the need for high expertise in simulation modelling and also the high cost and time involved to get an operational simulation model that reflects the ever changing shop floor. Issues of investment cost and the time required to generate practical results can be solved with various solutions. If the simulation model can be hosted and maintained by an application service provider with access to simulation engines and preferably grid-based computing power, it is likely that companies could be encouraged to use these facilities for simulation modelling experimentation.

9.2 Description of the research

The proposed framework aims to process map the manufacturing environment/system with a set of best practice templates that can easily be reconfigured and scaled to suit different companies and integrate to a simulation model. With various levels of accessibility in the framework, security of data are also controlled and monitored. The framework supports and identifies deficiencies in the traditional approach of simulation modelling. The use of Object-oriented UML diagrams to describe the manufacturing system provides a better outcome. Developers can facilitate the model development with choices of design patterns to represent both the process and control mechanisms as well as information flow.

A data collection questionnaire was developed which covers a comprehensive range of data involved in a manufacturing environment. The proposed questionnaire provides a structured approach to collect data that are required for a simulation study. Collecting the right data for the study is time consuming and difficult for simulation experts who are not the manufacturing system expert and at the other end, the company experts do not entirely understand the data requirements needs in a simulation modelling project. Therefore by designing this questionnaire the user can provide the data required in a quick and comprehensive manner.

The UML representation diagrams like class diagram, sequence diagram, and swimlane (activity) diagram are easy to create and understand. They display information of the process being described clearly and in a standard fashion and consequently communication is made more efficient.

The modular approach in simulation modelling has proven to be slightly more time-consuming in constructing at the initial stage, but after the initial design of the components, the modification and traceability is less complex and fast. Modular design of elements in the manufacturing environment makes the classification of all components more structured and clear. The traditional approach of simulation modelling is to directly map the manufacturing system to the elements in the simulation package canvas without classifying the data, hence the representation is not always structured and in standardised manner. The data for each entity (machine, buffer, etc) specified individually. Although this approach allows the user to create the model quicker, the approach is not flexible, extendable, reconfigurable and reusable. Hence the new concept of modular design by continuing the object-oriented approach is proposed.

9.3 Case Studies

The first three case studies discussed in Chapter 4 and the final case study in Chapter 6 address three main points. The first was to explore the proposed framework in Chapter 1, creating the object-oriented UML process mapping for the manufacturing systems in the three case studies to validate its designs and limitations. The second was to apply the proposed methodology to the final case study for evaluation. This includes the data collection questionnaire approach, UML diagrams representation and modular design approach for simulation modelling in the manufacturing environment. The final aim was to evaluate the design and limitations of the proposed framework in Chapter 1 in an industrial context and to propose an integrated framework which facilitates all components, infrastructures and services required in a simulation project. This is discussed in chapter 8.

9.3.1 Case study 1 Evaluation

Case study 1 was an experimental case set in a beverage mixing production line. The case contributed towards one of the scenario for simulation modelling project, changeover effects on large mix product orders. The study scope is limited and specific to looking at one area of the manufacturing system problem. Other study issues like material requirement and replenishment, packaging speed are not analysed. The importance of data in this case study has contributed to start creating a questionnaire for the data collection process. Even though this is a simple manufacturing system, data regarding the operation and on changeover is critical for this project to be able to present a reasonable final result. This case study has allowed the proposed process mapping techniques to be experimented in one specific area to justify its function in a localised area without complicated data input and large report output. Although efforts in the case concentrated mostly on resolving the connection between Microsoft Excel and the simulation package, the case also contributed to the integration of using Excel spreadsheet into data input, storage, processing and displaying of the results.

This case study has demonstrated the importance of a user interface to the simulation model by which it can be easily controlled and maintained by non simulation modelling experts for scenario generation to decide daily operations or to support and enhance the decision making. The simulation model and the user interface, are both scalable for future development.

9.3.2 Case study 2 Evaluation

From the experience of modelling a simple manufacturing system and integrating with excel spreadsheet in the first case study; this case study looks at a larger system with more complicated workstations in a process-type manufacturing system. This case study analysed the synchronisation of a specific production process which share resources and facilities in a job shop type plant. The simulation model has provides a valuable demonstration of Just-in-Time philosophies to balance the manufacturing system. Good material and tools management in the shop floor contributed to the success of the system. Scheduling the right amount to the shop floor is critical in this study. Due to the uncertainties in one of the processes producing the required quality, some orders may be delayed costing the company high penalty cost. Although improvement have been made in the design of the products, defects still happens at times, hence more rigid control on other processes beside this process are required. Objective of the simulation model is to make sure that the approach of optimising the number of runs of moulds and lid is circulating in the shop floor and the rate which the system is balanced to ensure no bottleneck occur at any point. The simulation model has been used as a presentation tool to illustrate and explain the working of the material flow and allocation of operators to the workforce and management of the company. This simulation model showed the criticality and importance of synchronisation in a manufacturing system.

The manufacturing system has been process mapped with UML class and sequence diagrams. This case study validated the proposal that a class diagram can be used in a made-to-order process-type layout manufacturing system but the unclear definition of the manufacturing elements in the simulation model made the classification of the elements unclear. Sequence diagram are created to map the information control in the system, this simulation model had been created solely to monitor the material flow hence the information control is not shown.

9.3.3 Case study 3 Evaluation

The third case study is a simulation modelling project to propose a new semi-automated production line utilising existing machines for process performance improvement. The proposed design for this case study is a multiple workstations continuous production system. The final assembly machine dictates the pace of the production running in the whole line starting from the stapler assembly units. Demand files, process data and downtimes data are fed in with excel files. Downtimes in this case study has extended from just changeover to cover six different downtime activities which affect the workstations and require the operator to carry out different jobs. Due to that each order is customised, the product mix in this case study is high. Labour groupings and labour requirements are also put to test in this simulation model. One of the main aims of this new design is to reduce the number of operators. The controls that are placed in the simulation modelling on the conveyor and assembly machine are translated into the logic for the PLC in the real manufacturing system. The findings from the simulation model had proved that the new proposed system is feasible and provided good results. This project had also enabled the company to implement the idea in a structured manner and improved the success rate. The elements in the simulation model have been grouped into modules. Hence classification of the manufacturing elements in the class diagram is clear and easy. Some of the general properties can be taken out of each workstation and stored in one general control module. The operation of each workstation is process mapped with sequence diagrams to fully describe the rules and logic applied. This case study validated that the UML diagrams proposed are capable to describe a continuous production line of multi workstations.

9.3.4 Case study 4 Evaluation

The fourth case study revealed that the methodology was more than adequate at capturing most of the elements in manufacturing systems in a large manufacturing environment. This case study illustrated a large complex manufacturing system with a high number of machines and operators that requires re-configuring constantly due to changes and growth with time. The case study revealed that the data collection questionnaire was adequate to cover a large and complicated system project. The questionnaire has probed questions and thinking for the company to provide the required data to build the system they desired. The data collection task has been passed to the company expert and the process has been fast tracked and with better quality data. The UML approach has proved to be an efficient tool to use to represent the processes. They have provides extensive representation of the large system for understanding and presentation purposes.

The entire simulation model has been designed using the modular approach established. Although classifying the elements in the system and implementing this design required more time in the initial stage of the project, the overall time saving still out-weights the traditional approach. There is a significant reduction of development time and simulation experimentation time. Furthermore the simulation model can simulate a year's production in under 4 hours. Agility, scalability and flexibility are incorporated into the design of the entire system with a database as the user interface to facilitate the data and the modular design in the simulation model was developed. Data are collected and classified in a structured manner. The simulation model can be used as a training tool to display the operations and controls in a manufacturing system. This project is still on going. The simulation model built is still being up-dated to accommodate the changes in the project. Hence, this simulation model has achieved its aims to be continuously used in the project development planning and is also developed to be an operational tool for decision making.

9.3.5 Case Studies Summary

All the cases have contributed to satisfying the aims and objectives of this work and to validate the proposed methods in data collection questionnaires, UML object-oriented representation diagrams, and modular simulation modelling design approach. Each case has added a different set of skills, experience and elements that contributed to the next case. The first case study highlighted the importance of integrating simulation modelling tool with other tools, the second case study highlighted the power of simulation modelling tool for manufacturing process optimisation. The third case study showed the benefit of simulation modelling in new design proposed as well as the implementation process. And the fourth case study has demonstrated a full approach of modular design simulation model, with object-oriented representation of elements in class diagrams, and manufacturing system behaviours in sequence diagram and swimlane (activity) diagram. The exploration of using other software integrating to simulation model in case study 1 has lead to the use of a database to drive and control the data in case study 4. The integration process of simulation model/package to other software tools is expanding rapidly and requires computer languages expertise to bring the integration of component in the proposed framework together. A multi-tier approach is suggested with structured and error-proof data entry into a database, either creating the user interface from the database or using excel spreadsheet as a user interface, and import the data into the simulation model. Scenarios are configured through the user interface and results generated from the simulation model are displayed through the user interface.

9.4 Summary

The major concern that triggers this research is the difficulties and time-consuming activities in the development of a simulation modelling project specifically if models are to be reconfigurable. Aims and objectives set out in the introduction of this research (chapter one) focused on the front end operations of a simulation modelling project like data collection and process mapping before approaching the new modular design of a simulation model. Discussions in the subsequent chapters illustrated and explained the important building blocks; hence validating and quantifying the potential of the proposed framework. Each chapter has provided work that contributed to the knowledge areas highlighted in chapter one, through a sequential process that included tools and technology review, proposed framework, diagrams and case studies.

The review highlighted that simulation modelling is a valuable tool to improve manufacturing systems. The literature review also identifies the lack of standardisation of process mapping techniques in manufacturing environment. Besides that, object-oriented approach using UML diagrams is identified to be a suitable tool with high potential to integrate with other software packages in the manufacturing system.

The methodology and a front end framework were proposed in Chapter 1. Three methodology approaches were reviewed and applied according to suitability to the research. The front end framework proposed the UML representation of process mapping the simulation model, leading to modular design of simulation elements and scenarios generation.

Chapter 3 started explaining the object-oriented representation with UML diagrams. An example demonstrated the representation proposed. Industrial case studies were then used to explore the UML methodology in chapter 4.

The modular simulation modelling approach in chapter 5 continued to illustrate and explain the design of individual modules that could be quickly reconfigured and duplicated across the whole manufacturing system in a simulation modelling project. A library of machine types and supporting operations modules are proposed. The case studies provided an industrial context to support the aims and objectives of the research. It had provided the opportunity to apply and refine the UML representation. A set of structured questionnaire is proposed based on the industrial cases contribution.

The above chapters cover the following elements:

- The range of data type in the manufacturing environment
- Standardise and simply the classification and representation of manufacturing systems in Object-Oriented Approach
- Simulation modelling approach to different manufacturing systems
- Simulation modelling design to represent a real system
- Representation of decisions required to run a manufacturing system independent of its size

The final case study in chapter 6 had applied the proposed methodology from the start of the project. Having the data collection questionnaire filled in by the engineer, has enhance the data quality for the project and has make the scope of study clearer and defined. The UML representation proposed has been validated with the details provided in the data collection questionnaires and observation.

The application of the modular approach introduced in case study 4 showed the benefits and potential of the design on simulation modelling design and development. The new approach to simulation model design had proved to bear characteristics of agility, flexibility, scalability and good visual displays. Easier traceability is obvious in the modular design of the elements created in the simulation model. Development time and simulation experimentation time are reduced.

In addition to the object-oriented UML representation of manufacturing elements from process mapping to simulation modelling, a database is used as a data reconfigurable tool in chapter 7. The designs and concepts in creating the database influenced by object-oriented approach are illustrated. This had enabled structured and error minimised data entry.

Chapter 8 then continues to propose an integrated framework that described how the approach provides capabilities like standardisation and automation of part of the simulation modelling process, effective involvements and interaction with experts of the system, and, the creation, capture and display of all relevant information. Optimisation techniques in experimentation and applying the computing power of Grid-based technology are explored to solve major concerns of many in simulation modelling project optimisation.

9.5 Limitations of this research

The proposed preliminary front end framework has various limitations. Most of the works carried out are done manually by experts depending on their skills and knowledge. The translation of the UML diagram to the simulation model package is carried out by the expert developing the simulation modelling project. The analysis and optimisation of results generated by the simulation model are carried out by the experts to decide the optimum search range and parameters. Besides that, template of design patterns of manufacturing system is limited collected from the four case studies in this research. Many assumptions are made for each of the case studies in order to focus on the simulation modelling project objectives, but these assumptions should be revisit at the completion of the project for further consideration.

9.6 Future Work

From the framework, the key components proposed had been researched and built with relatively sufficient work done. The next step would be programming and coding work carried out by computing experts to integrate all the major components together and refine the work in each blocks in the framework. The UML approach is popular and commonly used in the software industry but rarely used in the manufacturing improvement projects. By using XML as a process description or process mapping tools, the representation can then be easily integrated into other software used in the company. Most materials and books had suggested that UML can be translated into XML language which can describe multiple views. XML language is one of the formats which most simulation packages accept directly besides other commonly used data collection and scheduling packages as a front-end. Hence it is possible to convert from UML to XML. XML has long been recommended and used to help interchange simulation data (DaCosta 2002). The advantage of XML markup includes that it is an open standard that is vendor-neutral and supported by Commercial Off-the-Shelf (COTS) packages. Although XML solves many format and structure interchange problems, it does not provide explicit semantics. Therefore, it is difficult for commercial software applications to correctly interpret the meaning of the data without extensive programming by software engineers that understand how the data should be interpreted. XML provides a great deal of flexibility for language designers to organize interchange formats. However, that flexibility leads to potential problems because there are too many ways to represent the same information.

What could be a problem is that some packages have unique naming convention for their components, which may create some problems due to lack of standardisation. For example, in Witness simulation modelling package, process is created as machine, whereas in Simul8 simulation modelling package the operations are created as workstations. A middleware with a translator customising the UML representation towards the simulation package the user preferred is therefore important. Filev et al (2003) stated the .Net technology cannot translate dynamic views of UML such as sequence diagrams and activity diagram. Due to rapid improvement in software, this problem will be over-come to provide the link in near future.

Limitation of translating of UML work to XML currently requires computing coding experts to perform the task. Dynamic Simulation Construction will gradually be a practical tool that can be used by many. A future scenario could be envisaged when an end user could use a web-based application to define their requirements for a simulation model. Software agents could scour the web for available web services to compose a simulation model. Domain descriptions and parametric data could be gathered from authoritative sources to support the composed simulation. An existing scenario could be found that could be tailored to meet the requirements. All of these activities are possible if simulation web services are described and information is represented.

The translation between the UML to XML and to Simulation Model package must be vendor neutral, and supported by a wide variety of Commercial Off-the-Shelf (COTS) software tools. Using COTS instead of developing custom code reduces development costs. Also, representations that can be read by both humans and computers are one of the key criteria.

The development of simulation scenarios and associated initial conditions represents a major investment of time and resources. Standard descriptions of scenarios should reduce the time and effort required to prepare for a simulation execution. The technology should support the definition of classes, individual instances, and property relationships between classes, individuals, and properties. It should also be an open W3C Recommendation (standard), and potential intellectual property or proprietary licensing issues should be sorted. Upgrading the database user interface into a web form user interface will be the next step to start the process of web integration into the framework.

The proposed framework of having an integrated system where local SME not only large corporation have the benefits of accessing the services by an application service provider with access to simulation engines and Grid-based technology is a great ambition. Simulation models with simple user interfaces and data storage are hosted and maintained by a service provider. Grid-based technologies are connected to the simulation engine for more distributed computing power. This provides speed to simulate a large numbers of scenario trials. Results can be compiled in a reasonable and practical time. Below are some suggestions to extending the capability of the modular simulation model through a computing network with server-based and web-enabled functionality. The features aimed for in future work:

- It provides a thin client/server-based computing model for simulation model, whereby a developer can conduct modelling and simulation interactively using the combined resources of a computing network.

- It provides a parallel and distributed simulation environment to conduct batch experiments.
- It provides a knowledge-based model library whereby a developer can benefit from reusable best practice templates/models.
- It provides seamless model migration between local and remote hosts

The contribution of this research is proposing a new approach to simulation modelling projects. This methodology could save time and provide a better quality model. To fully get the benefits of the framework, more work and effort is needed in various areas not only in manufacturing studies, but computing and technologies evolvement too. So far, this research has contributed to a large part on the manufacturing studies and improvement concepts, but not as much in putting the technologies required in place. Prototypes will need to be built to host the model and provide remote access. Licensing issues with simulation package providers need to be discussed and negotiated. By having their support, this work will benefit many companies and enhance the economy.

Finally, process optimisation is challenging. Promoting the creativity and openness to all the technologies and information which will allow organisations to respond to so many changes and challenges is becoming a prime task of the company. They should aim to find the solutions to technological and environmental challenges, the pressures to be socially responsible, and ability to handling the increasing globalisation of markets and the difficult-to-define of knowledge management.

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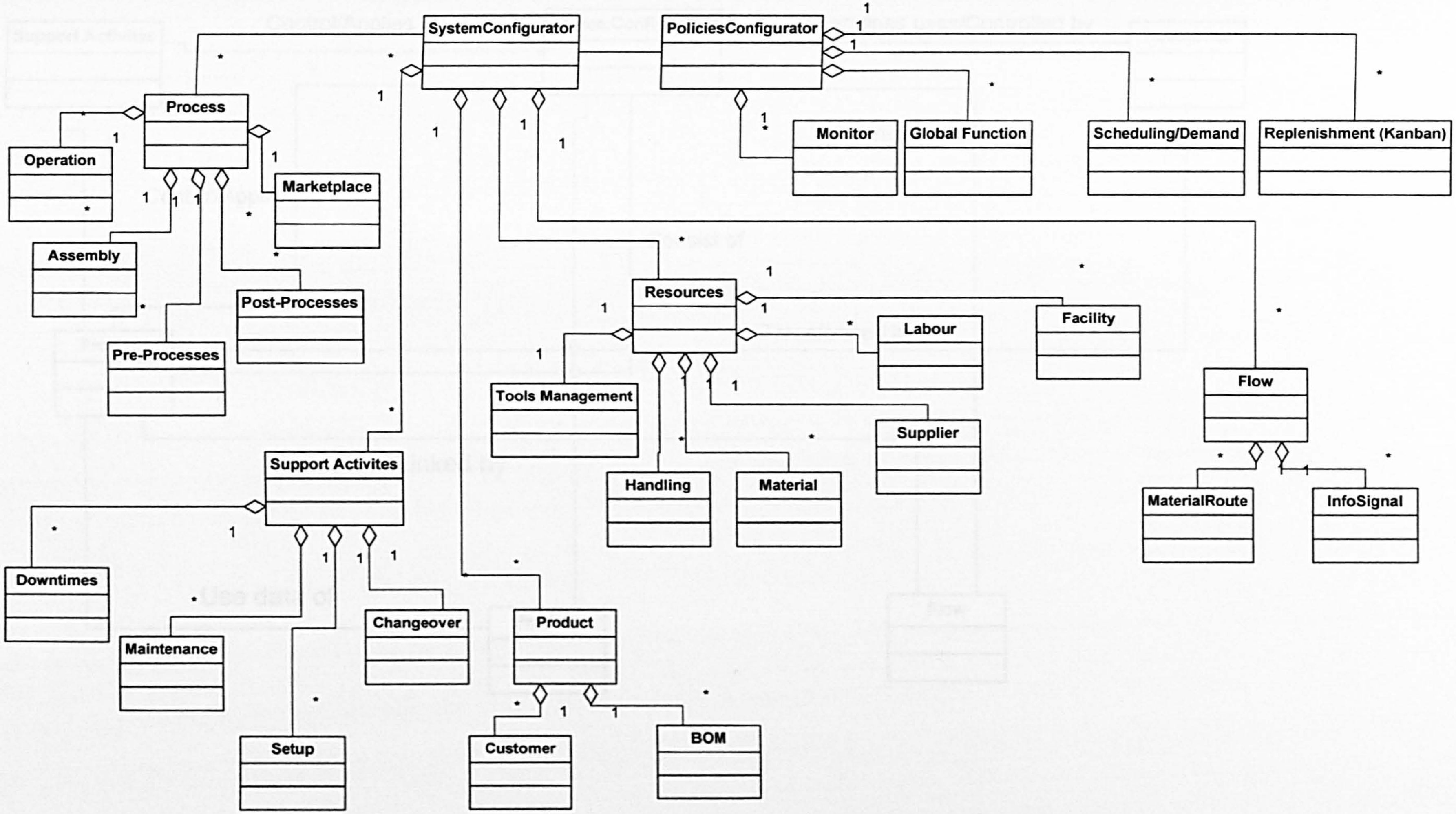
Appendix A

UML Diagrams

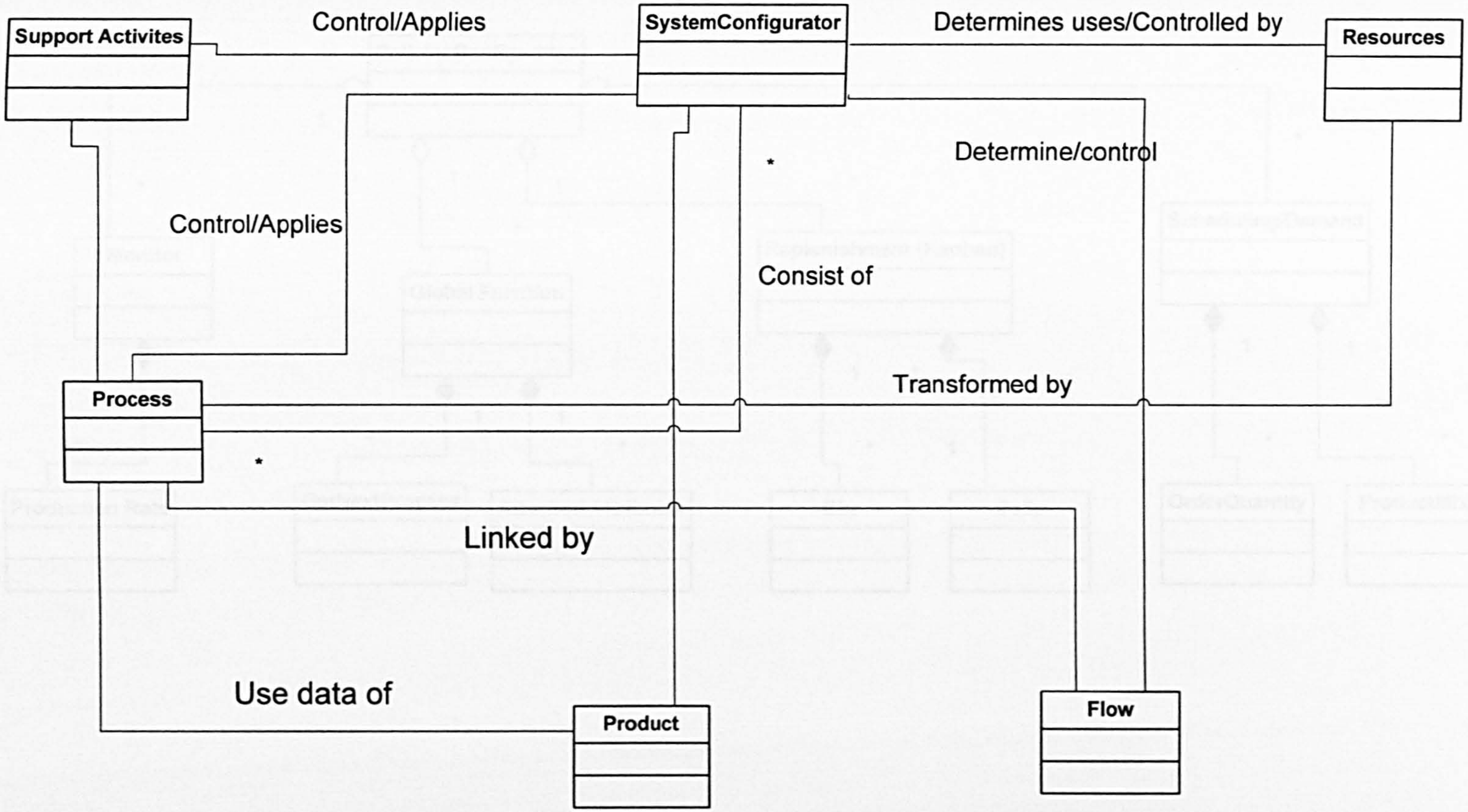
- UML General Class Diagram Template
  - Main Diagram
  - Relationship
  - Policies Configurator
  - Process
  - Resources
  - Support Activities
  - Product
  - Flow

- Case Study 1: General Class Diagram
- Case Study 1: Class Diagram with Instances
- Case Study 2: General Class Diagram
- Case Study 2: Class Diagram with Instances
- Case Study 3: General Class Diagram
- Case Study 3: Class Diagram with Instances
- Case Study 4: General Class Diagram
- Behavioural Pattern: Sequence Diagram of General Process A
- Behavioural Pattern: Sequence Diagram of General Process B
- Sequence Diagram: Operation cell with conveyor
- Sequence Diagram: Operation cell with conveyor-Case study 3
- Sequence Diagram: Operation without conveyor
- Sequence Diagram: Case Study 2-PrepMould
- Sequence Diagram: Case Study 2-DeMould

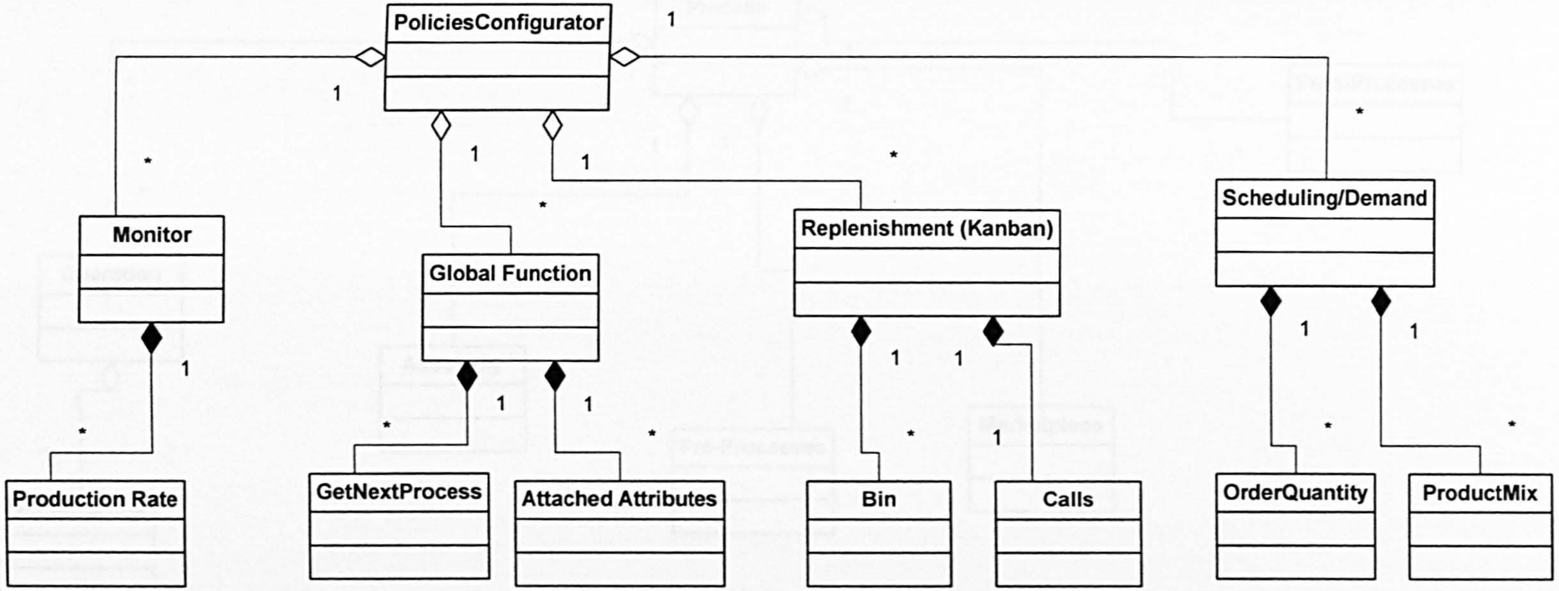
UML General Class Diagram: Main Diagram



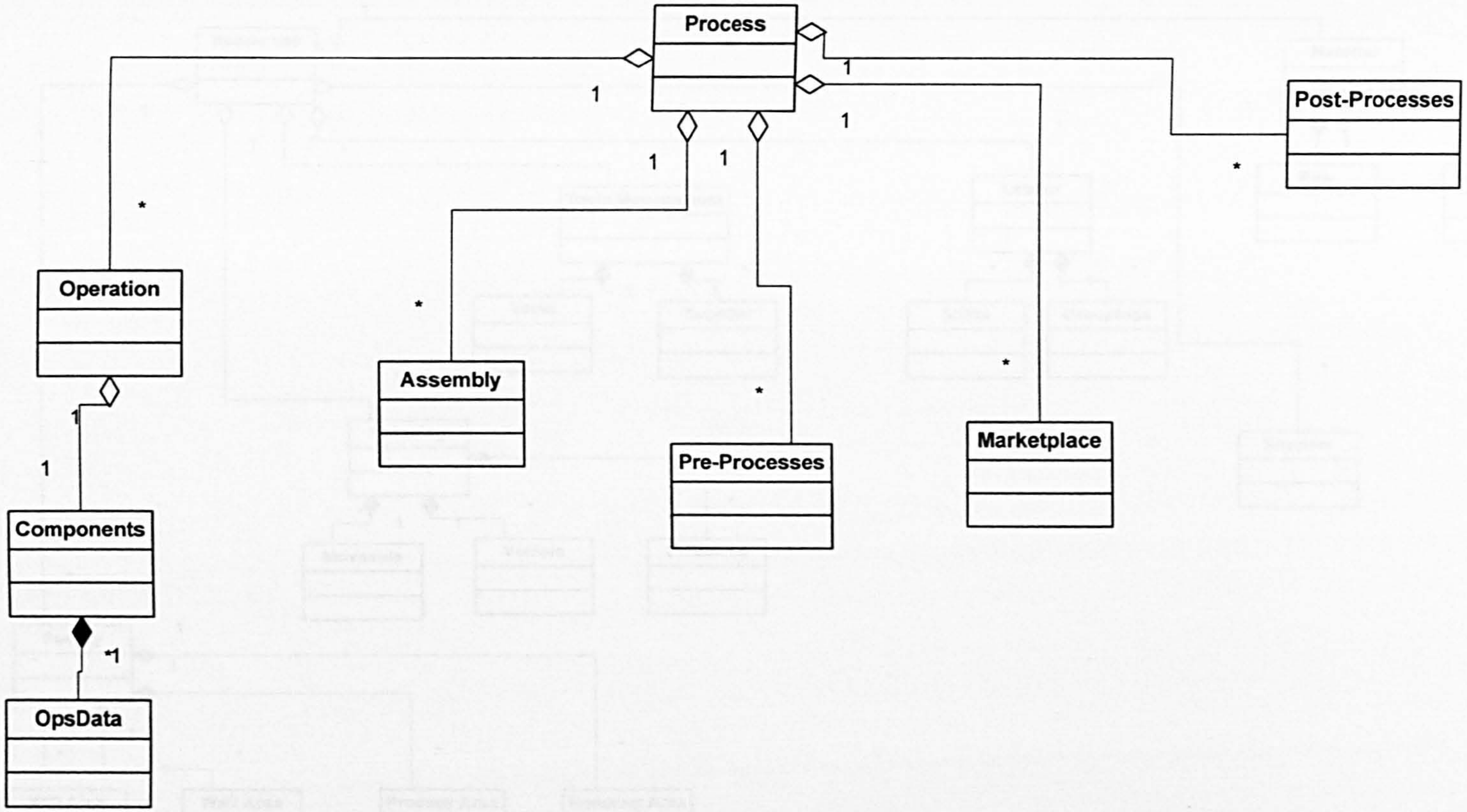
UML General Class Diagram: Relationship



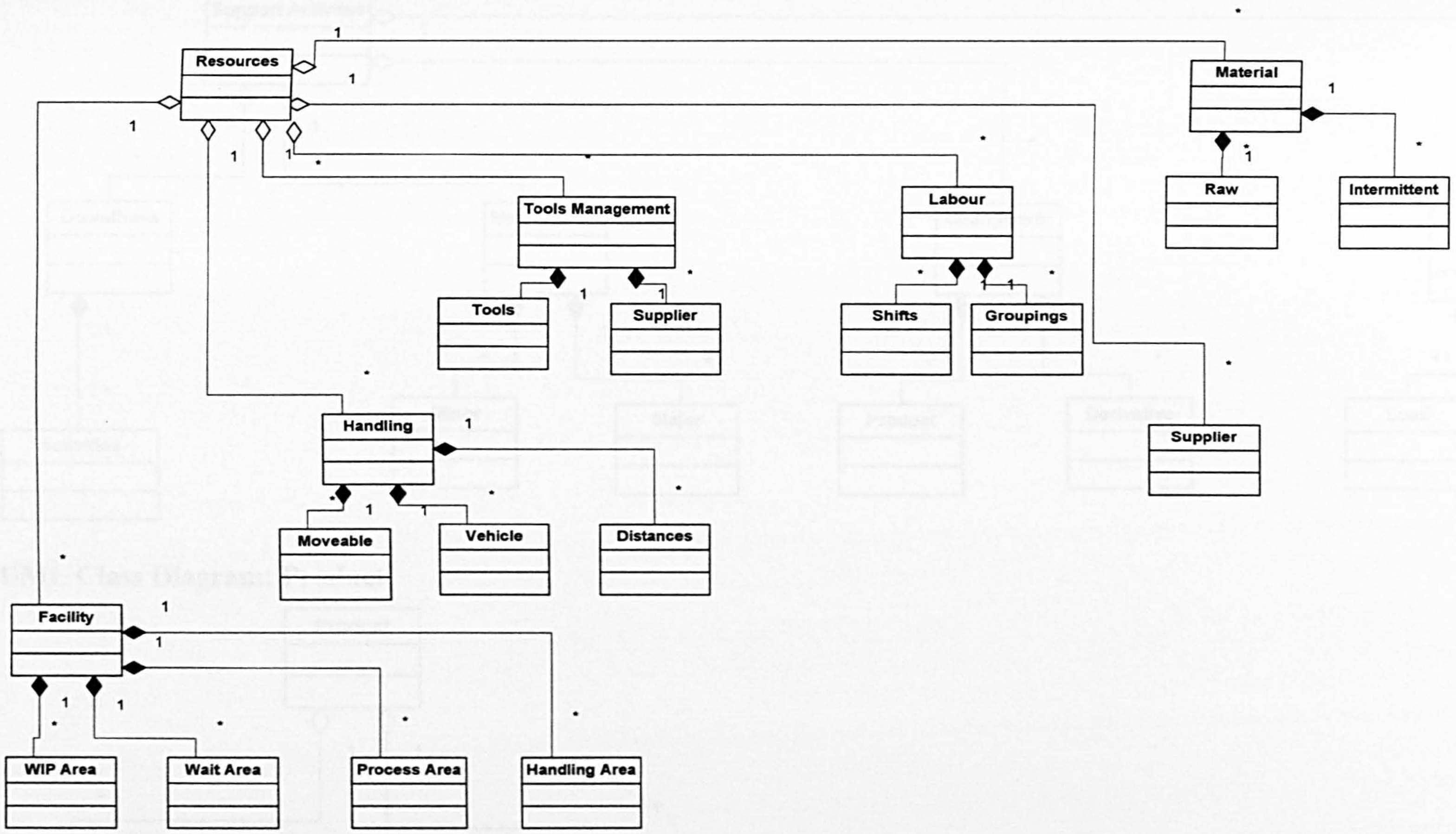
UML General Class Diagram: Policies Configurator



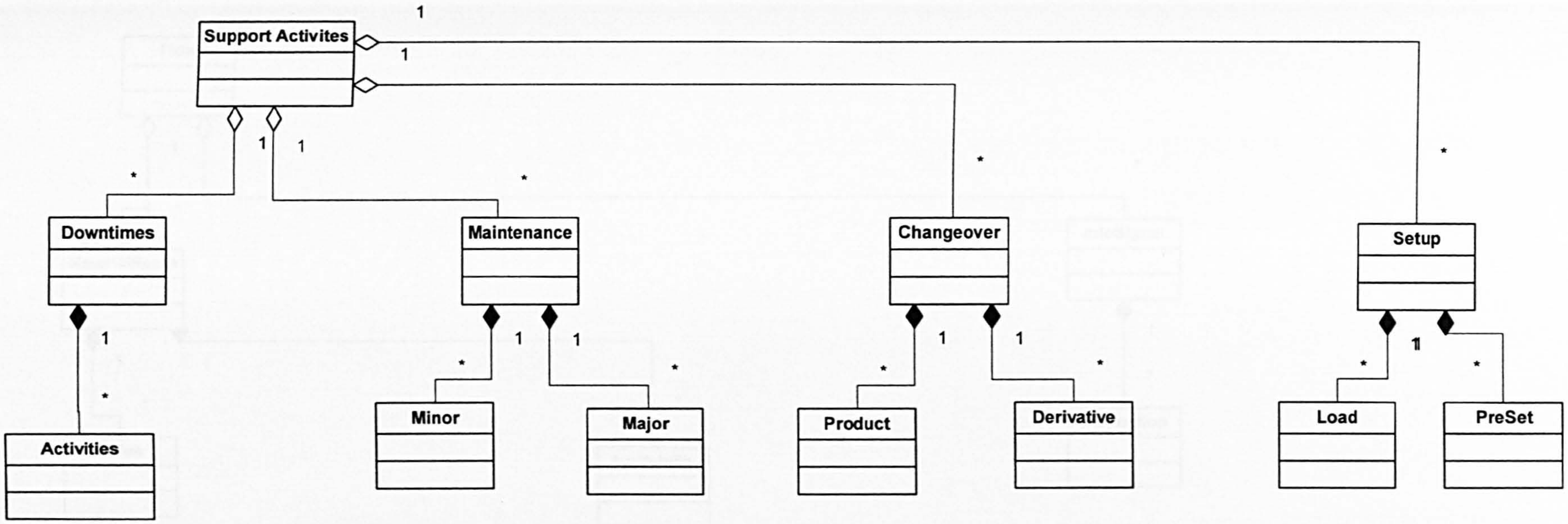
UML General Class Diagram: Process



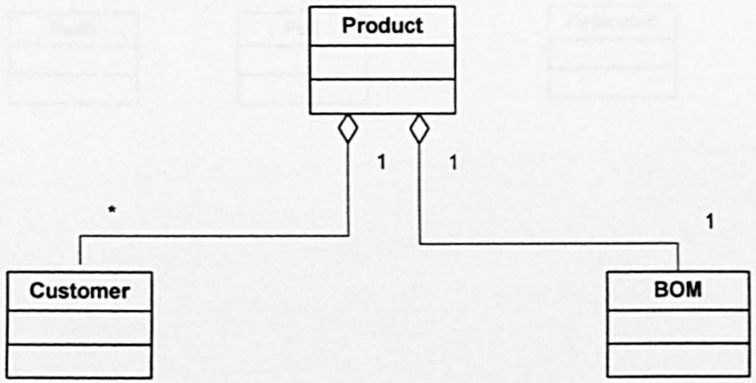
UML Class Diagram: Resources



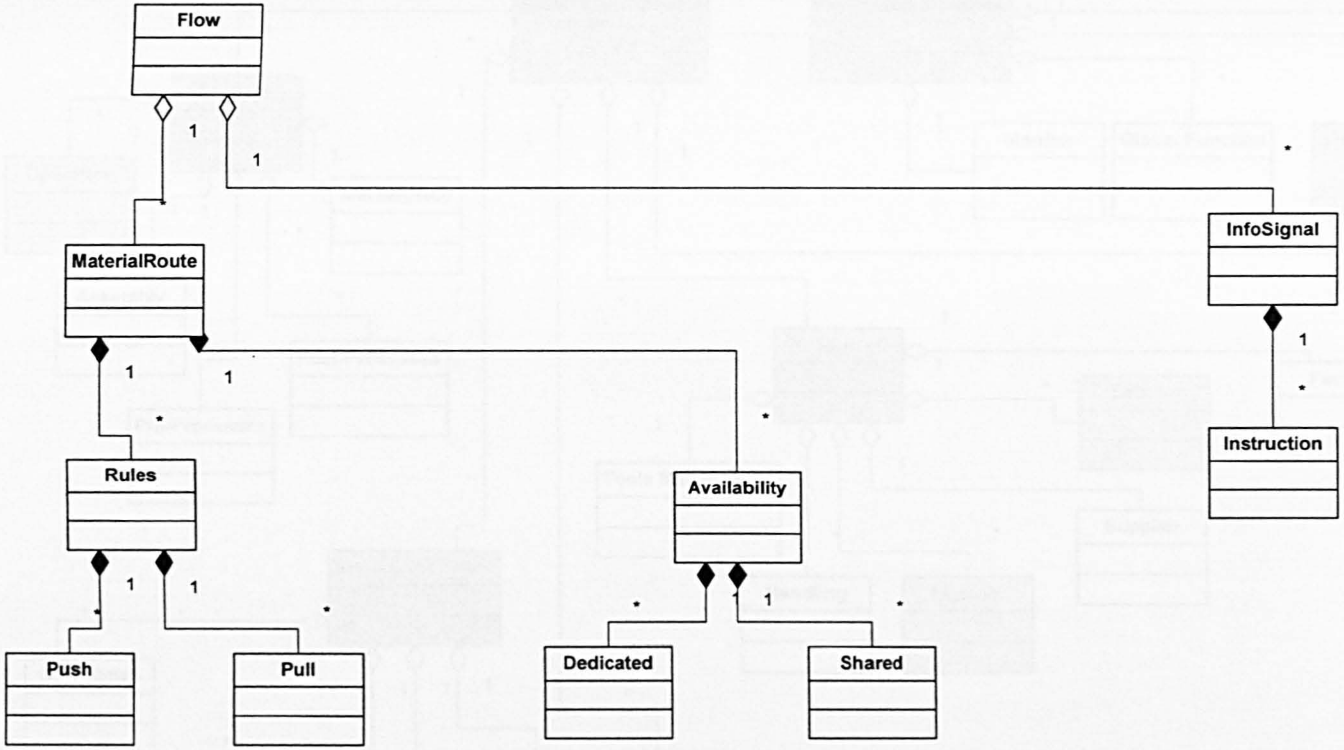
UML Class Diagram: Support Activities



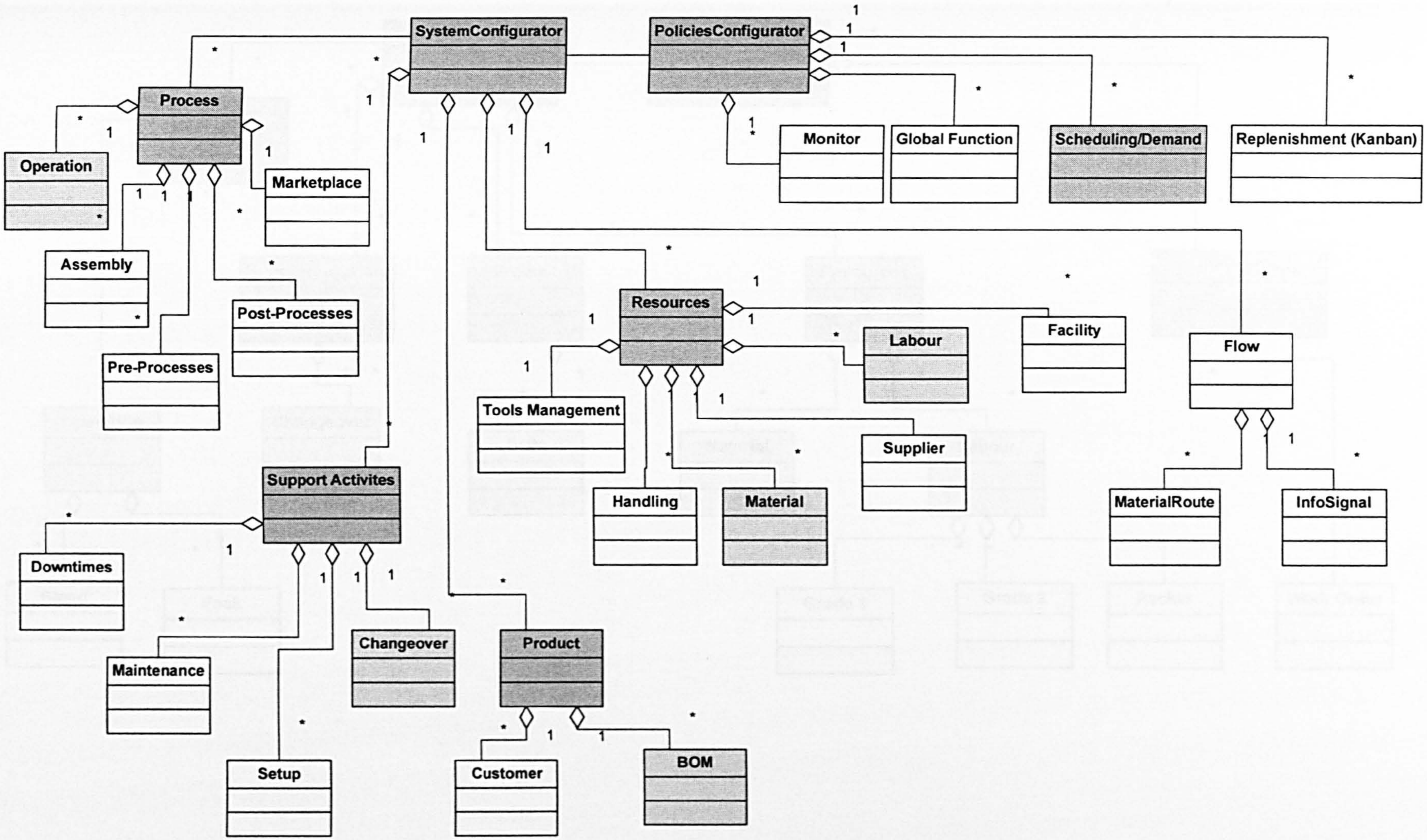
UML Class Diagram: Product



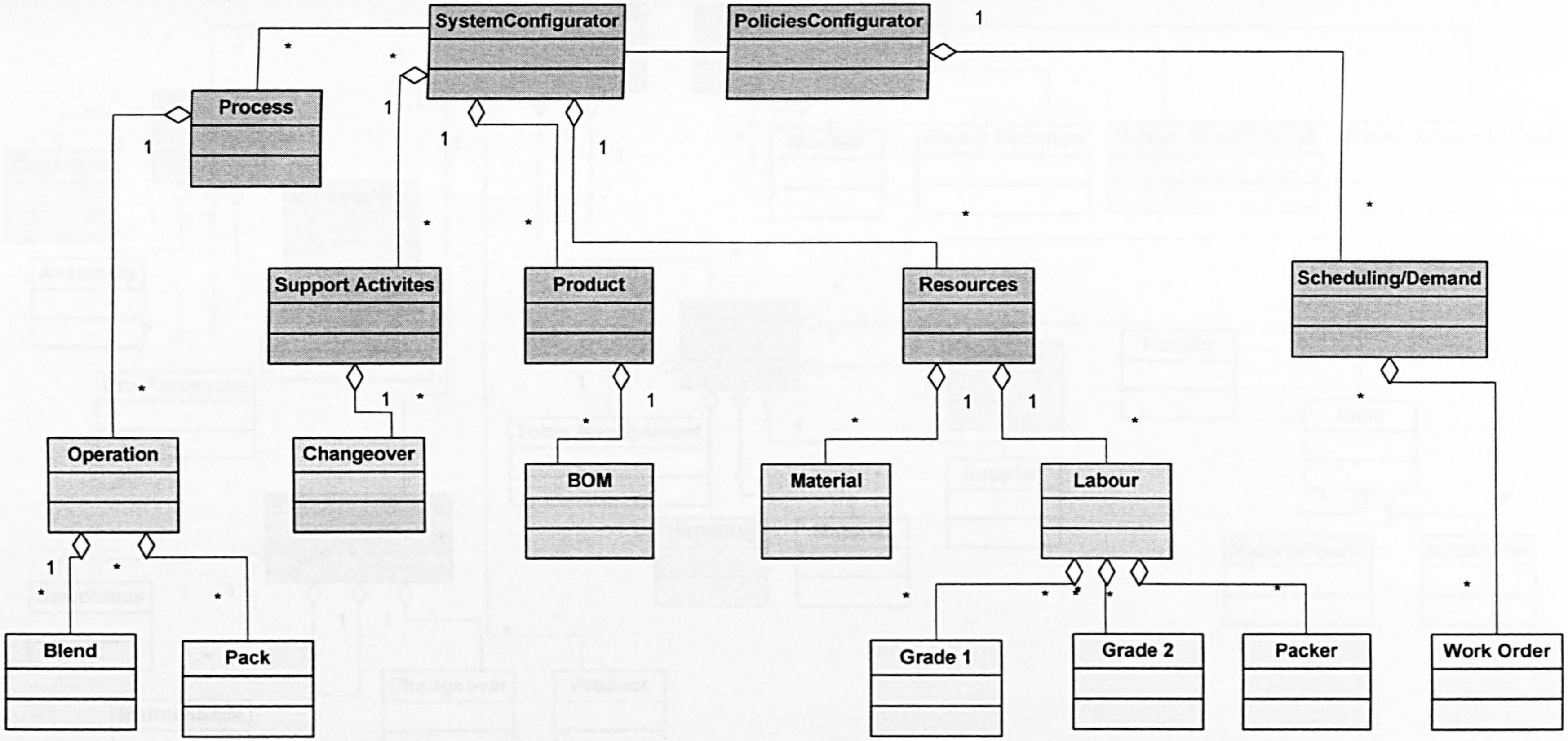
UML Class Diagram: Flow



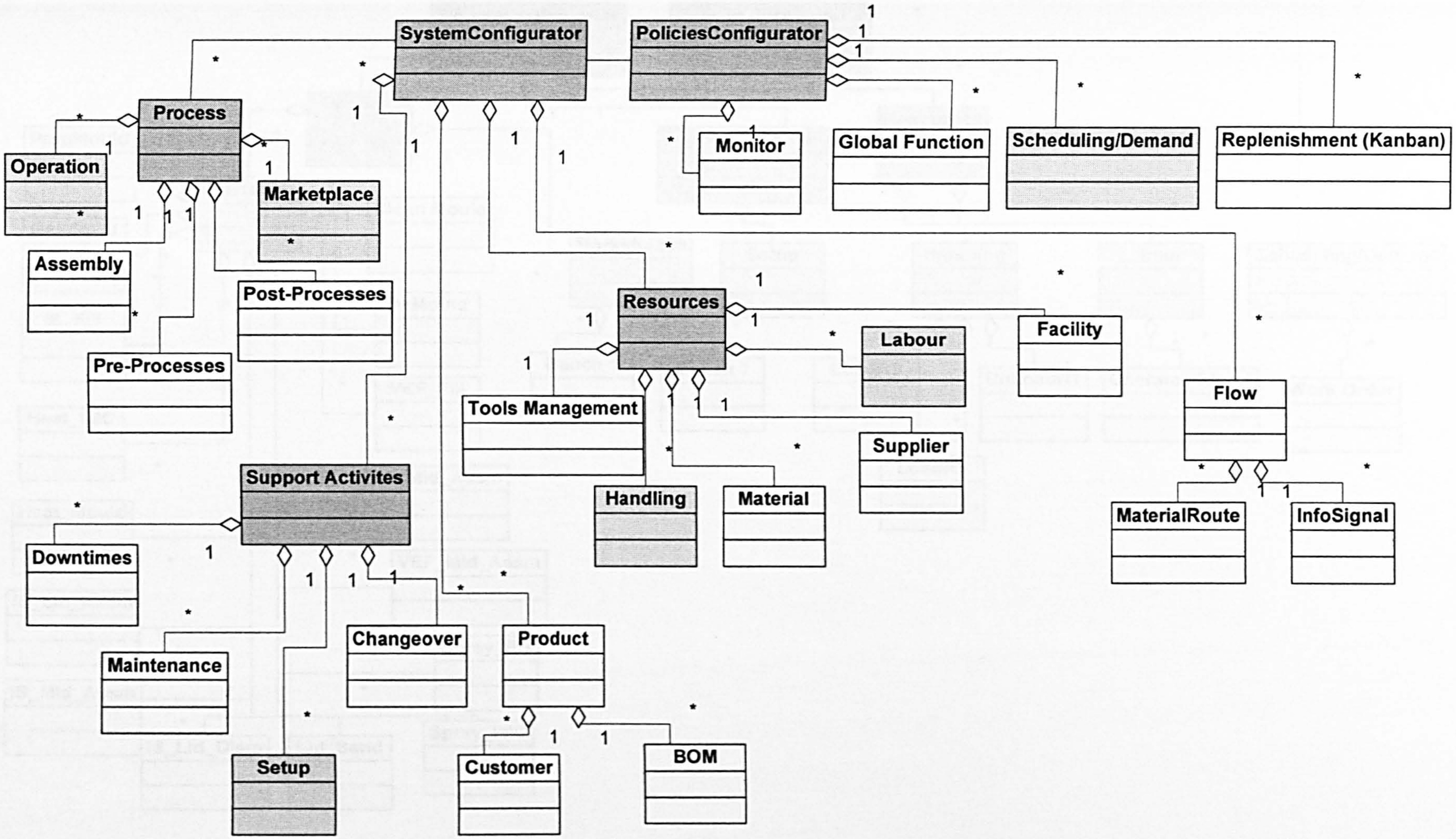
Case Study 1: General Class Diagram



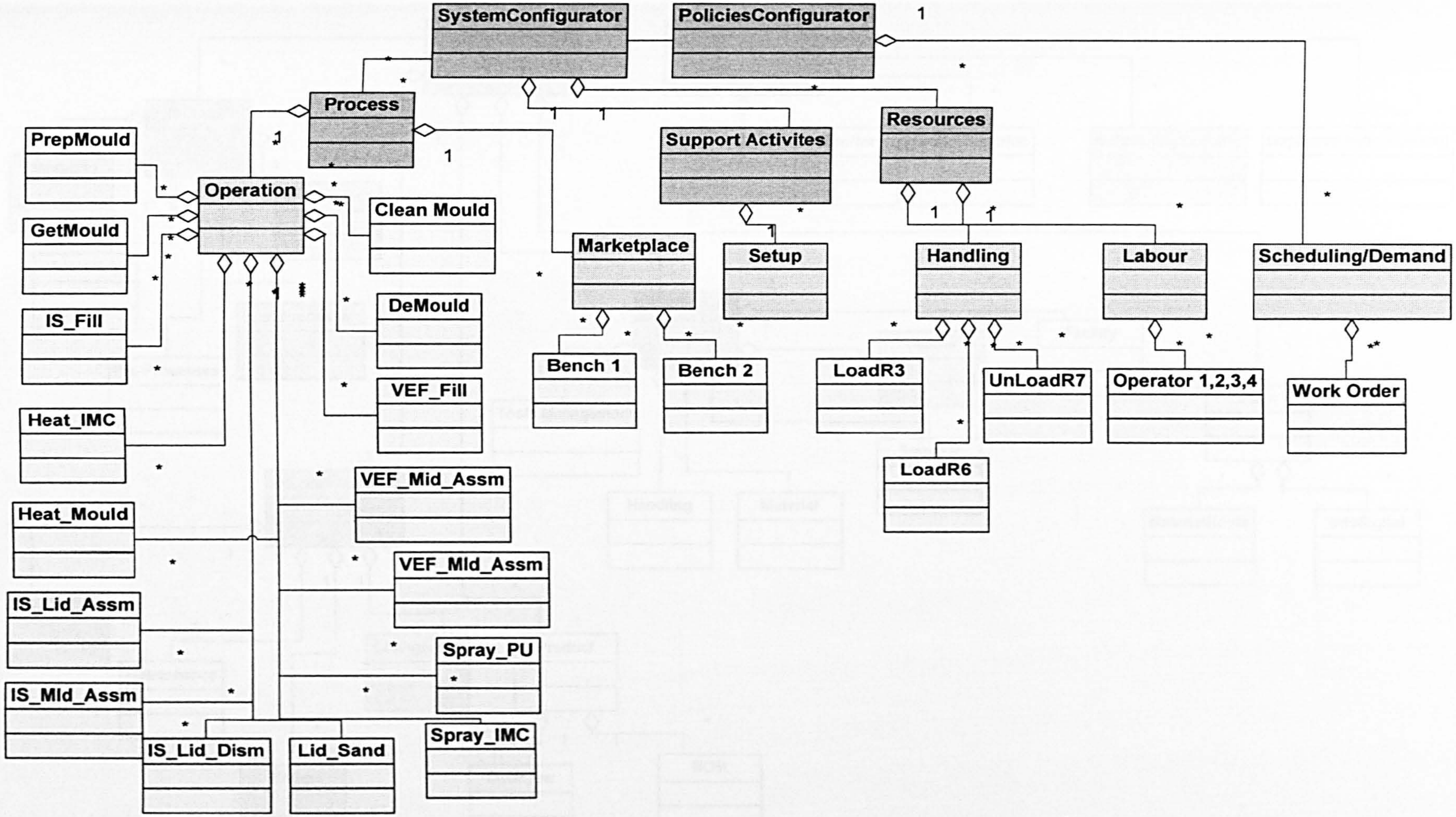
Case Study 1: Class Diagram with Instances



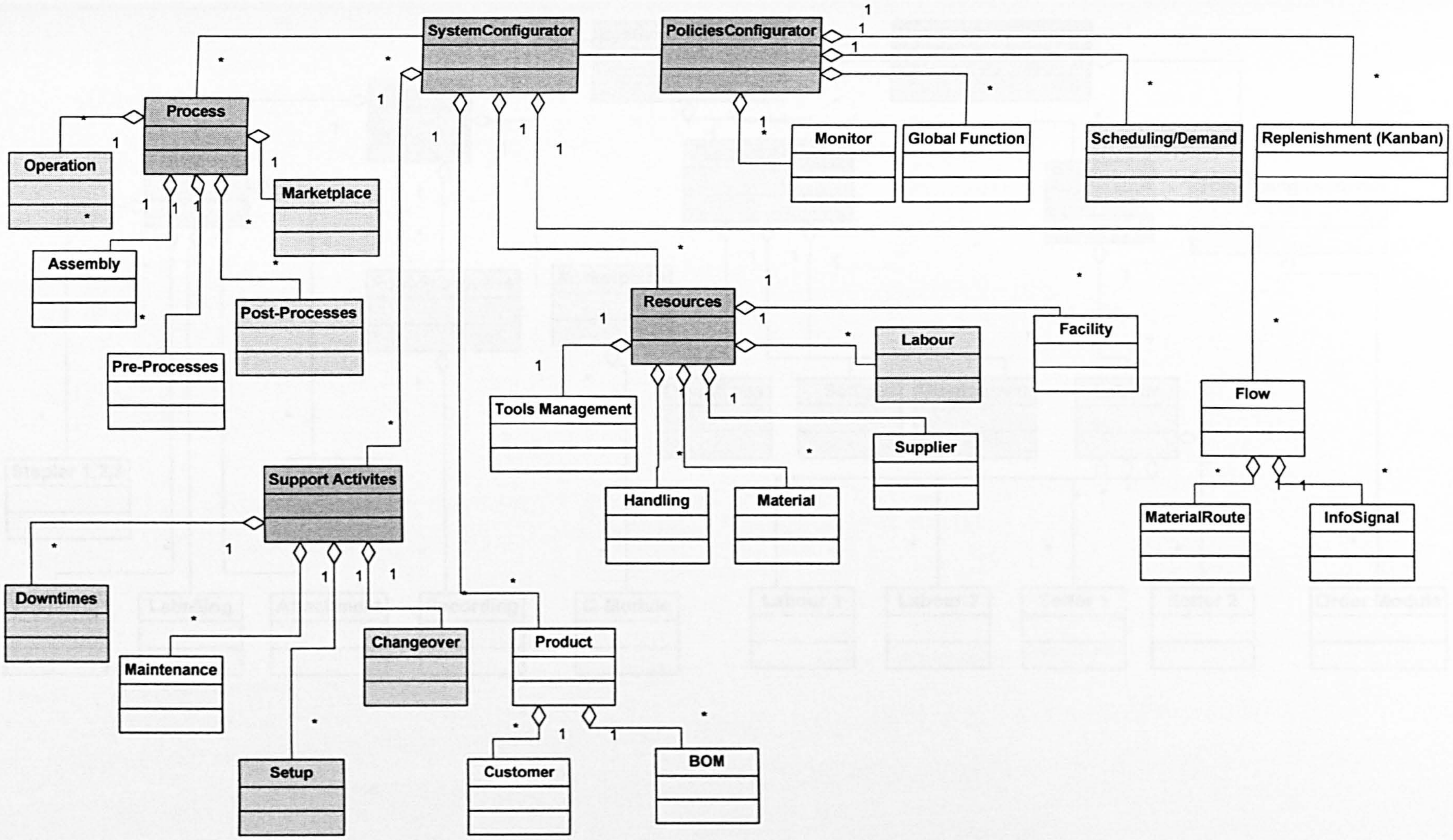
Case Study 2: General Class Diagram



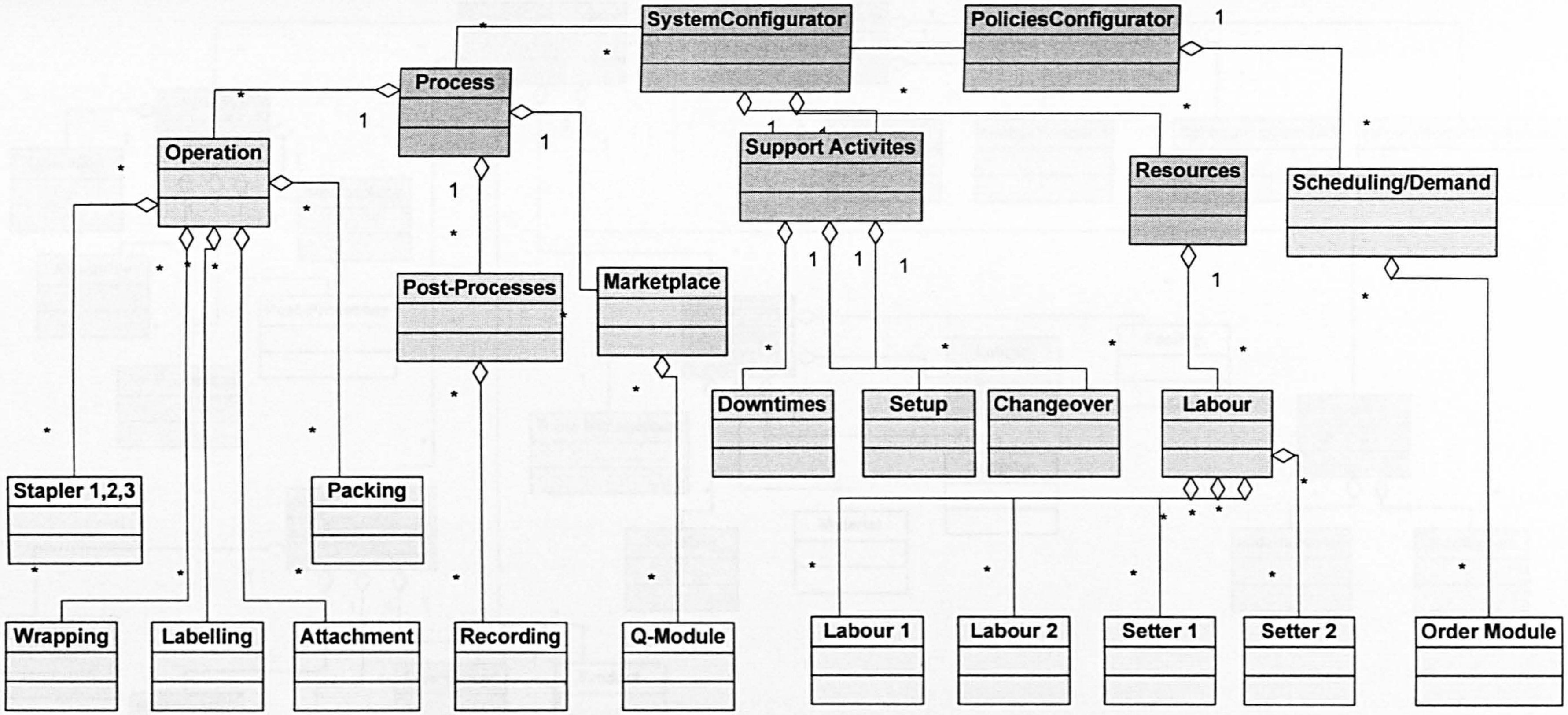
Case Study 2: Class Diagram with Instances



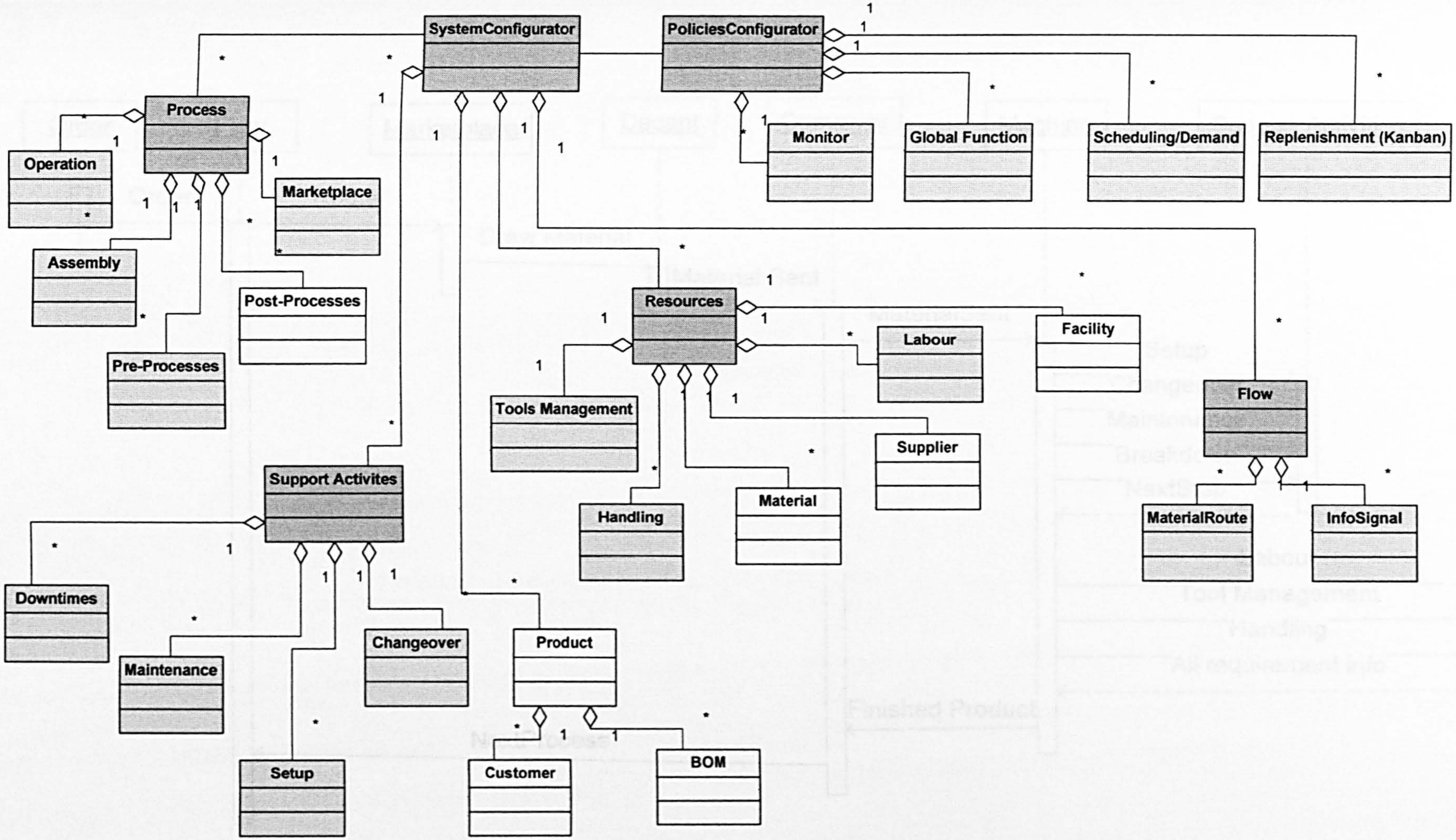
Case Study 3: Class Diagram



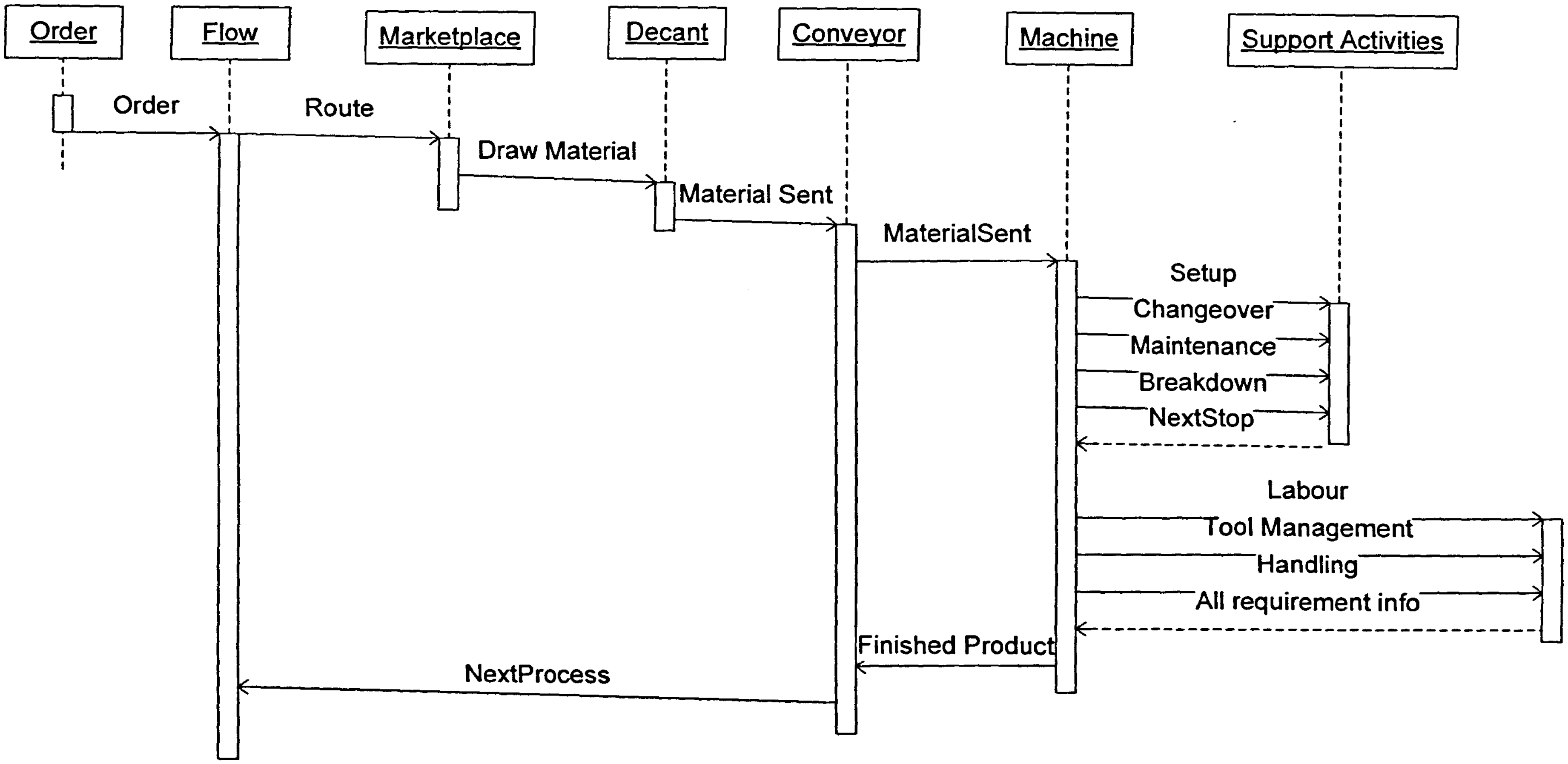
Case Study 3: Class Diagram with Instances



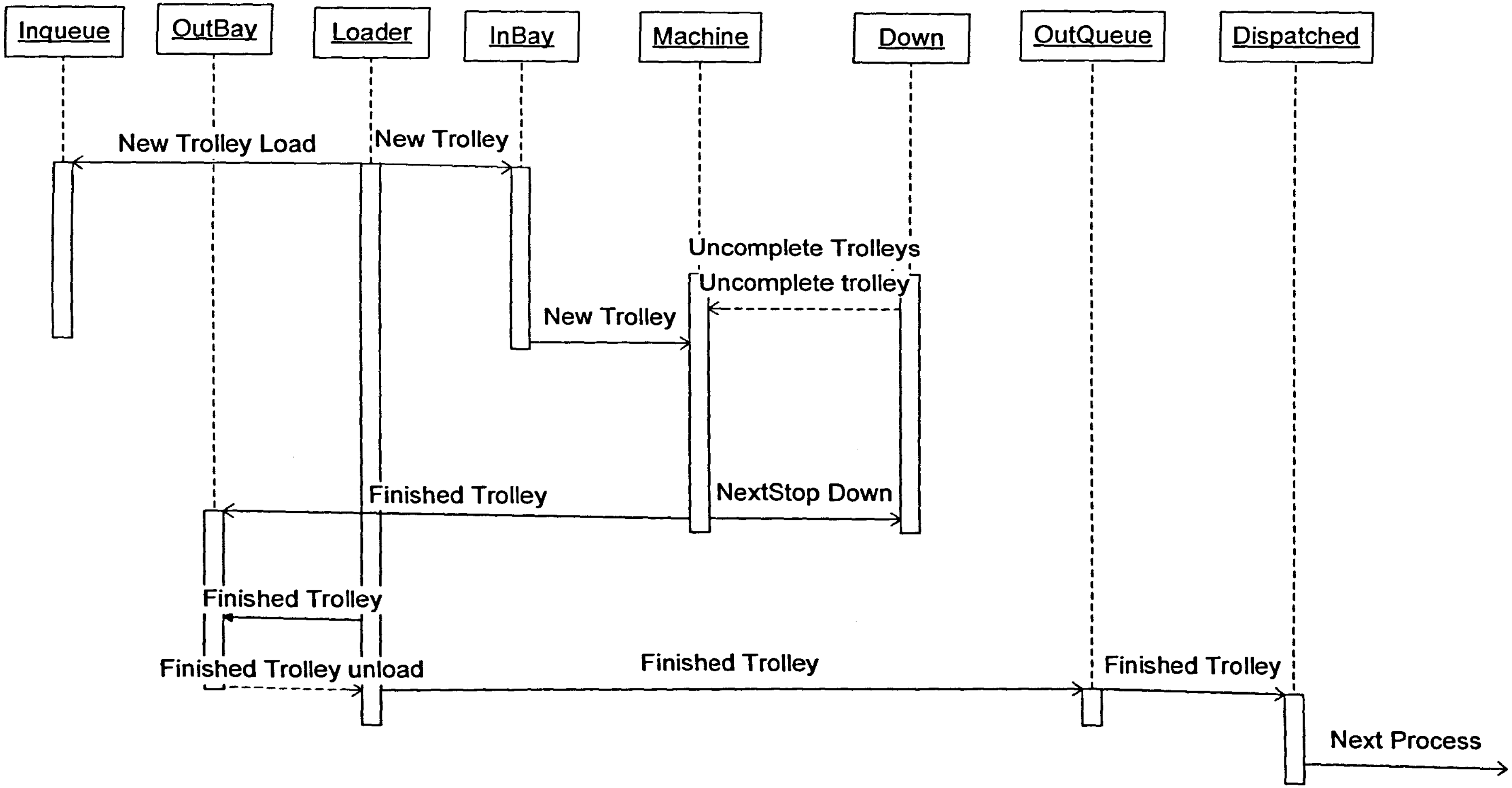
Case Study 4: Class Diagram



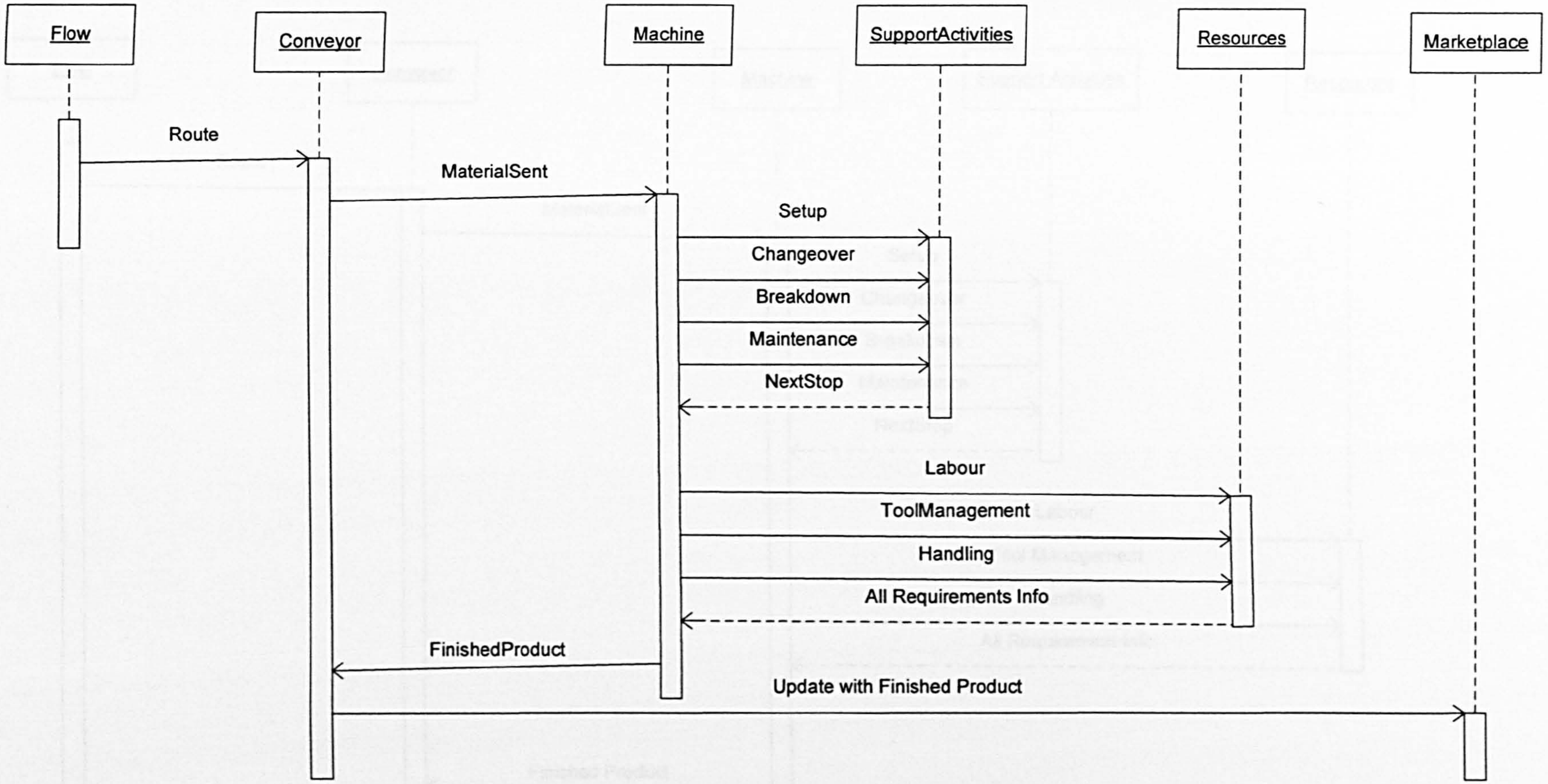
Behavioural Pattern: Sequence Diagram of General Process A



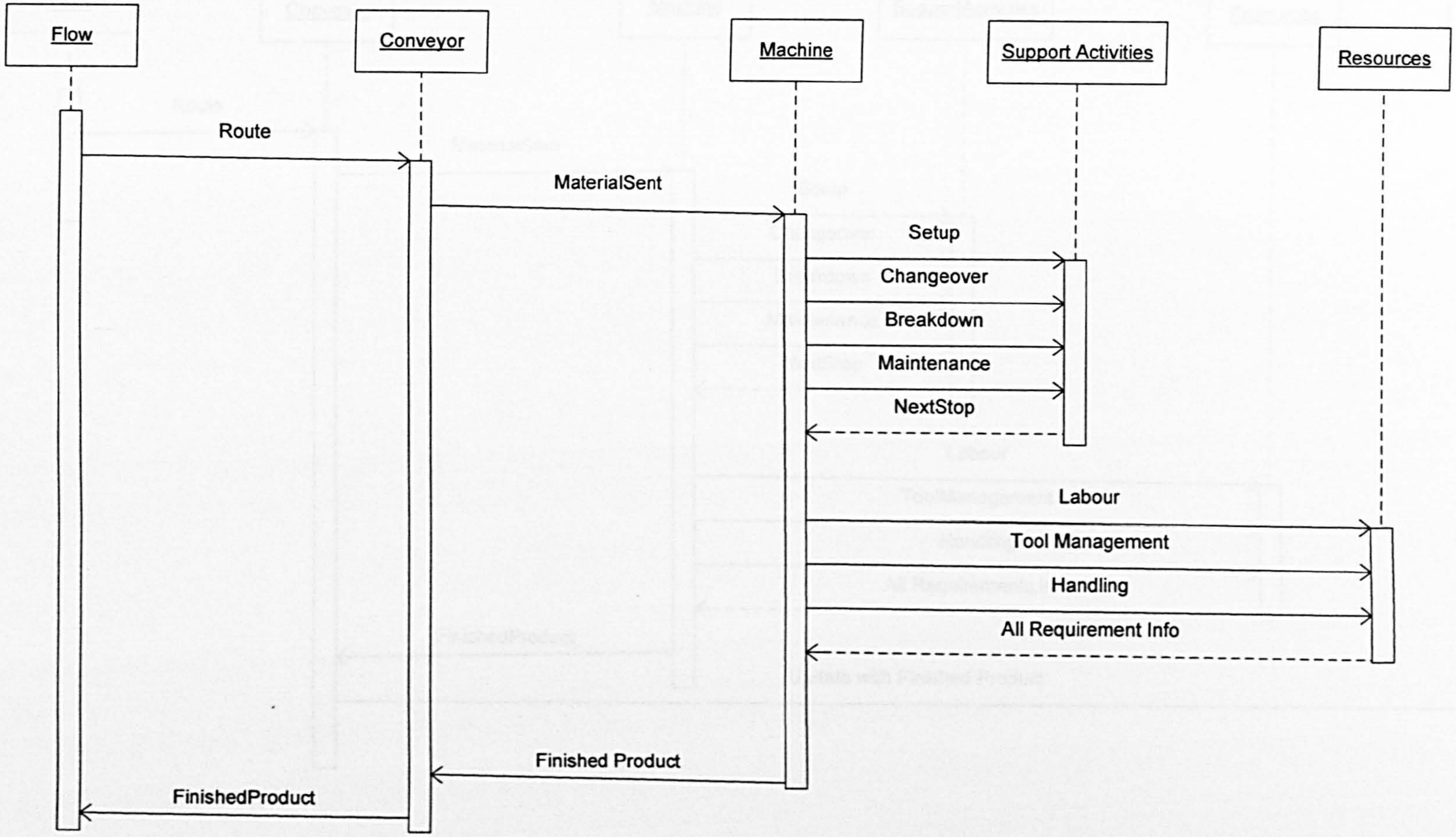
Behavioural Pattern: Sequence Diagram of General Process B



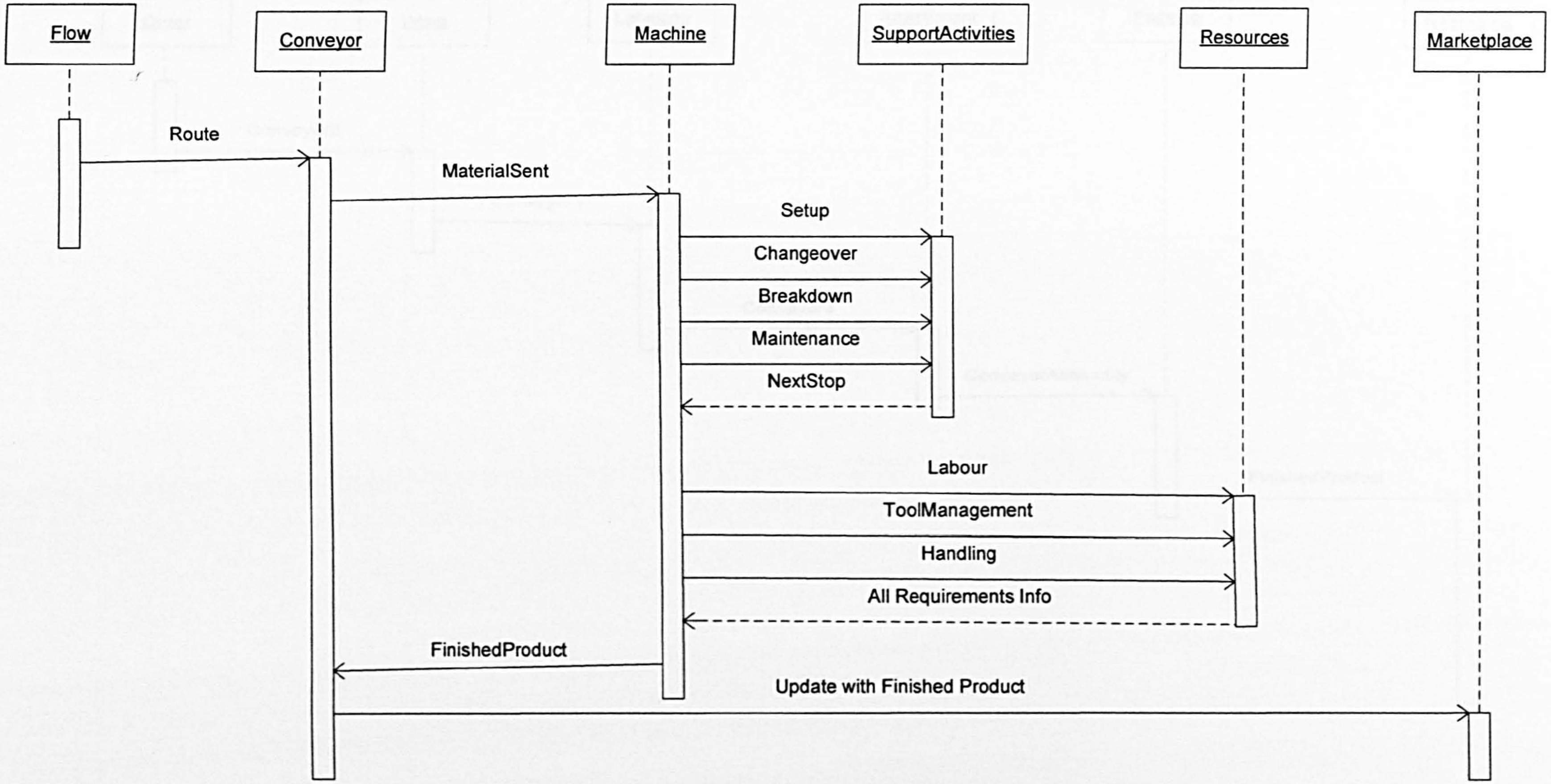
Sequence Diagram: Operation cell with conveyor: Start Process- InfoFlow



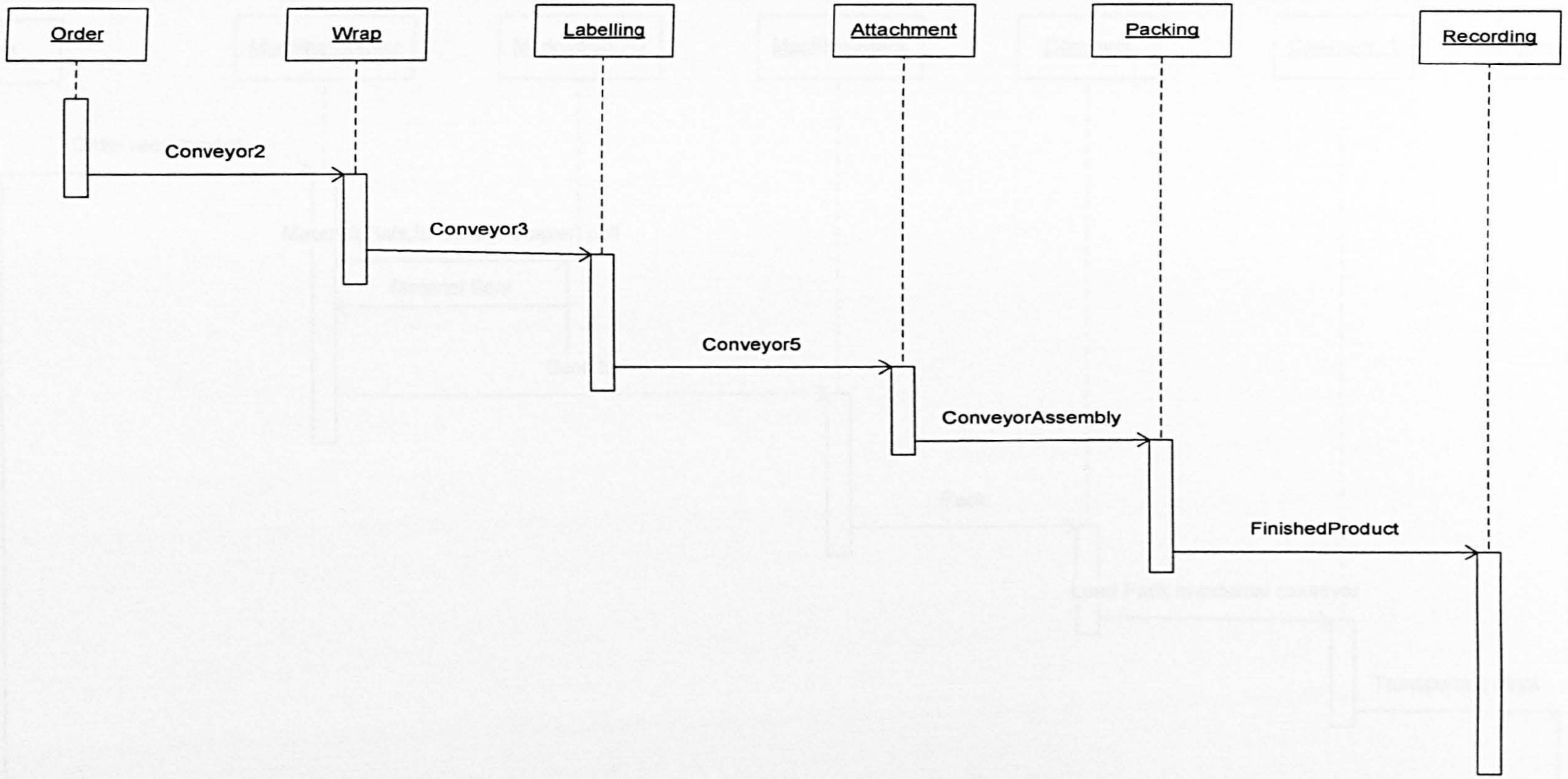
Sequence Diagram: Operation cell with conveyor: Intermediate Process- InfoFlow



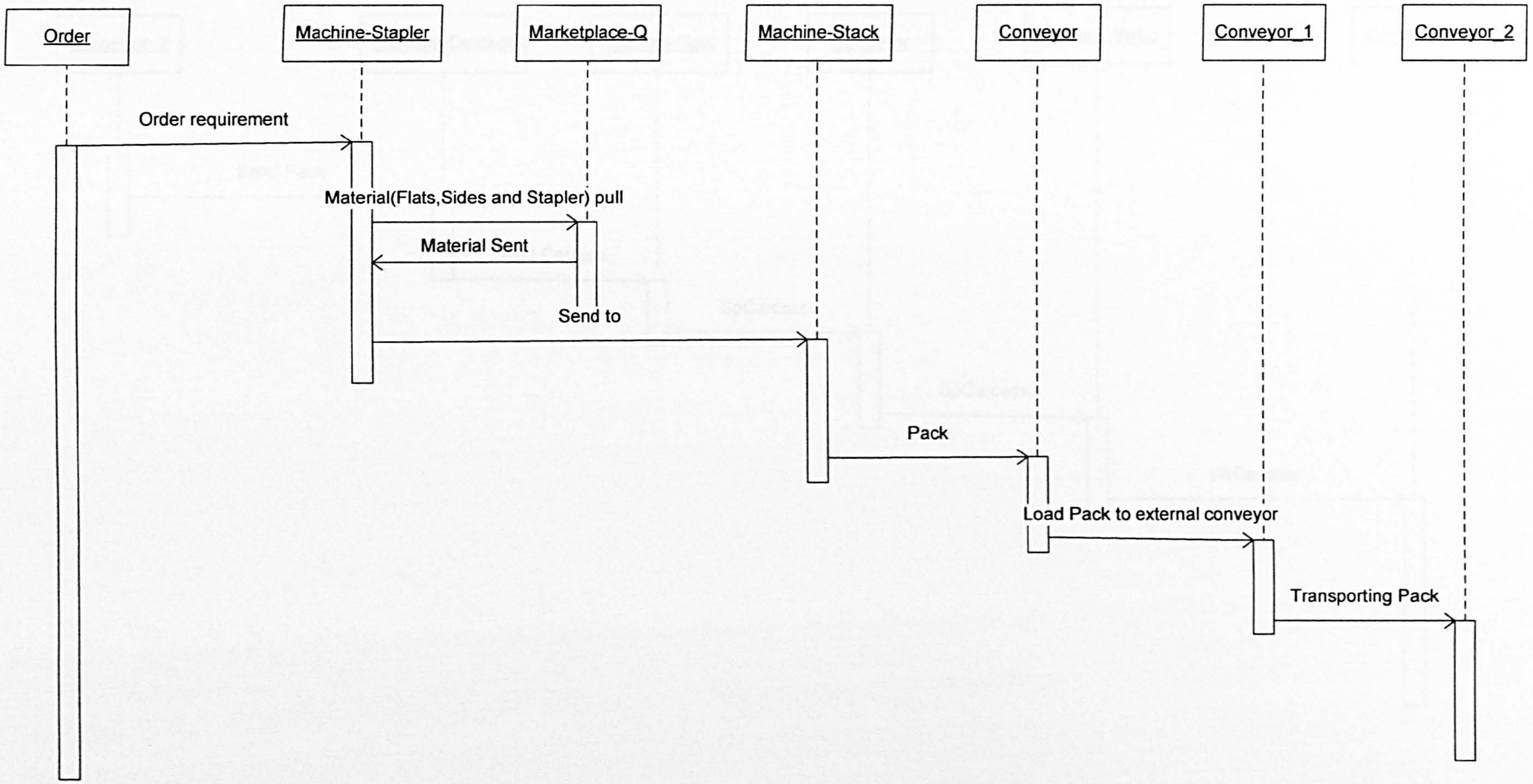
Sequence Diagram: Operation cell with conveyor: End Process- InfoFlow



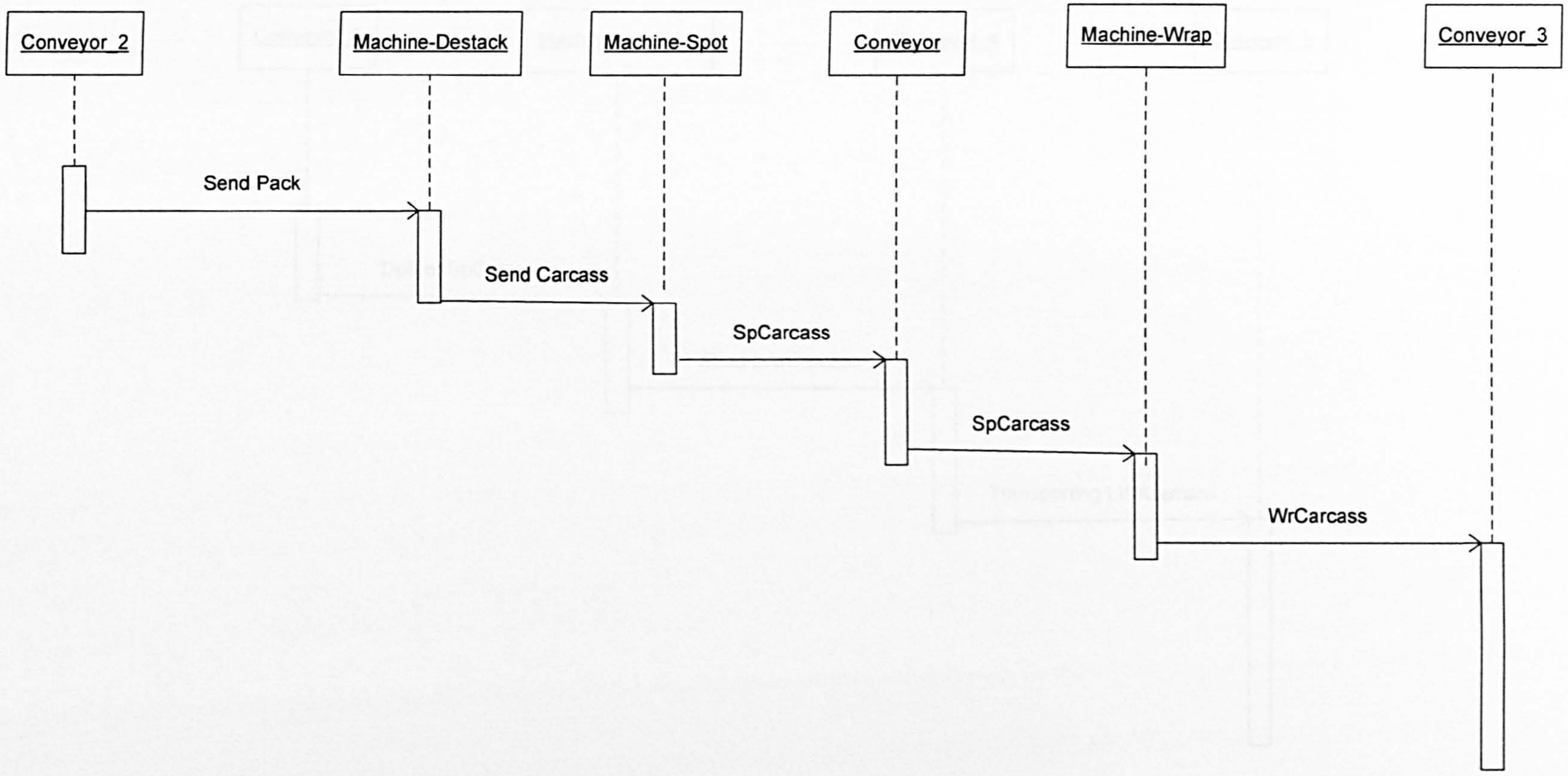
Sequence Diagram: Operation cell with conveyor: Case Study 3- Main Processes



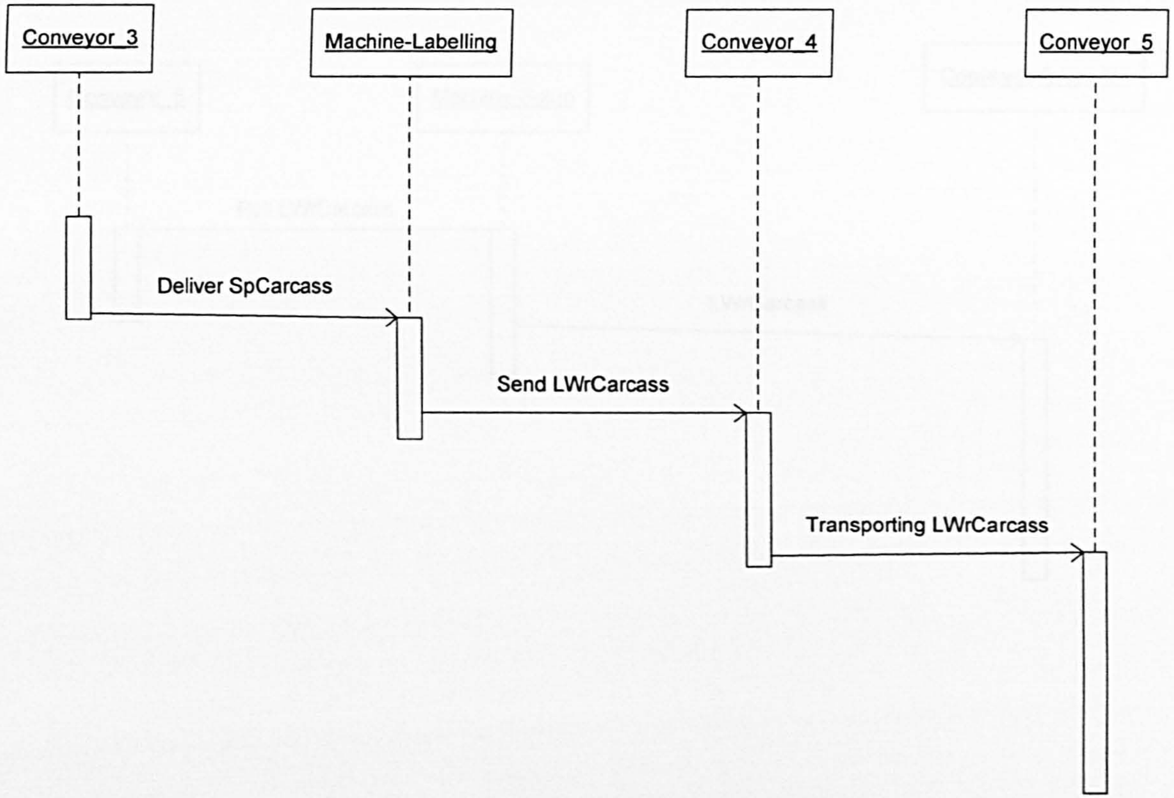
Sequence Diagram: Operation cell with conveyor: Case Study 3: Start Process-InfoFlow



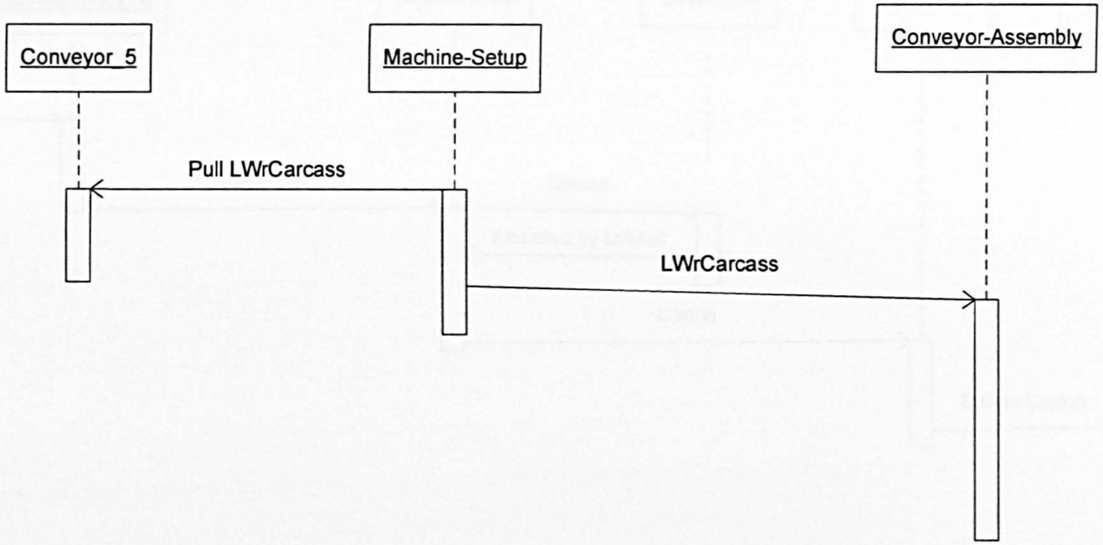
Sequence Diagram: Operation cell with conveyor: Case Study 3: Intermediate Process- Wrap



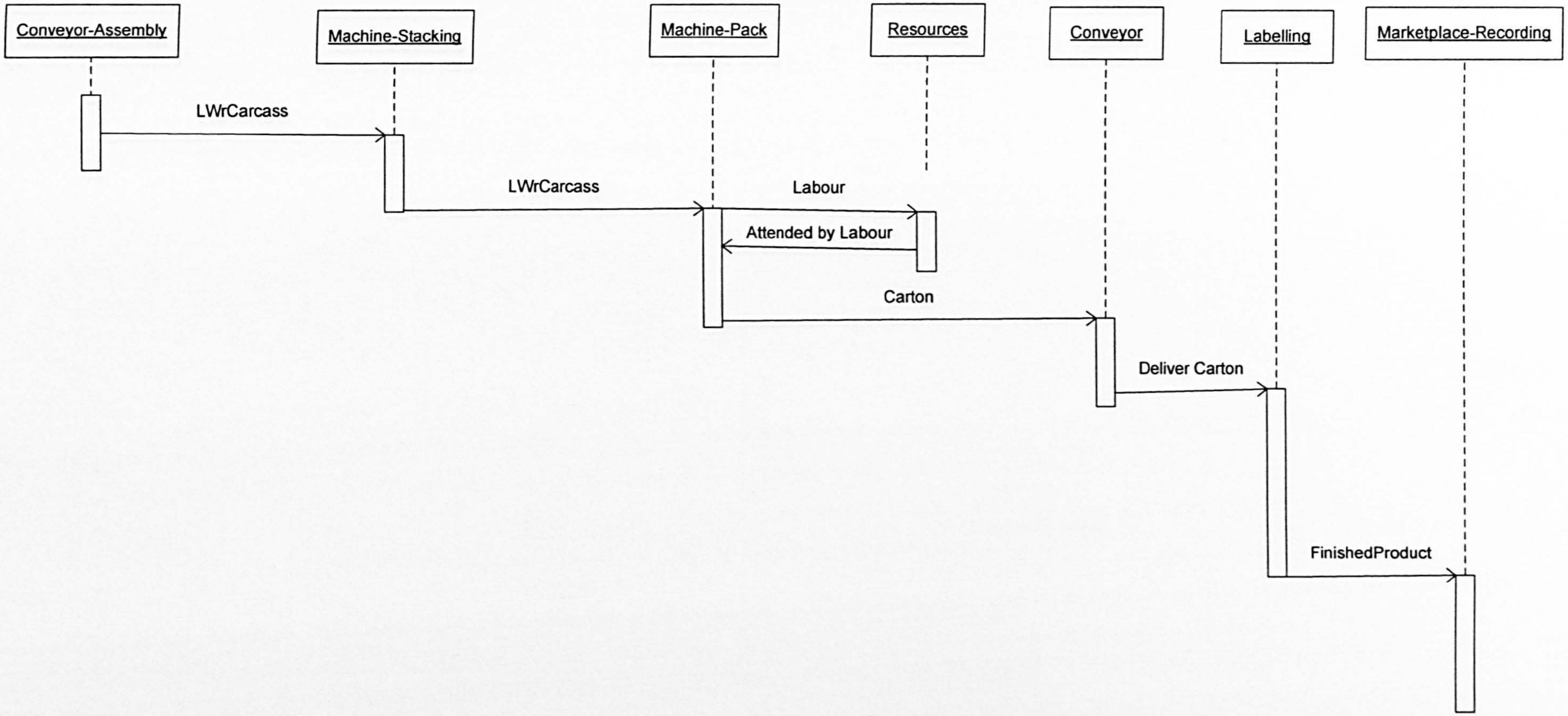
Sequence Diagram: Operation cell with conveyor: Case Study 3: Intermediate Process- Labelling



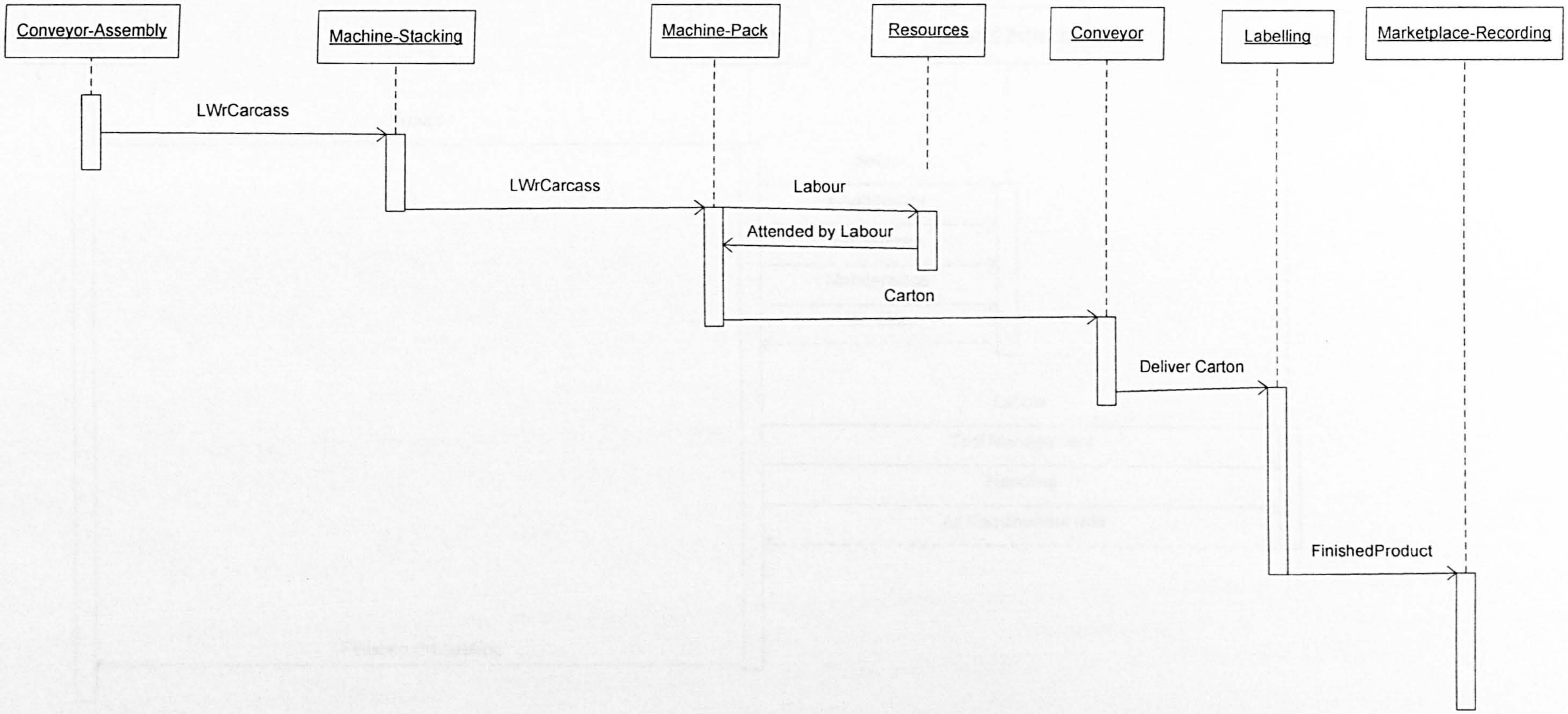
Sequence Diagram: Operation cell with conveyor: Case Study 3: Intermediate Process- Attachment



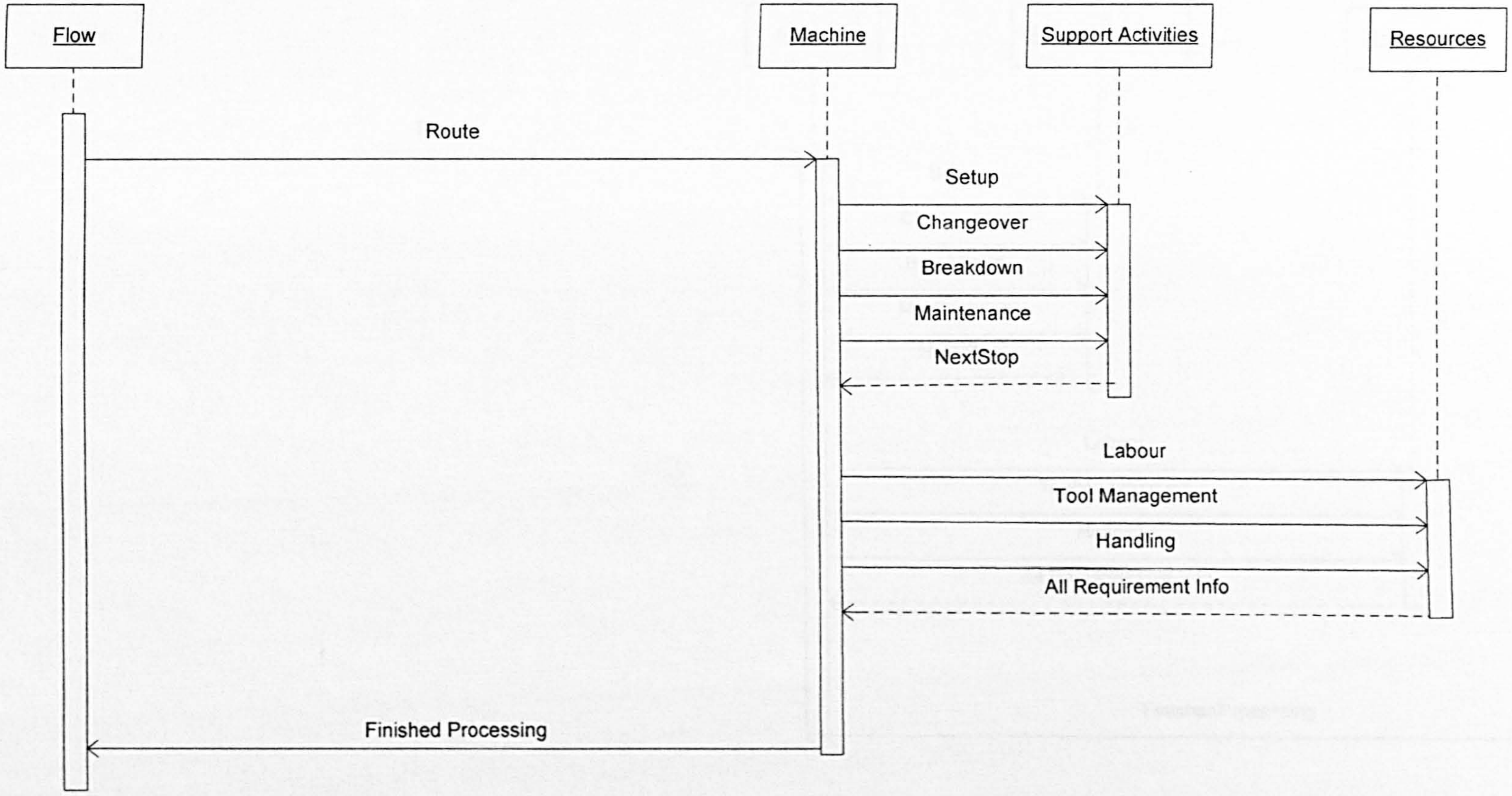
Sequence Diagram: Operation cell with conveyor: Case Study 3: End Process- Packing



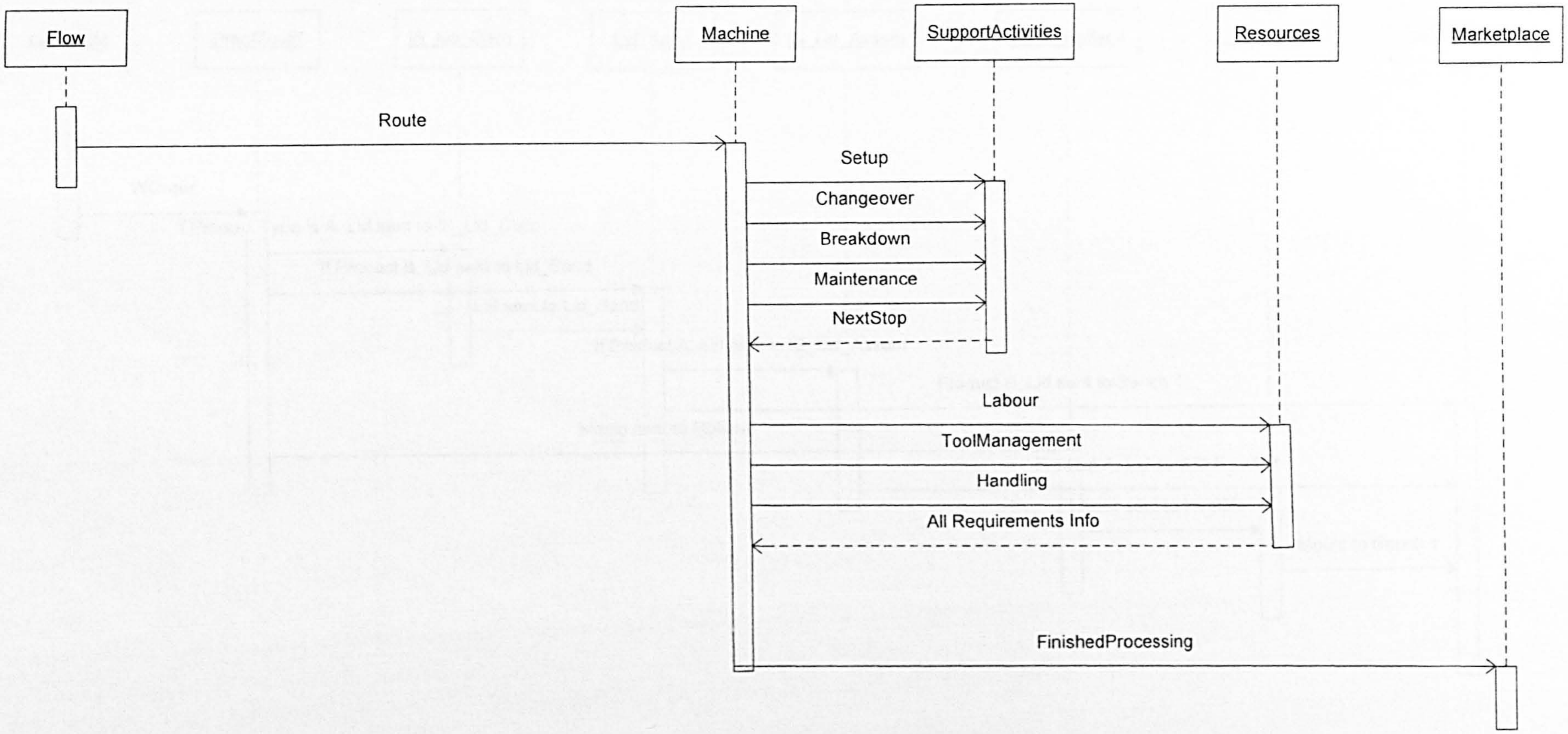
Sequence Diagram: Operation cell without conveyor: Start Process-InfoFlow



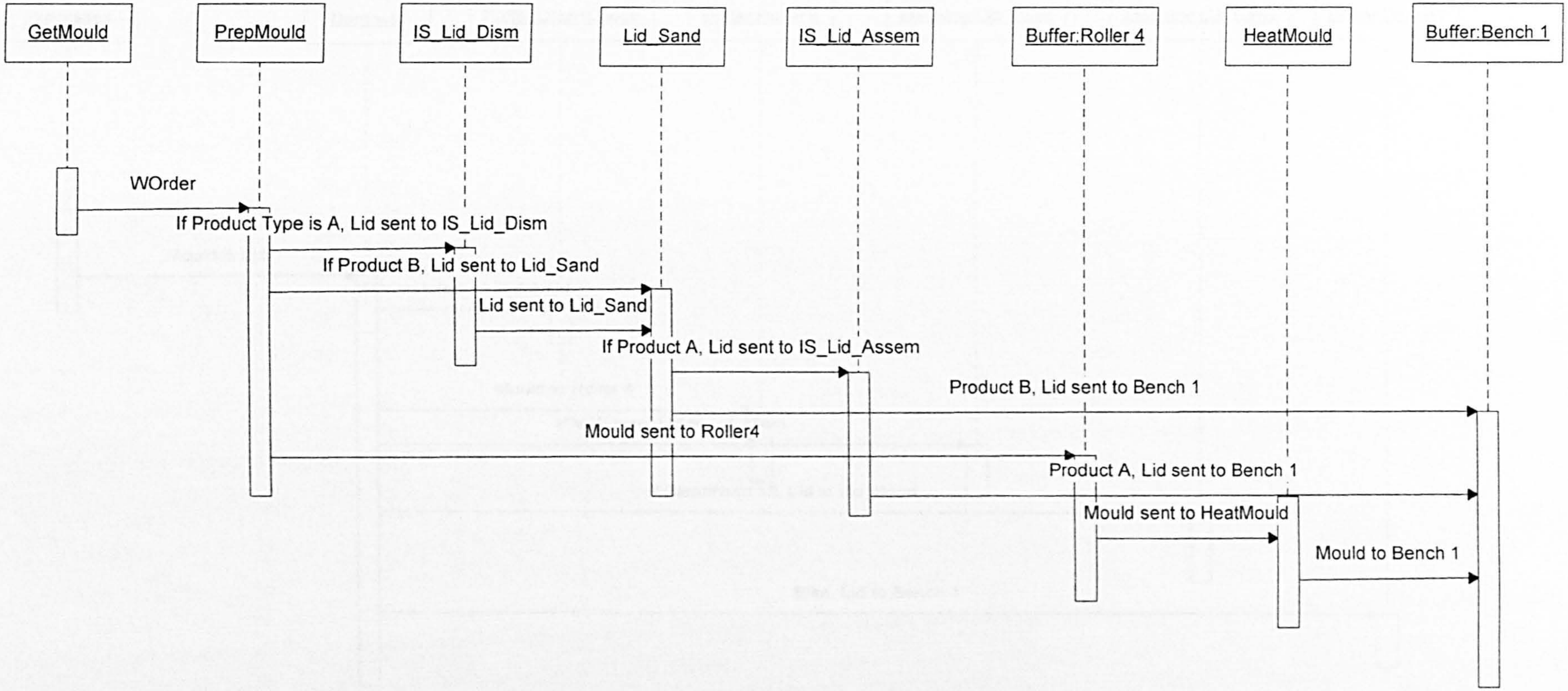
Sequence Diagram: Operation cell without conveyor: Intermediate Process-InfoFlow



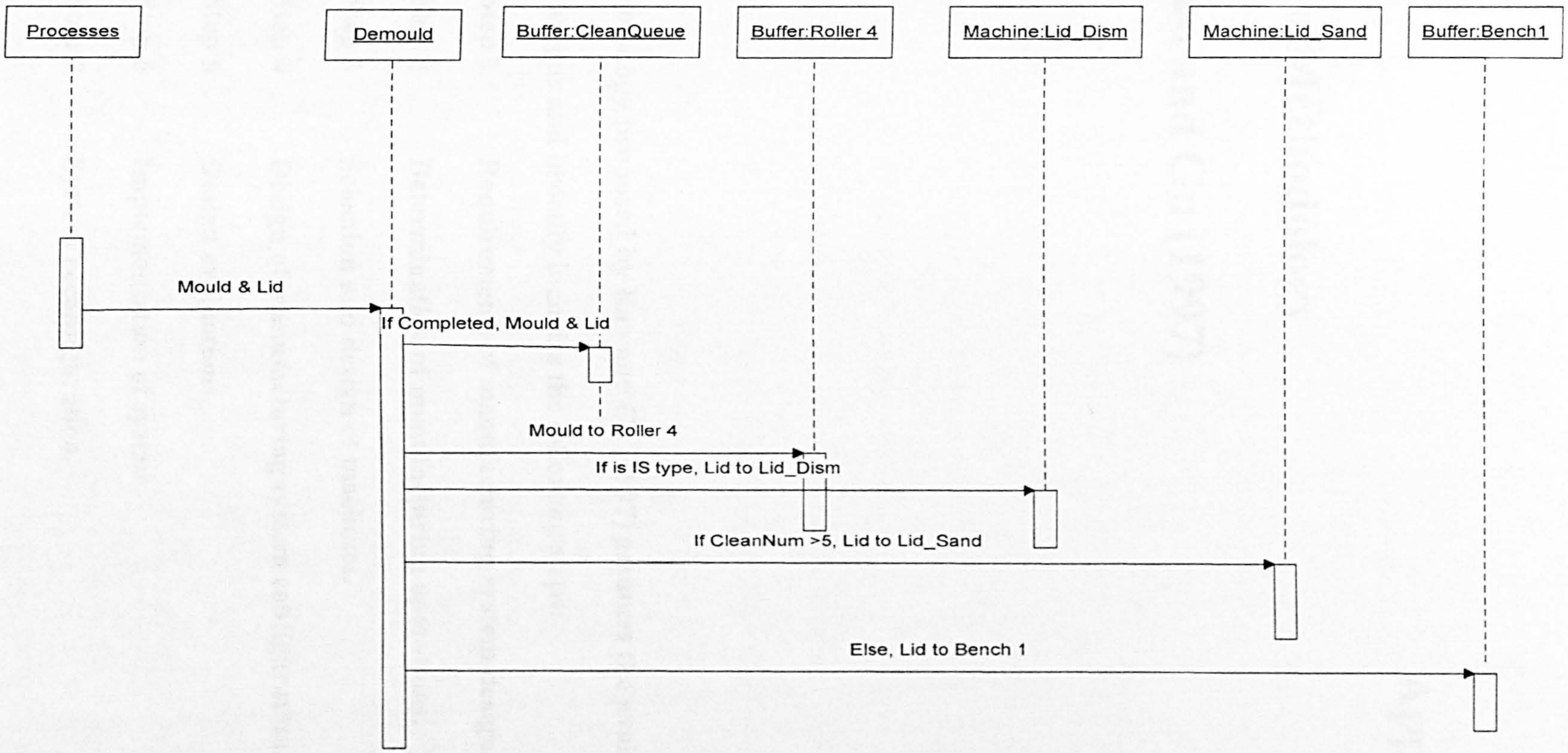
Sequence Diagram: Operation cell without conveyor: End Process-InfoFlow



Sequence Diagram: Case Study 3- PrepMould



Sequence Diagram: Case Study 2- DeMould



Appendix B

Design Methodology

By Rao and Gu (1997)

The methodology proposed by Rao and Gu (1997) assumes the availability of the product designs and broadly includes the following steps:

- **Step 1 Requirements of manufacturing system design.**
- **Step 2 Determination of manufacturing operations.**
- **Step 3 Selection and design of machines.**
- **Step 4 Design of manufacturing system configuration.**
- **Step 5 Design evaluations.**
- **Step 6 Implementation of system.**
- **Step 7 System reconfiguration.**

Design methodology of manufacturing systems by Rao and Gu, 1997

a) Step 1 Requirements of manufacturing system design

Technological constraints play a crucial role in the determination of machine and process flexibility. Out of many such restrictions that may play a role during system design, the ones that are considered are the limitations placed on the feasibility of grouping operations on a machine, such as:

- feasibility of the operations in terms of accuracy and surface finish;
- availability of tools and work holding devices;
- feasibility of grouping operations;
- physical constraints;
- layout constraints in terms of available space; and
- constraints on the material handling system.

The requirements are not general but technical on the machine of a process. The results of this step are the requirements or constraints for the manufacturing system to be designed, which include changes to product design, production volume, capabilities, capacities and short and long-term production forecasts.

b) Step 2 Determination of manufacturing operations

Once product design, production volumes and forecasts of demands are known, the next step to addresses the examination of the processes that should be used to manufacture the products. This is an important step as it governs the design of the entire manufacturing system. The operations are defined as the fundamental building blocks. All other aspects of system design, such as needs and objectives, are reflected through these building blocks. The building block refers to that "operation" which govern one set of processes. For example: the process of generating a hole (drilling operation) is similar to a number of other operations such as hole enlarging, rough, boring and reaming, but for the tools involved. Therefore "drilling" operations are considered as the abstract operation which describes all other similar operations. Accordingly, the following activities are proposed to determine the capabilities required for the selection and design of machines:

- manufacturing process analysis;
- determination of the cost effective operations to manufacture the products;
- determination of the tools needed; and
- determination of tolerance requirements for the operations.

The output from this step includes manufacturing operations, critical tooling requirements, accuracy and other technical constraints which are essential for machine selections.

c) Step 3 Selection and design of machines

Machine requirement design involves determining the operational requirements and machine capabilities for the system that needs to be designed. When selecting machines, the following are taken into account:

- accommodation of uncertainties in the demand forecasts for a certain time period;
- the number of each type of operation required to be present within the system;
- determination and incorporation of the desired operational and process flexibility;
- incorporation of the technological constraints identified at the conceptual stage while determining the number and type of operations to be present on each machine;

- a concurrent consideration of the system configuration; and
- a concurrent consideration of the material handling requirements.

Based on the above analysis, selection or design of machines can be carried out. Output of this stage is a list of machines to be purchased or designed, or which already exist.

d) Step 4 Design of manufacturing system configurations

After machines are determined, the next logical step is to arrange the machines into a system, i.e. layout design. When determining a layout, other factors such as the machine selection, production strategies (make to order or make to stock) and types of manufacturing systems (flexible manufacturing systems, cellular manufacturing systems or job-shop systems) are also considered. The selection of the proper type of system has a significant impact on the productivity, cost of the systems, and the flexibility for accommodating any future changes. In order to achieve the best layout of machines and the location of groups of these machines (depending on the configuration chosen) in relation to one another, the space requirements or availability should first be considered. These are imposed in the form of configuration constraints at the conceptual stage. In most cases, existing machines, environmental and other constraints must also be considered.

Furthermore, requirements to determine an acceptable configuration involve:

- determination of the frequency of movement of parts between machines;
- determination of the buffer sizes and storage requirements needed at each of the machines;
- specification of the physical and locational constraints;
- specification of the priorities in scheduling parts; and
- specification of the process plan.

Buffer sizes, batch sizes and storage space can all have a major effect on the ability of a company to meet its overall objectives. These must be considered during the system design process to achieve long-term optimisation.

Consequently, the desirable characteristics of the system being designed need to be established at the conceptual stage to achieve a balance between the desired levels of these operating parameters, and the costs which will be incurred. To establish the implications (in operational terms) of different tradeoffs between batch size and in-process storage quantities, a discrete event simulation model provides a useful analysis tool (Wu, 1992).

The specifications of the Material Handling System (MHS) are directly tied to machine requirement design, system configuration, process planning and scheduling systems. Process plans are also important to identify at this stage as they provide the sequence of productions. The process sequences should be reflected in the layout design.

At this stage, the detailed scheduling techniques such as despatching rules have not been finalised. Production strategies also have an impact on scheduling approach selection. These should also be considered when selecting a material handling system such as conveyor systems or forklift trucks. The concurrent consideration of the material handling system requirements will avoid the occurrence of bottlenecks through changes in machine requirement design and system configuration.

e) Step 5 Design evaluation

Once system layout is generated, the following step is to evaluate the layout and suggest the necessary changes on the design to meet the business objectives and constraints. Modelling and simulation tools are needed here to give a comprehensive evaluation. The purpose of the simulation model is to determine the impact of the machine layout on the utilisation of the machines, idle time at each machine, material handling time and throughput time. It can also evaluate other characteristics of the systems. Essentially, the last three steps are iterative.

f) Step 6 Implementation of system

At the early stages of manufacturing systems design model development will involve a number of assumptions and some details are left due to the lack of detailed information about the systems. Once the design is evaluated, good design candidates can be selected for implementation. In this stage, further analyses might be needed with more detailed information and practical constraints are added to the model. In the implementation, these details are constantly reviewed so that the implementation can achieve the balanced optimum results.

g) Step 7 System reconfiguration

This stage identifies the changes a designed system needs to undergo to accommodate the variation in the previously defined goals and objectives. It also determines certain aspects of system reconfiguration such as system life and intricate changes at the system, subsystem and machine levels. It should be remembered that system design was carried out based on forecasts for a specified time period. Accordingly, system reconfiguration involves the following steps:

- Step 1: Identification of a particular point in the current position when reconfiguration is carried out.
- Step 2: Identification of the point of reconfiguration, i.e. the point in the new forecast at which the current system may require reconfiguration.
- Step 3: Determination of the nature of reconfiguration needed, (e.g. system level, cell level or machine level).

- Step 4: Determination of the changes to system configuration that may be needed.
- Step 5: Determination of changes that may be required to the material handling system.

Step 1 determines the point at which sudden changes require the current system to be reconfigured. At Step 2 the identification of the point of reconfiguration is dependent on the forecasts received in future. The point of reconfiguration identifies the approximate time at which the current system is unable to handle the changes in product volume and design. The same strategy can be used to determine the point of re-configuration if the forecasts change within the current design period.

Step 3 determines the nature of reconfiguration that is imposed by the change in product demand and design changes. This step derives from the integrated design methodology to determine the changes at the system or sub-system level.

Steps 4 and 5 are called for dependent on the situation and the nature of reconfiguration required (Rao and Gu, 1995).

The major steps above cover a series of steps to carry out the main task. And it is adapted from work by Rao and Gu (1997) paper. The design methodology covers in detail a manufacturing system optimisation procedure. These steps identify some key issues like technology requirement and decisions on selection whether it is the operational procedure or hardware is required to carry out the functionality. With a structured manner and established methods, less time and effort to carry out a manufacturing system study project.

Appendix C

Use Case Scenarios

by McLean and Leong (2002)

McLean and Leong (2002) identify an initial sampling of simulation case study types. Each study is briefly defined below:

Market forecast – model past, present, and future economic and market trends to forecast future demand for products and estimate required production levels.

Logistics network – model order processing, warehousing, inventory, and transportation activities to optimise performance of a supply chain and meet customer performance levels, see (Shapiro 2001).

Site selection – evaluate the cost and expected performance of a plant given different projected operating levels at various sites based on differences in the cost of real estate, transportation, utilities, labour availability, etc.

Business process – model the flow and sequence of business processes, events, conditions on users and organisational units to optimise overall system performance through the reduction of bottlenecks, duplicate, and non-value added activities.

Scheduling – evaluate the effect of changes of scheduling policies and algorithms on operational cost, performance, throughput, etc.

Plant layout – evaluate the effects of different layout configurations on the performance of a system, floor space requirements, material handling costs, buffer storage requirements, throughput, interactions between systems (vibration, heat, cleanliness issues), etc.

Capital equipment – model production operations with changes to capital equipment configurations to evaluate changes in production capacity and operational costs.

Workforce – determine effects on operational costs of changes in workforce including modifications to employee skill levels, work calendar, shift schedules, layoffs, use of contract workers, absenteeism, etc.

Product mix – evaluate the effects of changes of product mix on performance including cost of operations, capacity, resource utilisation, schedule, etc.

Capacity analysis – model existing and projected workloads to determine available (un-used) capacity of production and support resources.

Line balancing – model changes in flow line performance, throughput, cycle time, etc. due to changes in the line configuration, assignment of operations and workers station on the production line.

Cost Estimation – simulate actual production operations for a product or order to generate expected labour, material, and processing costs.

Process validation – simulate the execution of manufacturing plans, programs, and processes to validate that data is correct and will produce expected results.

Process capability – model systems to determine whether production capabilities are sufficient to meet process requirements including the use of statistical process control techniques to determine whether processes can be kept in control range.

Tolerance analysis – model the effects of tolerance stack up on overall tolerance budget for a product or machine setup configuration to determine the probability that an instance of the product will meet specifications.

Ergonomic analysis – evaluate ergonomic aspects of worker tasks for efficiency of operation, theoretical production rate, risk of injury, rest requirements, etc.

Tooling – model various tool management plans, definition of standard tool sets, tool wear monitoring, tool crib stocking levels, and allocation strategies to evaluate their impact on overall system performance and production costs.

Inventory – evaluate impact on system performance, reduction of work-in-process, and carrying costs due to changes in inventory management policies. Policies include size, location, allocation strategies for storage areas, reorder point and safety stock levels, Just-in-Time (JIT) delivery from suppliers, security systems, inventory tracking mechanisms, etc.

Material handling – model the effects of changes to material delivery, storage and retrieval systems, shipping and receiving, kitting stations, etc. on performance, operational costs, etc.

Maintenance – model the effects of changes in preventive maintenance schedules, maintenance personnel, availability of repair parts, equipment maintenance costs, equipment reliability, etc. on the overall performance of the plant and cost of operations.

Appendix D

Data Collection Questionnaire

- Process Data
- Downtimes Data
- Labour Data
- Demand Data
- Process Details

Questionnaire

Process Data **Company Name:**

Historical Data Y/N

New Data Y/N

List the Main Processes

Name	Cycle time (mins)	Critical Level (1-100)	Deviation (SML)	Process Variability (~-)	Changeover Affect (SML)	Labour Dependant %	Dedication Level %	Mean time to Failure	Mean Time to Repair	Replaceable Machines

Downtimes Activities

Historical Data Y/N
New Data Y/N

Downtimes Activities	Time	Frequency	Labour Type	Labour Requirement	Processes Involved	Tools Involved	Replaceable Tools

Downtimes include all auxiliary activities like changeover, setup, loading, cleaning and etc.

Process Details

1	Process Routes:	Product-based
		Process-based
		Production-line
		Layout-based
		Cellular
		Functional
		Assembly-line
		FMS
		Fluids Flow
		Fixed position layouts
		Others.Please specify
2	Frequency of changes on routes	SML
3	Changes of Routes	Particular pattern
		Changes all the time
4	Replenishment system:	Cell-based
		Pre-kitted
		Kanban-bin
		Scheduled release
		Supplier delivered
		Others.Please specify
5	Spaces of Marketplace	SML
6	Changes of Marketplace	SML
7	Changes of Space in Marketplace	SML

Material Handling

8	Material Handling time	SML
9	Impact of Material handling time on Lead Time	SML
10	% of Material Transport time against Lead time	
11	Changes of Material Handling routes	SML
12	Material Handling Systems Reconfigurability	SML
13	Labour Intensive	Y/N
14	The percentage of ratio	% Automatic
		% Labour
15	Automatic Handling	Conveyor
		AGV
		Robot
		Others.Please specify
		Linked system
16	Other Tools	Trolleys
		Baskets
		Stack
		Boxes
		Others.Please specify

Quality Issues

17	What quality measurement is put in place?	Random Test

		TQM	
		Statictical Quality Control	
		Preventive Maintenance	
		Others please specify	
18	The percentage of ratio	% Scrap	
		% Rework	
19	What happen to rework parts?		
20	Which have a higher priority?	Parts in Queue	
		Rework parts	
21	Machine Quality Control		
22	Tooling Quality Control		
23	People Quality Control		
24	Materials Handling Quality Control		

Management Policies

25	Use of any visual management	Kanban	
		Others.Please specify	
26	Number of Kanban		
27	Kanban Zones?	Y/N	
28	Implementation of SMED	Y/N	
29	Implementation of 5S	Y/N	
30	Implementation of Five Zeros	Y/N	
31	Analytical Tool	Pipeline Map	
		Process Flow chart	
		Ishikawa Diagram	
		Frequency Checksheet	
		Overall Equipment effectiveness	
		Pareto Analysis	
		ABC Analysis	
		Improvement monitoring charts	
		Statistical Quality Control charts	
		Scatter Diagram	
		Quality Function Deployment	
		Quality Circle	
		Failure Mode, Effect and Criticality analysis (FMECA)	

Process Performance

32	Machine Utilisation	
33	Tool Utilisation	
34	People utilisation	
35	Material Handling Utilisation	
36	Throughput Time	
37	Capacity	

Product

1	Range of Product	SML
2	Percentage of Products that are Bespoke	
3	Percentage of Products that are Re-Configurable	
4	Product Similarity	SML
5	Component Replacibility	
6	Component Replacibility by Alternative supplier	
7	Component Process Replacibility	
8	Product Variation	SML
9	% of Product Mix	
10	Future Introduction of Product	Y/N
11	Product Termination	Y/N
12	If Yes, please indicate what happen to the product	
13	Prioritise Product Policy	Y/N
14	If Yes, please name the product:	
15	Do you have core component that is share across product?	Y/N
16	If Yes, please name the component:	
17	Volume of Finished Inventory	SML
18	Volume of Work In Progress	SML
19	Inventory Carrying cost	
20	Inventory Ordering cost	
21	Inventory Stockout Cost	
22	Safety stock	

Demand

1	Demand Stability	SML	
2	Demand Fluctuation	(~-)	
3	Demand Source		
4	Demand Pattern	Changes all the time	
		Same Pattern	
		Others.Please specify	
5	Availability of Historical Demand Data	Y/N	
6	Demand Direct from Customer	Y/N	
7	Demand Direct from Sales Department	Y/N	
8	Planing Tools?	Please specify	
9	Split order	Y/N	
10	Material Ordering Policy	Safety Stock Trigger Point	
		Economic Order Quantity	
		Kanban Trigger Point	
		Others.Please specify	
11	Shop floor Ordering Policy	FIFO	
		Batching	
		Customer Prioritise	
		Shortest Lead Time	
		Longest Lead Time	
		Others.Please specify	
12	Calculation of Lead time		

Breakdown of calculation

Elements	Time

Labour

1 Labour Skill Level SML
2 Ease of Training SML
3 Time to Train SML
Labour Skills Replacibility SML
7 Labour Type

	Cost

4 How many Shifts are there?
5 Are all shift the same pattern?
6 The break down of in a shift

Shift 1

Time	Activities

Shift 2

Time	Activities

Shift 3

Time	Activities

Shift 4

Time	Activities

8 Changes in Labour Requirement SML

9 Number of Labour Involved in Process		Cost
10 Total Labour Requirement		

Appendix E

Data Collection Questionnaire
Case Study 4

- **Process Details**
- **Demand Data**
- **Labour Data**

The following data are in the Excel spreadsheet (Appendix F):

Process Data
Machine Data
Downtimes Data
Product Data

Labour, Layout and Control details are not defined.
Due to New Processes, performance section is irrelevant.

Process Details

1	Process Routes:	Product-based	
		Process-based	√
		Production-line	√
		Layout-based	
		Cellular	
		Functional	
		Assembly-line	
		FMS	
		Fluids Flow	
		Fixed position layouts	
		Others.Please specify	
2	Frequency of changes on routes	SML	L
3	Changes of Routes	Particular pattern	
		Changes all the time	√
4	Replenishment system:	Cell-based	
		Pre-kitted	
		Kanban-bin	√
		Scheduled release	
		Supplier delivered	
		Others.Please specify	
5	Spaces of Marketplace	SML	L
6	Changes of Marketplace	SML	L
7	Changes of Space in Marketplace	SML	S

Material Handling

8	Material Handling time	SML	L
9	Impact of Material handling time on Lead Time	SML	M
10	% of Material Transport time against Lead time		
11	Changes of Material Handling routes	SML	M
12	Material Handling Systems Reconfigurability	SML	M
13	Labour Intensive	Y/N	Y
14	The percentage of ratio	% Automatic	90%
		% Labour	10%
15	Automatic Handling	Conveyor	√
		AGV	
		Robot	
		Others.Please specify	Promote
16	Other Tools	Linked system	√
		Trolleys	√
		Baskets	√
		Stack	
		Boxes	
		Others.Please specify	Heat treat containers

Quality Issues

17	What quality measurement is put in place?	Random Test	√

		TQM	
		Statictical Quality Control	√
		Preventive Maintenance	√
		Others please specify	
18	The percentage of ratio	% Scrap	15%
		% Rework	
19	What happen to rework parts?		
20	Which have a higher priority?	Parts in Queue	√
		Rework parts	
21	Machine Quality Control		
22	Tooling Quality Control		
23	People Quality Control		
24	Materials Handling Quality Control		

Management Policies

25	Use of any visual management	Kanban	√
		Others.Please specify	
26	Number of Kanban		
27	Kanban Zones?	Y/N	Y
28	Implementation of SMED	Y/N	
29	Implementation of 5S	Y/N	
30	Implementation of Five Zeros	Y/N	
31	Analytical Tool	Pipeline Map	
		Process Flow chart	√
		Ishikawa Diagram	√
		Frequency Checksheet	
		Overall Equipment effectiveness	
		Pareto Analysis	
		ABC Analysis	
		Improvement monitoring charts	
		Statistical Quality Control charts	
		Scatter Diagram	
		Quality Function Deployment	
		Quality Circle	
		Failure Mode, Effect and Criticality analysis (FMECA)	

Product

1	Range of Product	SML L
2	Percentage of Products that are Bespoke	
3	Percentage of Products that are Re-Configurable	
4	Product Similarity	SML M

5	Component Replaceable		
6	Component Replaceable by Alternative supplier		
7	Component Process Replaceable		
8	Product Variation	SML	L
9	% of Product Mix	L	
10	Future Introduction of Product	Y/N	Y
11	Product Termination	Y/N	Y
12	If Yes, please indicate what happen to the product		
13	Prioritise Product Policy	Y/N	N
14	If Yes, please name the product:		
15	Do you have core component that is share across product?	Y/N	
16	If Yes, please name the component:		
17	Volume of Finished Inventory	SML	M
18	Volume of Work In Progress	SML	L
19	Inventory Carrying cost		L
20	Inventory Ordering cost		L
21	Inventory Stockout Cost		L
22	Safety stock		L

Demand

		Option	Answer
1	Demand Stability	SML	M
2	Demand Fluctuation	(~-)	
3	Demand Source		
4	Demand Pattern	Changes all the time	
		Same Pattern	√
		Others.Please specify	
5	Availability of Historical Demand Data	Y/N	N
6	Demand Direct from Customer	Y/N	Y
7	Demand Direct from Sales Department	Y/N	Y
8	Planing Tools?	Please specify	
9	Split order	Y/N	N
10	Material Ordering Policy	Safety Stock Trigger Point	
		Economic Order Quantity	
		Kanban Trigger Point	√

		Others.Please specify	
11	Shop floor Ordering Policy	FIFO	√
		Batching	
		Customer Prioritise	
		Shortest Lead Time	
		Longest Lead Time	
		Others.Please specify	

	Labour	Option	Answer
1	Labour Skill Level	SML	S
2	Ease of Training	SML	M
3	Time to Train	SML	M
4	Changes in Labour Requirement	SML	M

Appendix F

Case Study 4
Excel Spreadsheets

- **Demand (4 different configurations)**
- **Operations Data**
- **Labour Data**
- **Marketplaces Data**
- **Product A and C Cycle Times (Gear)**
- **Product A and C Routes (Gear)**
- **Product A and C Distances (Gear)**
- **Product B Cycle Times (Shaft)**
- **Product B Routes (Shaft)**
- **Product B Distances (Shaft)**
- **Downtimes Data**

Shift (Calculated)	Num of Shifts	Demand Per Shift	Total Demand (Calculated)	Set Name	Set Quantity	Gear Trans 1st O/S	Gear Trans 2nd O/S	Gear Trans 3rd I/S	Gear Trans 4th I/S	Gear Trans 5th I/S	Gear Trans 6th I/S	Gear Trans Rev	Gear Trans 3rd O/S	Gear Trans 4th O/S	Gear Trans 5th O/S	Gear Trans 6th O/S	Ring Gear	Input Shaft	Rev Shaft	Output Shaft
						7M161/AA 7M161/AB	7M162b/AA 7M162b/AB	7M003b/AA 7M003b/AB	7M004/AA 7M004/AB	7M005/AA 7M005/AB	7H518/AA 7H518/AB	7M006/AA 7M006/AB	7137/AA 7137/AB	7112/AA 7112/AB	7144/AA 7144/AB	7M202/AA 7M202/AB	7G334/AA 7G334/AB	7L253/AA 7L253/AB	7A356/AA 7A356/AB	7061/AA 7061/AB
1	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
18	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
35	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
45	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
52	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
86	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
103	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
113	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
120	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
154	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
171	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
181	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
188	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
222	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
239	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
249	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
256	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
290	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
307	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
317	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
324	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
358	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
375	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
385	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
392	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
426	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
443	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
453	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
460	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
494	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
511	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
521	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
528	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
562	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
579	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
589	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
596	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
630	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
647	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
657	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
664	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
698	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
715	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
725	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
732	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
766	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
783	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
793	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
800	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
834	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
851	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
861	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
868	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
902	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
919	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
929	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
936	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
970	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
987	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
997	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1004	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1038	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1055	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1065	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1072	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1106	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1123	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1133	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1140	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1174	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1191	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1201	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1208	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1242	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1259	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1269	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1276	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1310	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1327	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1337	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1344	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1378	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1395	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1405	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1412	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1446	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1463	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1473	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1480	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1514	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1531	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1541	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB
1548	34	509	17306	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1582	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1599	10	509	5090	Set3	15	7M161/AA	7M162b/AB	7M003b/AA	7M004/AB	7M005/AA	7H518/AB	7M006/AA	7137/AB	7112/AA	7144/AB	7M202/AA	7G334/AB	7L253/AA	7A356/AB	7061/AA
1609	7	509	3563	Set4	15	7M161/AB	7M162b/AA	7M003b/AB	7M004/AA	7M005/AB	7H518/AA	7M006/AB	7137/AA	7112/AB	7144/AA	7M202/AB	7G334/AA	7L253/AB	7A356/AA	7061/AB

Shift (Calculated)	Num of Shifts	Demand Per Shift	Total Demand (Calculated)	Set Name	Set Quantity	Gear Trans 1st O/S	Gear Trans 2nd O/S	Gear Trans 3rd I/S	Gear Trans 4th I/S	Gear Trans 5th I/S	Gear Trans 6th I/S	Gear Trans Rev	Gear Trans 3rd O/S	Gear Trans 4th O/S	Gear Trans 5th O/S	Gear Trans 6th O/S	Ring Gear	Input Shaft	Rev Shaft	Output Shaft
						7M161/AA 7M161/AB	7M162b/AA 7M162b/AB	7M003b/AA 7M003b/AB	7M004/AA 7M004/AB	7M005/AA 7M005/AB	7H518/AA 7H518/AB	7M006/AA 7M006/AB	7137/AA 7137/AB	7112/AA 7112/AB	7144/AA 7144/AB	7M202/AA 7M202/AB	7G334/AA 7G334/AB	7L253/AA 7L253/AB	7A356/AA 7A356/AB	7061/AA 7061/AB
1	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
18	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
35	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
52	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
69	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
86	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
103	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
120	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
137	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
154	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
171	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
188	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
205	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
222	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
239	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
256	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
273	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
290	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
307	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
324	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
341	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
358	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
375	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
392	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
409	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
426	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
443	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
460	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
477	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
494	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
511	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
528	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
545	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
562	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
579	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
596	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
613	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
630	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
647	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
664	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
681	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
698	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
715	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
732	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
749	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
766	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
783	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
800	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
817	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
834	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
851	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
868	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
885	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
902	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
919	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
936	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
953	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
970	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
987	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1004	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1021	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1038	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1055	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1072	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1089	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1106	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1123	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1140	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1157	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1174	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1191	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1208	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1225	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1242	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1259	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1276	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1293	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1310	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1327	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1344	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1361	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1378	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1395	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1412	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1429	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1446	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1463	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1480	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1497	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1514	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1531	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1548	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1565	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1582	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1599			0																	
1616			0																	

Shift (Calculated)	Num of Shifts	Demand Per Shift	Total Demand (Calculated)	Set Name	Set Quantity	Gear Trans 1st O/S	Gear Trans 2nd O/S	Gear Trans 3rd I/S	Gear Trans 4th I/S	Gear Trans 5th I/S	Gear Trans 6th I/S	Gear Trans Rev	Gear Trans 3rd O/S	Gear Trans 4th O/S	Gear Trans 5th O/S	Gear Trans 6th O/S	Ring Gear	Input Shaft	Rev Shaft	Output Shaft
						7M161/AA 7M161/AB	7M162b/AA 7M162b/AB	7M003b/AA 7M003b/AB	7M004/AA 7M004/AB	7M005/AA 7M005/AB	7H518/AA 7H518/AB	7M006/AA 7M006/AB	7137/AA 7137/AB	7112/AA 7112/AB	7144/AA 7144/AB	7M202/AA 7M202/AB	7G334/AA 7G334/AB	7L253/AA 7L253/AB	7A356/AA 7A356/AB	7061/AA 7061/AB
1	17	200	3400	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
18	17	300	5100	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
35	17	400	6800	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
52	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
69	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
86	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
103	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
120	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
137	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
154	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
171	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
188	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
205	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
222	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
239	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
256	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
273	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
290	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
307	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
324	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
341	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
358	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
375	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
392	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
409	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
426	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
443	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
460	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
477	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
494	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
511	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
528	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
545	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
562	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
579	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
596	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
613	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
630	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
647	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
664	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
681	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
698	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
715	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
732	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
749	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
766	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
783	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
800	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
817	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
834	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
851	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
868	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
885	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
902	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
919	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
936	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
953	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
970	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
987	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1004	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1021	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1038	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1055	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1072	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1089	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1106	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1123	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1140	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1157	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1174	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1191	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1208	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1225	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1242	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1259	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1276	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1293	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1310	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1327	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1344	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1361	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1378	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1395	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1412	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1429	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1446	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1463	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1480	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1497	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1514	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1531	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1548	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1565	17	509	8653	Set2	15	7M161/AB	7M162b/AB	7M003b/AB	7M004/AB	7M005/AB	7H518/AB	7M006/AB	7137/AB	7112/AB	7144/AB	7M202/AB	7G334/AB	7L253/AB	7A356/AB	7061/AB
1582	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1599			0																	
1599			0																	

Shift (Calculated)	Num of Shifts	Demand Per Shift	Total Demand (Calculated)	Set Name	Set Quantity	Gear Trans 1st O/S	Gear Trans 2nd O/S	Gear Trans 3rd I/S	Gear Trans 4th I/S	Gear Trans 5th I/S	Gear Trans 6th I/S	Gear Trans Rev	Gear Trans 3rd O/S	Gear Trans 4th O/S	Gear Trans 5th O/S	Gear Trans 6th O/S	Ring Gear	Input Shaft	Rev Shaft	Output Shaft
						7M161/AA 7M161/AB	7M162b/AA 7M162b/AB	7M003b/AA 7M003b/AB	7M004/AA 7M004/AB	7M005/AA 7M005/AB	7H518/AA 7H518/AB	7M006/AA 7M006/AB	7137/AA 7137/AB	7112/AA 7112/AB	7144/AA 7144/AB	7M202/AA 7M202/AB	7G334/AA 7G334/AB	7L253/AA 7L253/AB	7A356/AA 7A356/AB	7061/AA 7061/AB
1	17	200	3400	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
18	17	300	5100	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
35	17	400	6800	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
52	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
69	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
86	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
103	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
120	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
137	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
154	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
171	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
188	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
205	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
222	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
239	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
256	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
273	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
290	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
307	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
324	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
341	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
358	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
375	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
392	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
409	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
426	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
443	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
460	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
477	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
494	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
511	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
528	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
545	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
562	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
579	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
596	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
613	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
630	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
647	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
664	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
681	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
698	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
715	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
732	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
749	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
766	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
783	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
800	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
817	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
834	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
851	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
868	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
885	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
902	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
919	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
936	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
953	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
970	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
987	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1004	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1021	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1038	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1055	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1072	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1089	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1106	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1123	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1140	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1157	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1174	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1191	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1208	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1225	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1242	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1259	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1276	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1293	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1310	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1327	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1344	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1361	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1378	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1395	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1412	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1429	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1446	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1463	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1480	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1497	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1514	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1531	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1548	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1565	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1582	17	509	8653	Set1	15	7M161/AA	7M162b/AA	7M003b/AA	7M004/AA	7M005/AA	7H518/AA	7M006/AA	7137/AA	7112/AA	7144/AA	7M202/AA	7G334/AA	7L253/AA	7A356/AA	7061/AA
1599			0																	
1616			0																	

Operations

	PRID	Total Number of Machines	Number in Model	Max Input buffer in trollys	Max output buffer in trollys	OP MODEL NAME	Labour Type	Labourt Number	Max Wait	Dedicated = 1	2	3	4	5	6	7	8	9	10	11	12
Decant Gears	1	4	4	1000	1000	DEC_G	0	0	15	0	0	0	0								
Decant Ring Gears	2	1	1	1000	1000	DEC_R	1	1	15	0											
Marketplace Green Gear	3	1	1	1000	1000	MRK_GRN_G	0	0	15	0											
Turn+Hob+Deburr	4	12	12	1000	1000	10_20_30_35_G	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0
Turn (Ring Gear Only)	5	2	2	1000	1000	10_20_25_R	0	0	15	0	0										
Hob& Deburr/Chanmfer (Ring Gear only)	6	2	2	1000	1000	35_R	0	0	15	0	0										
Measure Gear	7	2	2	1000	1000	40_G	1	1	15	0	0										
Wash For Laser	8	2	2	1000	1000	55_G	0	0	15	0	0										
Assy/Laser Welding Green	9	1	1	1000	1000	60_70_G	0	0	15	0											
Decant Gear For HT	10	4	4	1000	1000	DECH_G	0	0	15	0	0	0	0								
Decant Ring Gear HT	11	1	1	1000	1000	DECH_R	0	0	15	0											
Heat Treatment	12	1	1	1000	1000	80_B	0	0	15	0											
Market Place Hard Gear	13	1	1	1000	1000	MRK_HRD_G	0	0	15	0											
Grind + Hardturning Bore & Cone & Coneface	14	12	12	1000	1000	110_1_G	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0
Grind + Hardturning Bore & Cone & Coneface(Ring Gear)	15	1	1	1000	1000	110_1_R	0	0	15	0											
Hard Finish Teeth (RZ400) (Ring Gear Only)	16	2	2	1000	1000	120_R	0	0	15	0	0										
Hard Finish Teeth (RZ150)	17	5	5	1000	1000	120_RZ150_G	0	0	15	0	0	0	0	0							
Hard Finish Teeth (Prawema)	18	4	4	1000	1000	120_Prw_G	0	0	15	0	0	0	0								
Assy/Laser Welding Hard	19	1	1	1000	1000	140_150_G	0	0	15	0											
Grind+Hardturning Bore & Cone & Coneface	20	7	7	1000	1000	155_G	0	0	15	0	0	0	0	0	0	0					
Wash Green/Hard	21	1	1	1000	1000	160_B	0	0	15	0											
Phosphation	22	1	1	1000	1000	210_B	0	0	15	0											
Wash Final	23	1	1	1000	1000	200_B	0	0	15	0											
Crack Detection	24	2	2	1000	1000	210_G	1	1	15	0	0										
Market Place Finished	25	1	1	1000	1000	MRK_FIN	0	0	15	0											
Decant Shaft	26	2	2	1000	1000	DEC_S	0	0	15	0	0										
Market Place Green Shaft	27	1	1	1000	1000	MRK_GRN_S	0	0	15	0											
Face, Center & Thread/Turn Profile Complete	28	4	4	1000	1000	10_20_S	0	0	15	0	0	0	0								
Hob Helical Teeth 1st Speed	29	5	5	1000	1000	30_40_S	0	0	15	0	0	0	0	0							
Deburr and Chamfer (Shaft)	30	2	2	1000	1000	50_S	0	0	15	0	0										
Check Teeth	31	1	1	1000	1000	60_S	1	1	15	0											
Roll Splines	32	2	2	1000	1000	70_80_S	0	0	15	0	0										
Gun Drill/Drill Cross Holes & Deburr	33	2	2	1000	1000	90_100_S	0	0	15	0	0										
Wash Green	34	0	0	1000	1000	45_B	0	0	15	0											
Turn Grooves	35	2	2	1000	1000	120_S	0	0	15	0	0										
Load HT Fixture	36	2	2	1000	1000	125_S	0	0	15	0	0										
UnLoad HT Fixture	37	2	2	1000	1000	175_S	0	0	15	0	0										
Market Place Hard Shaft	38	1	1	1000	1000	MRK_HRD_S	0	0	15	0											
Straighten 1	39	3	3	1000	1000	140_S	0	0	15	0	0	0									
Grind Grooves	40	3	3	1000	1000	180_S	0	0	15	0	0	0									
Grind Diameters and Length	41	7	7	1000	1000	190_S	0	0	15	0	0	0	0	0	0	0					
Profilegrinding Gear Teeth	42	2	2	1000	1000	220_S	0	0	15	0	0										
Powerhoning	43	4	4	1000	1000	230_S	0	0	15	0	0	0	0								
Grinding Diameters	44	1	1	1000	1000	255_S	0	0	15	0											
Assembly Line	45	1	1	1000	1000	ASSEM	0	0	0	0											

Labour

Labour Area	Labour Type	Labour Number	Operation Includes:	Number of Machines	
Green Gear	**A**	**2**	Ops 10_20_30_35_G	6	
	B	**2**	Ops 10_20_30_35_G	6	
	C	**1**	45_B,60_70_G,140_150_G	4	If there is 3 Laser Machines
	D	**-**			
	E	**-**			
	IMT	**2**			
Labour Total		**7**			
Ring Gear	**A**	**2**	10_20_25_R, 35_R	4	
	B	**1**	110_R, 120_R	3	
	C	**-**			
	D	**-**			
	E	**-**			
	IMT	**-**			
Labour Total		**3**			
Green Shaft	**A**	**1**	Ops 10_20_S	4	Maybe 5
	B	**1**	Ops 30_40_S	5	
	C	**1**	50_S, 70_80_S	4	
	D	**1**	90_100_S, 120_S	4	
	E	**-**			
	IMT	**2**			
Labour Total		**6**			
Hard Gear	**A**	**1**	Ops 110_G	4	
	B	**1**	Ops 110_G	4	
	C	**1**	Ops 110_G	4	
	D	**5**	Ops 120_RZ150_G, 120_Prw_	16	
	E	**-**			
	IMT	**2**			
Labour Total		**10**			
Hard Shaft	**A**	**1**	Ops 140_S, 180_S	7	
	B	**1**	Ops 190_S	4	
	C	**1**	Ops 190_S, 220_S,		
	D	**1**	Ops 230_S, 255_S,160_B	6	
	E	**-**			
	IMT	**0**			
Labour Total		**4**			

Market Places

					Handling	Basket Size	Basket per Trolley	Part Per Trolley	Mkt Place GREEN	Trolley per Batch			Trolleys	Quantity	Mkt Place HARD	Trolley per Batch			Trolleys	Quantity	Market Place Finishec	Trolley per Batch			Trolleys	Quantity				Total	By Type	Total	By Type	Total	By Type			not assigned	Finished	
30	Code	Derv	PartIndex	DERVID	Variable	Pt_Bkt	Bkt_Tr	Pt_Tr	Variable	Tr_Bat	Batch	MaxBatch	Trolleys	Quantity	Variable	Tr_Bat	Batch	MaxBatch	Trolleys	Quantity	Variable	Tr_Bat	Batch	Maxbatch	Trolleys	Quantity	Type	Index	EmpTies	Trolleys1	Basket 1	Trolleys2	Basket 2	Racks	Fixtures	Trolleys1 not assigned	Trolleys2 not assigned	Racks	Residual	Rand
Gear Trans 1st O/S	7M161	AA	1	1		8	12	96		7	672	1	7	672		7	672	6	42	4032		7	672	4	28	2688	1	1		28	336	28	336	28	336	100	100	100	1	1
Gear Trans 1st O/S	7M161	AB	1	2		8	12	96		7	672	1	7	672		7	672	6	42	4032		7	672	4	28	2688	1	2		28	336	28	336	28	336				4	1
Gear Trans 2nd O/S	7M162b	AA	2	1		12	12	144		5	720	1	5	720		5	720	6	30	4320		5	720	4	20	2880	1	3		20	240	20	240	20	240				2	3
Gear Trans 2nd O/S	7M162b	AB	2	2		12	12	144		5	720	1	5	720		5	720	6	30	4320		5	720	4	20	2880	1	4		20	240	20	240	20	240				2	0
Gear Trans 3rd I/S	7M003b	AA	3	1		12	10	120		5	600	1	5	600		5	600	6	30	3600		5	600	4	20	2400	1	5		20	200	20	200	20	200				1	3
Gear Trans 3rd I/S	7M003b	AB	3	2		12	10	120		5	600	1	5	600		5	600	6	30	3600		5	600	4	20	2400	1	6		20	200	20	200	20	200				3	2
Gear Trans 4th I/S	7M004	AA	4	1		12	10	120		5	600	1	5	600		5	600	6	30	3600		5	600	4	20	2400	1	7		20	200	20	200	20	200				0	2
Gear Trans 4th I/S	7M004	AB	4	2		12	10	120		5	600	1	5	600		5	600	6	30	3600		5	600	4	20	2400	1	8		20	200	20	200	20	200				0	2
Gear Trans 5th I/S	7M005	AA	5	1		12	14	168		4	672	1	4	672		4	672	6	24	4032		4	672	4	16	2688	1	9		16	224	16	224	16	224				3	3
Gear Trans 5th I/S	7M005	AB	5	2		12	14	168		4	672	1	4	672		4	672	6	24	4032		4	672	4	16	2688	1	10		16	224	16	224	16	224				2	0
Gear Trans 6th I/S	7H518	AA	6	1		11	12	132		5	660	1	5	660		5	660	6	30	3960		5	660	4	20	2640	1	11		20	240	20	240	20	240				1	0
Gear Trans 6th I/S	7H518	AB	6	2		11	12	132		5	660	1	5	660		5	660	6	30	3960		5	660	4	20	2640	1	12		20	240	20	240	20	240				3	0
Gear Trans Rev	7M006	AA	7	1		11	12	132		5	660	1	5	660		5	660	6	30	3960		5	660	4	20	2640	1	13		20	240	20	240	20	240				2	4
Gear Trans Rev	7M006	AB	7	2		11	12	132		5	660	1	5	660		5	660	6	30	3960		5	660	4	20	2640	1	14		20	240	20	240	20	240				2	2
Gear Trans 3rd O/S	7137	AA	8	1		11	12	132		5	660	1	5	660		5	660	6	30	3960		5	660	4	20	2640	1	15		20	240	20	240	20	240				3	3
Gear Trans 3rd O/S	7137	AB	8	2		11	12	132		5	660	1	5	660		5	660	6	30	3960		5	660	4	20	2640	1	16		20	240	20	240	20	240				2	3
Gear Trans 4th O/S	7112	AA	9	1		12	14	168		4	672	1	4	672		4	672	6	24	4032		4	672	4	16	2688	1	17		16	224	16	224	16	224				1	0
Gear Trans 4th O/S	7112	AB	9	2		12	14	168		4	672	1	4	672		4	672	6	24	4032		4	672	4	16	2688	1	18		16	224	16	224	16	224				3	2
Gear Trans 5th O/S	7144	AA	10	1		12	14	168		4	672	1	4	672		4	672	6	24	4032		4	672	4	16	2688	1	19		16	224	16	224	16	224				1	2
Gear Trans 5th O/S	7144	AB	10	2		12	14	168		4	672	1	4	672		4	672	6	24	4032		4	672	4	16	2688	1	20		16	224	16	224	16	224				1	2
Gear Trans 6th O/S	7M202	AA	11	1		12	14	168		4	672	1	4	672		4	672	6	24	4032		4	672	4	16	2688	1	21		16	224	16	224	16	224				3	2
Gear Trans 6th O/S	7M202	AB	11	2		12	14	168		4	672	1	4	672		4	672	6	24	4032		4	672	4	16	2688	1	22		16	224	16	224	16	224				0	1
Ring Gear	7G334	AA	12	1		3	14	42		4	168	4	16	672		4	168	24	96	4032		4	168	16	64	2688	1	23		16	224	16	224	16	224				3	3
Ring Gear	7G334	AB	12	2		3	14	42		4	168	4	16	672		4	168	24	96	4032		4	168	16	64	2688	1	24		16	224	16	224	16	224				0	2
Input Shaft	7L253	AA	13	1		5	8	40		4	160	4	16	640		4	160	24	96	3840		4	160	16	64	2560	2	1		16	128	16	128	16	128				3	1
Input Shaft	7L253	AB	13	2		5	8	40		4	160	4	16	640		4	160	24	96	3840		4	160	16	64	2560	2	2		16	128	16	128	16	128				1	0
Rev Shaft	7A356	AA	14	1		16	8	128		5	640	1	5	640		5	640	6	30	3840		5	640	4	20	2560	2	3		20	160	20	160	20	160				2	2
Rev Shaft	7A356	AB	14	2		16	8	128		5	640	1	5	640		5	640	6	30	3840		5	640	4	20	2560	2	4		20	160	20	160	20	160				4	2
Output Shaft	7061	AA	15	1		8	8	64		5	320	2	10	640		5	320	12	60	3840		5	320	8	40	2560	2	5		20	160	20	160	20	160				2	2
Output Shaft	7061	AB	15	2		8	8	64		5	320	2	10	640		5	320	12	60	3840		5	320	8	40	2560	2	6		20	160	20	160	20	160				1	2
										142			200						1200						800					568		568								

Gear CycleTimes

				Gear Trans 1st O/S - 7M161		Gear Trans 2nd O/S - 7M162b		Gear Trans 3rd I/S - 7M003b		Gear Trans 4th I/S - 7M004		Gear Trans 5th I/S - 7M005		Gear Trans 6th I/S - 7H518		Gear Trans Rev - 7M006		Gear Trans 3rd O/S- 7137		Gear Trans 4th O/S-7112		Gear Trans 5th O/S- 7144		Gear Trans 6th O/S - 7M202		Ring Gear-7G334		
			Name	7M161	7M161	7M162b	7M162b	7M003b	7M003b	7M004	7M004	7M005	7M005	7H518	7H518	7M006	7M006	7137	7137	7112	7112	7144	7144	7M202	7M202	7G334	7G334	
			Derv.	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	
		32	PID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Machine Name	OpNum	Num	Step	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	
Decant Gears	DEC_G	4	1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0	0	
Decant Ring Gear	DEC_R	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0.17	
Marketplace Green Gear	MRK_GRN_G	1	3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Turn+Hob+Deburr	10_20_30_35_G	12	4	1.06	1.06	0.88	0.88	0.81	0.81	0.82	0.82	0.82	0.82	0.83	0.83	0.78	0.78	0.8	0.8	0.78	0.78	0.8	0.8	0.77	0.77	0	0	
Turn (Ring Gear Only)	10_20_25_R	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.1	1.1	
Hob& Deburr/Chanmfer (Ring Gear only)	35_R	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.16	1.16	
Measure Gear	40_G	2	7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1 per trolley
Wash Green	45_B	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	per 2 basket
Wash For Laser	55_G	2	9	0.5	0.5	0.5	0.5	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	
Assy/Laser Welding Green	60_70_G	1	10	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0.2	0.2	0	0	0	0	0	0	0	0	0	0	
Decant Gear For HT	DECH_G	4	11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0	0	
Decant Ring Gear	DECH_R	1	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0.17	
Heat Treatment	80_B	1	13	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	perTrolley
Decant Ring Gear	DECH_R	1	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0.17	
Decant Gear For HT	DECH_G	4	15	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0	0	
Marketplace Hard Gear	MRK_HRD_G	1	16	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Grind + Hardturning Bore & Cone & Coneface	110_1_G	12	17	1	1	1	1	0.82	0.82	0.97	0.97	0.97	0.97	0.97	0.97	0	0	0.84	0.84	0.83	0.83	0.83	0.83	0.84	0.84	0	0	
Grind + Hardturning Bore & Cone & Coneface	110_1_R	1	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.8	
Hard Finish Teeth (RZ400) (Ring Gear Only)	120_R	2	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	1.3	
Hard Finish Teeth (RZ150)	120_RZ150_G	5	20	0.55	0.55	0.55	0.55	0	0	0	0	0	0	0	0	0	0	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0	0	
Hard Finish Teeth (Prawema)	120_Prw_G	4	21	0	0	0	0	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0	0	0	0	0	0	0	0	0	0	0	0	
Measure Gear	40_G	2	22	2	2	2	2	2	2	2	2	2	2	2	2	0	0	2	2	2	2	2	2	2	2	2	2	1 per trolley
Wash For Laser	55_G	2	23	0	0	0	0	3	3	3	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	
Assy/Laser Welding Hard	140_150_G	1	24	0	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	
Grind + Hardturning Bore & Cone & Coneface	155_G	7	25	0	0	0	0	0.97	0.97	0.95	0.95	0.95	0.95	0.95	0.95	1.27	1.27	0	0	0	0	0	0	0	0	0	0	
Wash Hard	160_B	1	26	0	0	3	3	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	per 2 basket
Phosphation	210_B	1	27	0	0	3	3	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	
Hard Finish Teeth (RZ150)	120_RZ150_G	5	28	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	
Wash Final	200_B	1	29	3	3	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	per 2 basket
Crack Detection	210_G	2	30	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	
Marketplace Finished	MRK_FIN	1	31	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Assembly Line	ASSEM	1	32	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	

Component 1	1.68	1.68	1.5	1.5	1.23	1.23	1.24	1.24	1.24	1.24	1.25	1.25	1.4	1.4	1.22	1.22	1.2	1.2	1.22	1.22	1.19	1.19	4.87	4.87
Component 2	1.65	1.65	1.65	1.65	2.86	2.86	2.99	2.99	2.99	2.99	2.99	2.99	1.87	1.87	1.49	1.49	1.48	1.48	1.48	1.48	1.49	1.49	2.2	2.2
Basket1	0.25	0.25	0.25	0.25	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0	0	0	0	0	1	1
Basket2	1.5	1.5	10.5	10.5	3	3	3	3	3	3	3	3	12	12	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Trolley1	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962	962
Trolley2	2	2	2	2	2	2	2	2	2	2	2	2	0	0	2	2	2	2	2	2	2	2	2	2

Pt_Bkt	8	8	12	12	12	12	12	12	12	12	11	11	11	11	11	11	12	12	12	12	12	12	3	3
Bkt_Tr	12	12	12	12	10	10	10	10	14	14	12	12	12	12	12	12	14	14	14	14	14	14	14	14
Pt_Tr	96	96	144	144	120	120	120	120	168	168	132	132	132	132	132	132	168	168	168	168	168	168	42	42

LT1	0.13	0.13	0.19	0.19	0.16	0.16	0.16	0.16	0.22	0.22	0.18	0.18	0.18	0.18	0.18	0.18	0.22	0.22	0.22	0.22	0.22	0.22	0.00	0.00
LT2	18.77	18.77	19.69	19.69	18.50	18.50	18.51	18.51	19.51	19.51	18.78	18.78	19.16	19.16	18.72	18.72	19.38	19.38	19.45	19.45	19.37	19.37	19.68	19.68
LT3	2.97	2.97	6.09	6.09	6.25	6.25	6.51	6.51	9.11	9.11	7.21	7.21	6.51	6.51	3.61	3.61	4.53	4.53	4.53	4.53	4.56	4.56	1.92	1.92
Sum	21.87	21.87	25.97	25.97	24.91	24.91	25.19	25.19	28.83	28.83	26.17	26.17	25.85	25.85	22.50	22.50	24.14	24.14	24.20	24.20	24.14	24.14	21.60	21.60

Gear Routes

				Gear Trans 1st O/S - 7M161		Gear Trans 2nd O/S - 7M162b		Gear Trans 3rd I/S - 7M003b		Gear Trans 4th I/S - 7M004		Gear Trans 5th I/S - 7M005		Gear Trans 6th I/S - 7H518		Gear Trans Rev - 7M006		Gear Trans 3rd O/S- 7137		Gear Trans 4th O/S-7112		Gear Trans 5th O/S- 7144		Gear Trans 6th O/S - 7M202		Ring Gear-7G334	
			Name	7M161	7M161	7M162b	7M162b	7M003b	7M003b	7M004	7M004	7M005	7M005	7H518	7H518	7M006	7M006	7137	7137	7112	7112	7144	7144	7M202	7M202	7G334	7G334
			Derv.	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB
		32	PID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Machine Name	OpNum	Num	Step	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Decant Gears	DEC_G	4	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
Decant Ring Gear	DEC_R	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
Marketplace Green Gear	MRK_GRN_G	1	3	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Turn+Hob+Deburr	10_20_30_35_G	12	4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
Turn (Ring Gear Only)	10_20_25_R	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
Hob& Deburr/Chanmfer (Ring Gear only)	35_R	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
Measure Gear	40_G	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wash Green/Hard	160_B	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
Wash For Laser	55_G	2	9	-1	-1	-1	-1	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0
Assy/Laser Welding Green	60_70_G	2	10	-1	-1	-1	-1	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0
Decant Gear For HT	DECH_G	4	11	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
Decant Ring Gear	DECH_R	1	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
Heat Treatment	80_B	1	13	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Decant Ring Gear	DECH_R	1	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
Decant Gear For HT	DECH_G	4	15	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
Marketplace Hard Gear	MRK_HRD_G	1	16	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Grind + Hardturning Bore & Cone & Coneface	110_1_G	12	17	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0
Grind + Hardturning Bore & Cone & Coneface	110_1_R	1	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
Hard Finish Teeth (RZ400) (Ring Gear Only)	120_R	2	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
Hard Finish Teeth (RZ150)	120_RZ150_G	5	20	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0
Hard Finish Teeth (Prawema)	120_Prw_G	4	21	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
Measure Gear	40_G	2	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wash For Laser	55_G	2	23	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
Assy/Laser Welding Hard	140_150_G	2	24	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
Grind + Hardturning Bore & Cone & Coneface	155_G	7	25	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0
Wash Final	200_B	1	26	0	0	-1	-1	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0
Phosphation	210_B	1	27	0	0	-1	-1	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0
Hard Finish Teeth (RZ150)	120_RZ150_G	5	28	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0
Wash Final	200_B	1	29	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Crack Detection	210_G	2	30	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
Marketplace Finished	MRK_FIN	1	31	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Assembly Line	ASSEM	1	32	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Gear Route Distances
meters

				Gear Trans 1st O/S - 7M161		Gear Trans 2nd O/S - 7M162b		Gear Trans 3rd I/S - 7M003b		Gear Trans 4th I/S - 7M004		Gear Trans 5th I/S - 7M005		Gear Trans 6th I/S - 7H518		Gear Trans Rev - 7M006		Gear Trans 3rd O/S- 7137		Gear Trans 4th O/S-7112		Gear Trans 5th O/S- 7144		Gear Trans 6th O/S - 7M202		Ring Gear-7G334	
			Name	7M161	7M161	7M162b	7M162b	7M003b	7M003b	7M004	7M004	7M005	7M005	7H518	7H518	7M006	7M006	7137	7137	7112	7112	7144	7144	7M202	7M202	7G334	7G334
			Derv.	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB	AA	AB
		32	PID	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Machine Name	OpNum	Num	Step	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Decant Gears	DEC_G	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Decant Ring Gear	DEC_R	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Marketplace Green Gear	MRK_GRN_G	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Turn+Hob+Deburr	10_20_30_35_G	12	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Turn (Ring Gear Only)	10_20_25_R	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Hob& Deburr/Chanmfer (Ring Gear only)	35_R	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Measure Gear	40_G	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wash Green/Hard	160_B	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Wash For Laser	55_G	2	9	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Assy/Laser Welding Green	60_70_G	2	10	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Decant Gear For HT	DECH_G	4	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Decant Ring Gear	DECH_R	1	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Heat Treatment	80_B	1	13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Decant Ring Gear	DECH_R	1	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Decant Gear For HT	DECH_G	4	15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Marketplace Hard Gear	MRK_HRD_G	1	16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Grind + Hardturning Bore & Cone & Coneface	110_1_G	12	17	1	1	1	1	1	1	0.97	0.97	0.97	0.97	0.97	0.97	0	0	1	1	1	1	1	1	1	1	0	0
Grind + Hardturning Bore & Cone & Coneface	110_1_R	1	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Hard Finish Teeth (RZ400) (Ring Gear Only)	120_R	2	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Hard Finish Teeth (RZ150)	120_RZ150_G	5	20	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
Hard Finish Teeth (Prawema)	120_Prw_G	7	21	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Measure Gear	40_G	2	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wash For Laser	55_G	2	23	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Assy/Laser Welding Hard	140_150_G	2	24	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Grind + Hardturning Bore & Cone & Coneface	155_G	7	25	0	0	0	0	1	0.97	0.95	0.95	0.95	0.95	0.95	0.95	1	1	0	0	0	0	0	0	0	0	0	0
Wash Final	200_B	1	26	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Phosphation	210_B	1	27	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Hard Finish Teeth (RZ150)	120_RZ150_G	5	28	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Wash Final	200_B	1	29	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Crack Detection	210_G	2	30	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Marketplace Finished	MRK_FIN	1	31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Assembly Line	ASSEM	4	32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Shaft Cycle times

				1	2	3	4	5	6	
				Input Shaft - 7L253		Rev Shaft - 7A356		Output Shaft - 7061		
			Name	7L253	7L253	7A356	7A356	7061	7061	
			Derv.	AA	AB	AA	AB	AA	AB	
		26	PID	1	2	3	4	5	6	
Machine Name	**PRID**	**Num**	**Step**	26	26	26	26	26	26	
Decant Shaft	DEC_S	2	1	0.12	0.12	0.12	0.12	0.12	0.12	
Marketplace Green Shaft	MRK_GRN_S	1	2	0.1	0.1	0.1	0.1	0.1	0.1	
Face, Center & Thread/Turn Profile Complete	10_20_S	4	3	1.14	1.14	0.84	0.84	1.29	1.29	
Hob Helical Teeth 1st Speed	30_40_S	5	4	1.3	1.3	1.02	1.02	1.02	1.02	
Deburr and Chamfer (Shaft)	50_S	2	5	0.45	0.45	0.45	0.45	0.45	0.45	
Check Teeth	60_S	1	6	2	2	2	2	2	2	1 per trolley
Roll Splines	70_80_S	2	7	0.5	0.5	0.4	0.4	0.4	0.4	
Gun Drill/Drill Cross Holes & Deburr	90_100_S	2	8	2.6	2.6	0	0	1.8	1.8	4 per cycle
Wash Green/Hard	160_B	1	9	3	3	3	3	3	3	per 2 basket
Turn Grooves	120_S	2	10	0.7	0.7	0	0	0.4	0.4	
Load HT Fixture	125_S	2	11	0.17	0.17	0.17	0.17	0.17	0.17	
Heat Treatment	80_B	1	12	960	960	960	960	960	960	
UnLoad HT Fixture	175_S	2	13	0.17	0.17	0.17	0.17	0.17	0.17	
MarketPlace Hard Shaft	MRK_HRD_S	1	14	0.1	0.1	0.1	0.1	0.1	0.1	
Straighten 1	140_S	3	15	0.6	0.6	0.6	0.6	0.6	0.6	
Grind Grooves	180_S	3	16	0.9	0.9	0	0	0.9	0.9	
Grind Diameters and Length	190_S	7	17	1.6	1.6	1.6	1.6	1.8	1.8	
Wash Final	200_B	1	18	3	3	3	3	3	3	per 2 basket
Phosphation	210_B	1	19	9	9	0	0	0	0	
Profilegrinding Gear Teeth	220_S	2	20	1.6	1.6	0	0	0	0	
Powerhoning	230_S	4	21	0.9	0.9	0.9	0.9	0.9	0.9	
Check Teeth	60_S	1	22	2	2	2	2	2	2	1 per trolley
Grinding Diameters	255_S	1	23	0.8	0.8	0	0	0	0	
Wash Final	200_B	1	24	3	3	3	3	3	3	per 2 basket
Marketplace Finished	MRK_FIN	1	25	0.1	0.1	0.1	0.1	0.1	0.1	
Assembly Line	ASSEM	1	26	0.1	0.1	0.1	0.1	0.1	0.1	

Component 1	7.03	7.03	3.05	3.05	5.7	5.7
Component 2	6.4	6.4	3.1	3.1	4.2	4.2
Basket1	1.5	1.5	1.5	1.5	1.5	1.5
Basket2	12	12	3	3	3	3
Trolley1	962	962	962	962	962	962
Trolley2	2	2	2	2	2	2

Pt-Bkt	5	5	16	16	8	8
Bkt	8	8	8	8	8	8
Pt	40	40	128	128	64	64

LT1	0.08	0.08	0.26	0.26	0.13	0.13
LT2	20.92	20.92	22.74	22.74	22.31	22.31
LT3	5.90	5.90	7.05	7.05	4.91	4.91
	26.90	26.90	30.04	30.04	27.35	27.35

Shaft Routes

				1	2	3	4	5	6
				Input Shaft - 7L253		Rev Shaft - 7A356		Output Shaft - 7061	
			Name	7L253	7L253	7A356	7A356	7061	7061
			Derv.	AA	AB	AA	AB	AA	AB
		26	PID	1	2	3	4	5	6
Machine Name	PRID	Num	Step	1	2	3	4	5	6
Decant Shaft	DEC_S	2	1	-1	-1	-1	-1	-1	-1
Marketplace Green Shaft	MRK_GRN_S	1	2	-1	-1	-1	-1	-1	-1
Face, Center & Thread/Turn Profile Complete	10_20_S	4	3	-1	-1	-1	-1	-1	-1
Hob Helical Teeth 1st Speed	30_40_S	5	4	-1	-1	-1	-1	-1	-1
Deburr and Chamfer (Shaft)	50_S	2	5	-1	-1	-1	-1	-1	-1
Check Teeth	60_S	1	6	0	0	0	0	0	0
Roll Splines	70_80_S	2	7	-1	-1	-1	-1	-1	-1
Gun Drill/Drill Cross Holes & Deburr	90_100_S	2	8	-1	-1	0	0	-1	-1
Wash Green/Hard	160_B	1	9	-1	-1	-1	-1	-1	-1
Turn Grooves	120_S	2	10	-1	-1	0	0	-1	-1
Load HT Fixture	125_S	2	11	-1	-1	-1	-1	-1	-1
Heat Treatment	80_B	1	12	-1	-1	-1	-1	-1	-1
UnLoad HT Fixture	175_S	2	13	-1	-1	-1	-1	-1	-1
MarketPlace Hard Shaft	MRK_HRD_S	1	14	-1	-1	-1	-1	-1	-1
Straighten 1	140_S	2	15	-1	-1	-1	-1	-1	-1
Grind Grooves	180_S	3	16	-1	-1	0	0	-1	-1
Grind Diameters and Length	190_S	7	17	-1	-1	-1	-1	-1	-1
Wash Final	200_B	1	18	-1	-1	-1	-1	-1	-1
Phosphation	210_B	1	19	-1	-1	0	0	0	0
Profilegrinding Gear Teeth	220_S	2	20	-1	-1	0	0	0	0
Powerhoning	230_S	4	21	-1	-1	-1	-1	-1	-1
Check Teeth	60_S	1	22	0	0	0	0	0	0
Grinding Diameters	255_S	1	23	-1	-1	0	0	0	0
Wash Final	200_B	1	24	-1	-1	-1	-1	-1	-1
Marketplace Finished	MRK_FIN	1	25	-1	-1	-1	-1	-1	-1
Assembly Line	ASSEM	1	26	1	1	1	1	1	1

ShaftDistance

				1	2	3	4	5	6	
				Input Shaft - 7L253		Rev Shaft - 7A356		Output Shaft - 7061		
			Name	7L253	7L253	7A356	7A356	7061	7061	
			Derv.	AA	AB	AA	AB	AA	AB	
		26	PID	30	30	30	30	30	30	m/min
Machine Name	**PRID**	**Num**	**Step**	**1**	**2**	**3**	**4**	**5**	**6**	
Decant Shaft	DEC_S	2	1	1	1	1	1	1	1	
Marketplace Green Shaft	MRK_GRN_S	1	2	1	1	1	1	1	1	
Face, Center & Thread/Turn Profile Complete	10_20_S	4	3	1	1	1	1	1	1	
Hob Helical Teeth 1st Speed	30_40_S	5	4	1	1	1	1	1	1	
Deburr and Chamfer (Shaft)	50_S	2	5	1	1	1	1	1	1	
Check Teeth	60_S	1	6	0	0	0	0	0	0	
Roll Splines	70_80_S	2	7	1	1	1	1	1	1	
Gun Drill/Drill Cross Holes & Deburr	90_100_S	2	8	1	1	0	0	1	1	
Wash Green/Hard	160_B	1	9	1	1	1	1	1	1	
Turn Grooves	120_S	2	10	1	1	0	0	1	1	
Load HT Fixture	125_S	2	11	1	1	1	1	1	1	
Heat Treatment	80_B	1	12	1	1	1	1	1	1	
UnLoad HT Fixture	175_S	2	13	1	1	1	1	1	1	
MarketPlace Hard Shaft	MRK_HRD_S	1	14	1	1	1	1	1	1	
Straighten 1	140_S	2	15	1	1	1	1	1	1	
Grind Grooves	180_S	3	16	1	1	0	0	1	1	
Grind Diameters and Length	190_S	7	17	1	1	1	1	1	1	
Wash Final	200_B	1	18	1	1	1	1	1	1	
Phosphation	210_B	1	19	1	1	0	0	0	0	
Profilegrinding Gear Teeth	220_S	2	20	1	1	0	0	0	0	
Powerhoning	230_S	4	21	1	1	1	1	1	1	
Check Teeth	60_S	1	22	0	0	0	0	0	0	
Grinding Diameters	255_S	1	23	1	1	0	0	0	0	
Wash Final	200_B	1	24	1	1	1	1	1	1	
Marketplace Finished	MRK_FIN	1	25	1	1	1	1	1	1	
Assembly Line	ASSEM	1	26	1	1	1	1	1	1	

Down Times

	ProcessID	PRN	Maximum wait time	Load / unload (mins)	Load Frequency	Labour Requirements	Labour Type	Toolchange (mins)	Toolchange (Frequency)	Labour Requirements #	Labour Type	Swarfing (mins)	Swarfing(Frequncy in operations)	Labour Requirements	Labour Type	Gauging (min)	Guaging (Frequency in Operations)	Labour Requirements	Labour Type	Dressing(min)	Dressing (Frequency in Operations)	Labour Requerements	Labour Type	Minor Maint(time)	Minor Miant (frequency in operations)	Labour requirements	Labour Type	Routine Operations (mins)	Routine Operations (frequensy in hours)	Labour Requirements	Labour Type	Derivative Change (min)	Labour Requirements	Labour Type	Component Change	Labour Requirement	Labour Type	BreakDown Times (mins)	BreakDown Operations (frequensy in hour	Labour Requirements	Labour Type
ID				1				2				3				4				5				6				7				8						9			
ChangeType				1				1				1				1				1				1				2				3						2			
Decant Gears	1	4	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	10	2361	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decant Ring Gears	2	1	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	10	2361	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marketplace Green Gear	3	1	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turn+Hob+Deburr	4	12	15	0	1	0	0	10	500	1	1	5.0	400	1	1	0	0	0	0	0	0	0	0	10	2360.7	1	1	0	0	0	0	20	1	1	40	1	1	60	4320	1	1
Turn (Ring Gear Only)	5	2	15	0	1	0	0	5	200	1	1	5.0	400	1	1	0	0	0	0	0	0	0	0	10	1309.1	1	1	0	0	0	0	10	1	1	0	0	0	60	4320	1	1
Hob& Deburr/Chanmfer (Ring Gear only)	6	2	15	0	1	0	0	20	2500	1	1	5.0	400	1	1	0	0	0	0	0	0	0	0	10	1241.4	1	1	0	0	0	0	44	1	1	0	0	0	60	4320	1	1
Measure Gear	7	2	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	5	1440	1	1	0	0	0	0	2	1	1	2	1	1	0	0	0	0
Wash fior Laser	8	2	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	2880	1	1	0	0	0	0	0	0	0	0	0	0	60	8640	1	1
Assy/Laser Welding Green	9	2	15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	7200	1	1	0	0	0	0	0	0	0	0	0	0	60	4320	1	1
Decant Gear For HT	10	4	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	10	2361	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decant Ring Gear HT	11	1	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	10	2361	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Treatment	12	1	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	4320	1	1
Market Place Hard Gear	13	1	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grind + Hardturning Bore & Cone & Coneface	14	12	15	0	1	0	0	10	300	1	1	5.0	400	1	1	0	0	0	0	0	0	0	0	10	1972.6	1	1	0	0	0	0	10	1	1	20	1	1	60	4320	1	1
Grind + Hardturning Bore & Cone & Coneface(Ring Gear)	15	1	15	0	1	0	0	10	300	1	1	5.0	400	1	1	0	0	0	0	0	0	0	0	10	1972.6	1	1	0	0	0	0	10	1	1	20	1	1	60	4320	1	1
Hard Finish Teeth (RZ400) (Ring Gear Only)	16	2	16	0	1	0	0	20	6000	1	1	0.0	0	1	1	0	0	0	0	0	0	0	0	10	1152	1	1	0	0	0	0	25	1	1	0	0	0	60	4320	1	1
Hard Finish Teeth (RZ150)	17	5	15	0	1	0	0	20	6000	1	1	0.0	0	1	1	0	0	0	0	0	0	0	0	15	6000	1	1	0	0	0	0	20	1	1	30	1	1	60	4320	1	1
Hard Finish Teeth (Prawema)	18	4	15	0	1	0	0	10	30000	1	1	0.0	0	1	1	0	0	0	0	0	0	0	0	10	1200	1	1	0	0	0	0	20	1	1	30	1	1	60	4320	1	1
Assy/Laser Welding Hard	19	1	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	5	1440	1	1	0	0	0	0	0	0	0	0	0	0	60	4320	1	1
Grind+Hardturning Bore & Cone & Coneface	20	7	15	0	1	0	0	10	300	1	1	5.0	400	1	1	0	0	0	0	0	0	0	0	10	1515.8	1	1	0	0	0	0	10	1	1	20	1	1	60	4320	1	1
Wash Green/Hard	21	1	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	5	1440	1	1	0	0	0	0	0	0	0	0	0	0	60	8640	1	1
Phosphation	22	1	15	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	8640	1	1
Wash Final	23	1	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	10	2361	1	1	0	0	0	0	0	0	0	0	0	0	60	8640	1	1
Crack Detection	24	2	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Market Place Finished	25	1	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decant Shaft	26	2	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	10	2361	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Market Place Green	27	1	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Face, Center & Thread/Turn Profile Complete	28	4	15	0	1	0	0	5	500	1	1	5	384	1	1	0	0	0	0	0	0	0	0	10	1800	1	1	0	0	0	0	5	1	1	10	1	1	60	4320	1	1
Hob Helical Teeth 1st Speed	29	5	15	0	1	0	0	9	300	1	1	5	624	1	1	0	0	0	0	0	0	0	0	10	1411.8	1	1	0	0	0	0	29	1	1	38	1	1	60	4320	1	1
Deburr and Chamfer (Shaft)	30	2	15	0	1	0	0	11	3000	1	1	5	216	1	1	10	0	1	1	0	0	0	0	10	3200	1	1	0	0	0	0	31	1	1	36	1	1	60	4320	1	1
Check Teeth	31	1	15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	2	1	1	2	1	1	0	0	0	0
Roll Splines	32	2	15	0	1	0	0	60	50000	1	1	5	192	1	1	0	0	0	0	0	0	0	0	10	3600	1	1	0	0	0	0	0	0	0	30	1	1	60	4320	1	1
Gun Drill/Drill Cross Holes & Deburr	33	1	15	0	1	0	0	10	781	1	1	5	624	1	1	0	0	0	0	0	0	0	0	10	1800	1	1	0	0	0	0	0	0	0	55	1	1	60	4320	1	1
Wash Green	34	1	15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1440	1	1	0	0	0	0	0	0	0	0	0	0	60	8640	1	1
Turn Grooves	35	2	15	0	1	0	0	5	300	1	1	5	336	1	1	0	0	0	0	0	0	0	0	10	3600	1	1	0	0	0	0	0	0	0	5	1	1	60	4320	1	1
Load HT Fixture	36	4	15	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	10	2361	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UnLoad HT Fixture	37	1	15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Market Place Hard	38	1	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Straighten	39	3	15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	2400	1	1	0	0	0	0	5	1	1	30	1	1	60	4320	1	1
Grind Grooves	40	3	15	0	1	0	0	60	60000	1	1	5	432	1	1	0	0	0	0	0	0	0	0	10	1600	1	1	0	0	0	0	0	0	0	60	1	1	60	4320	1	1
Grind Diameters and Length	41	7	15	0	1	0	0	60	60000	1	1	5	864	1	1	0	0	0	0	0	0	0	0	10	900	1	1	0	0	0	0	0	0	0	60	1	1	60	4320	1	1
Profilegrinding Gear Teeth	42	2	15	0	1	0	0	15	3000	1	1	5	768	1	1	0	0	0	0	0	0	0	0	10	900	1	1	0	0	0	0	15	1	1	30	1	1	60	4320	1	1
Powerhoning	43	4	15	0	1	0	0	20	6000	1	1	5	600	1	1	0	0	0	0	0	0	0	0	10	1152	1	1	0	0	0	0	25	1	1	50	1	1	60	4320	1	1
Grinding Diameters	44	1	15	0	1	0	0	60	60000	1	1	5	384	1	1	0	0	0	0	0	0	0	0	10	1800	1	1	0	0	0	0	0	0	0	0	0	0	60	4320	1	1
Assembly Line	45	1	0	0	1	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix G

Case Study 4
Results Samples

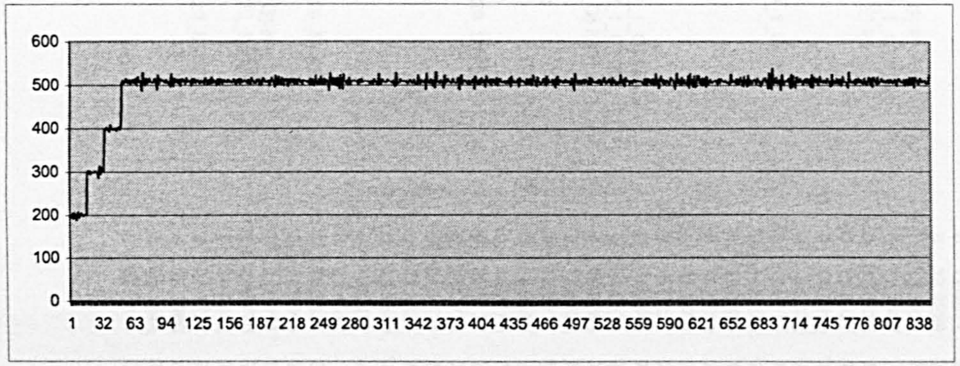
(Samples Taken from experimentations with Model 20f)

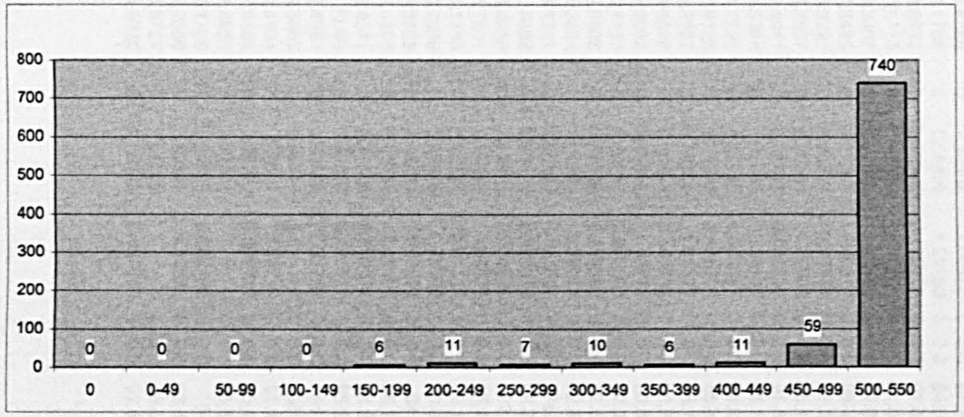
- **Set 1 Production Graphs**
- **Set 1 Process Utilisation**
- **Set 1 Trolley Totals Graphs**
- **Set 1 Lead Times Graphs**
- **Set 1 Results Collected in Period 816**
- **Set 2 Production Graphs**
- **Set 2 Process Utilisation**
- **Set 2 Trolley Totals Graphs**
- **Set 2 Lead Times Graphs**
- **Set 3 Production Graphs**
- **Set 3 Process Utilisation**
- **Set 3 Trolley Totals Graphs**
- **Set 3 Lead Times Graphs**
- **Set 4 Production Graphs**
- **Set 4 Process Utilisation**
- **Set 4 Trolley Totals Graphs**
- **Set 4 Lead Times Graphs**

	Freq	%	Cumulative	%
0	0	0.00%	0	0.0%
0-49	0	0.00%	0	0.0%
50-99	0	0.00%	0	0.0%
100-149	0	0.00%	0	0.0%
150-199	6	0.71%	6	0.7%
200-249	11	1.29%	17	2.0%
250-299	7	0.82%	24	2.8%
300-349	10	1.18%	34	4.0%
350-399	6	0.71%	40	4.7%
400-449	11	1.29%	51	6.0%
450-499	59	6.94%	110	12.9%
500-550	740	87.06%	850	100.0%
	850			

Total	*421991*
Av	496.46
StndDev	53.99345

Rate/Shift	509	
Shifts	799	from 66 forward
Planned	421991	
	0	
	0.00%	

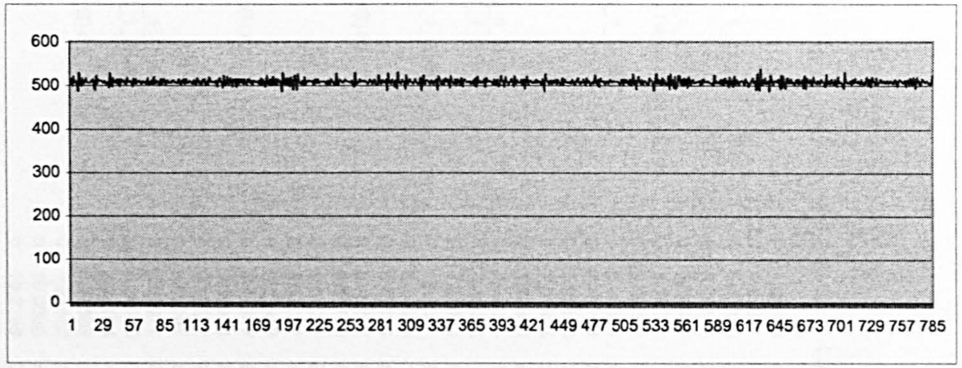


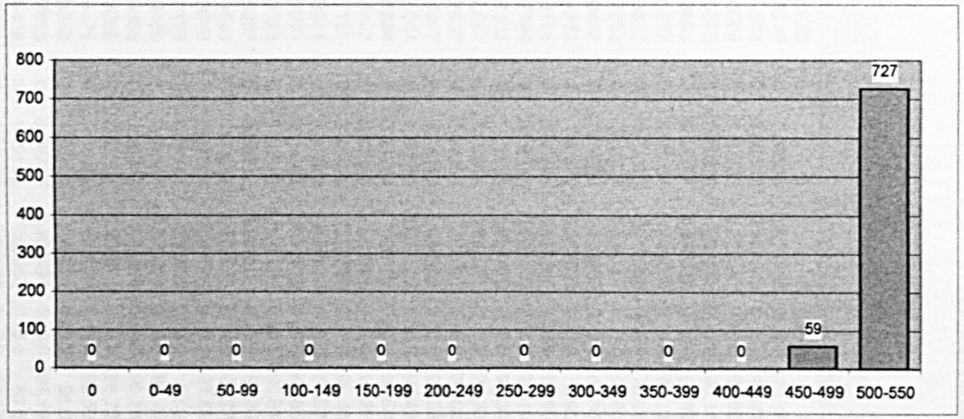


	Freq	%	Cumulativ	%
0	0	0.00%	0	0.0%
0-49	0	0.00%	0	0.0%
50-99	0	0.00%	0	0.0%
100-149	0	0.00%	0	0.0%
150-199	0	0.00%	0	0.0%
200-249	0	0.00%	0	0.0%
250-299	0	0.00%	0	0.0%
300-349	0	0.00%	0	0.0%
350-399	0	0.00%	0	0.0%
400-449	0	0.00%	0	0.0%
450-499	59	6.94%	59	6.9%
500-550	727	85.53%	786	92.5%
	786			

Total	400078
Av	509.0051
StndDev	7.088699

Rate/Shift	509
Shifts	786
Planned	400074
	-4
	0.00%





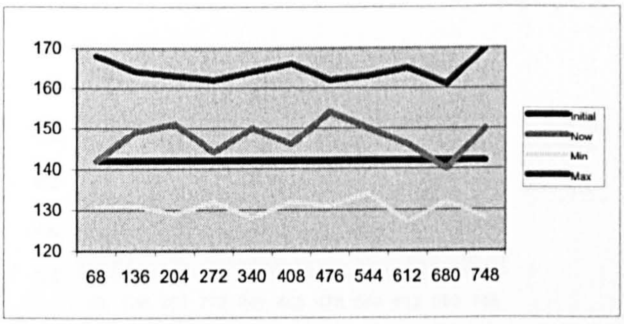
PROCESS UTILISATION
MACHINE

NAME	OFF-S	IDLE	BUSY	BLOC	DOWN	BREAKDOV	LA	LA	L	OEE
Assembly Machine(ASSEM) #1	6.25	0	93.75	0	0	0	0	0	0	100
Turn+Hob+Deburr (10_20_30_35_G) #7	0	4.02449	87.2219	0	7.36826	1.38532	0	0	0	90.8794
Turn+Hob+Deburr (10_20_30_35_G) #1	0	4.84341	86.618	0	7.99632	0.542243	0	0	0	91.0268
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #11	0	5.05849	88.0069	0	6.60233	0.332327	0	0	0	92.6959
Turn+Hob+Deburr (10_20_30_35_G) #4	0	5.75142	84.9643	0	7.61336	1.67094	0	0	0	90.1491
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #1	0	6.08045	86.3993	0	6.63297	0.887279	0	0	0	91.9929
Grind + Hardturning Bore & Cone & Coneface(Ring Gear) (110_1_R) #1	0	6.28136	87.277	0	5.65257	0.789074	0	0	0	93.1266
Deburr and Chamfer (Shaft) (50_S) #1	0	6.31806	73.5662	0	19.7378	0.377968	0	0	0	78.5276
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #9	0	6.38934	85.7503	0	7.3223	0.538102	0	0	0	91.6031
Turn+Hob+Deburr (10_20_30_35_G) #3	0	6.47794	85.0482	0	7.09252	1.38132	0	0	0	90.9392
Deburr and Chamfer (Shaft) (50_S) #2	0	6.65173	73.4248	0	19.565	0.358502	0	0	0	78.6569
Turn+Hob+Deburr (10_20_30_35_G) #9	0	7.01815	83.3198	0	8.74694	0.915141	0	0	0	89.6086
Turn+Hob+Deburr (10_20_30_35_G) #6	0	7.07605	83.7794	0	8.19547	0.949133	0	0	0	90.1591
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #4	0	7.30094	84.7108	0	7.1538	0.834472	0	0	0	91.3826
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #7	0	7.43024	84.578	0	7.13848	0.853285	0	0	0	91.3668
Hard Finish Teeth (RZ150) (120_RZ150_G) #4	0	7.63039	83.7637	0	7.38358	1.2223	0	0	0	90.6832
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #6	0	8.3307	82.9917	0	7.01593	1.66165	0	0	0	90.5338
Profilegrinding Gear Teeth (220_S) #1	0	8.46003	89.244	0	1.37868	0.917267	0	0	0	97.4919
Hard Finish Teeth (RZ150) (120_RZ150_G) #1	0	8.47154	82.8884	0	7.35294	1.28707	0	0	0	90.5603
Grind+Hardturning Bore & Cone & Coneface (155_G) #6	0	8.49201	83.5407	0	6.43382	1.53346	0	0	0	91.2934
Turn+Hob+Deburr (10_20_30_35_G) #11	0	8.50179	82.7181	0	7.55208	1.22802	0	0	0	90.4041
Turn+Hob+Deburr (10_20_30_35_G) #5	0	8.94991	81.9244	0	8.37929	0.74638	0	0	0	89.9773
Turn+Hob+Deburr (10_20_30_35_G) #12	0	8.97097	81.7971	0	8.10355	1.12839	0	0	0	89.8582
Hard Finish Teeth (RZ150) (120_RZ150_G) #3	0	9.12813	82.3393	0	7.12316	1.40941	0	0	0	90.6103
Grind+Hardturning Bore & Cone & Coneface (155_G) #2	0	9.14887	83.6257	0	6.58212	0.643331	0	0	0	92.0469
Hard Finish Teeth (RZ150) (120_RZ150_G) #2	0	9.38034	83.1643	0	6.64828	0.807077	0	0	0	91.7729
Grind Diameters and Length (190_S) #4	0	9.54227	82.6976	0	7.09252	0.667648	0	0	0	91.4212
Grind Diameters and Length (190_S) #1	0	9.62191	83.2129	0	6.17341	0.991802	0	0	0	92.072
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #3	0	9.63477	82.9486	0	7.04657	0.370076	0	0	0	91.7926
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #5	0	9.80415	81.4366	0	6.96998	1.78928	0	0	0	90.2886
Grinding Diameters (255_S) #1	0	9.84154	87.2055	0	2.02206	0.930911	0	0	0	96.7247
Grind+Hardturning Bore & Cone & Coneface (155_G) #1	0	9.87503	83.4471	0	6.25	0.427824	0	0	0	92.5905
Assy/Laser Welding Hard (140_150_G) #1	0	9.99317	87.0348	0	1.51654	1.45551	0	0	0	96.698
Grind Diameters and Length (190_S) #5	0	10.0086	82.7019	0	6.38787	0.901691	0	0	0	91.8997
Roll Splines (70_80_S) #1	0	10.2199	71.8438	0	16.9118	1.02452	0	0	0	80.022
Hard Finish Teeth (RZ150) (120_RZ150_G) #5	0	10.5723	81.3754	0	7.01593	1.03633	0	0	0	90.9958
Turn+Hob+Deburr (10_20_30_35_G) #2	0	10.7418	80.3988	0	8.2261	0.633327	0	0	0	90.0744
Turn+Hob+Deburr (10_20_30_35_G) #10	0	10.764	79.9864	0	8.21078	1.03883	0	0	0	89.6347
Turn+Hob+Deburr (10_20_30_35_G) #8	0	11.4137	79.9651	0	7.9235	0.697717	0	0	0	90.268
Roll Splines (70_80_S) #2	0	11.5911	69.5621	0	17.3866	1.46015	0	0	0	78.6822
Profilegrinding Gear Teeth (220_S) #2	0	11.9517	85.6488	0	1.34804	1.05148	0	0	0	97.2748
Powerhoning (230_S) #2	0	12.9239	73.1708	0	12.6379	1.26753	0	0	0	84.0308
Grind+Hardturning Bore & Cone & Coneface (155_G) #7	0	13.2972	79.6532	0	6.12745	0.922118	0	0	0	91.8693
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #10	0	13.3469	79.173	0	6.6636	0.816536	0	0	0	91.3677
Grind+Hardturning Bore & Cone & Coneface (155_G) #3	0	13.6829	79.3407	0	5.7598	1.21655	0	0	0	91.9178
Grind Diameters and Length (190_S) #7	0	13.8027	77.5485	0	7.21507	1.43377	0	0	0	89.9662
Hob Helical Teeth 1st Speed (30_40_S) #5	0	14.0013	75.9297	0	9.09314	0.97581	0	0	0	88.2917
Hob Helical Teeth 1st Speed (30_40_S) #4	0	14.022	75.7557	0	9.05331	1.16905	0	0	0	88.1105
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #12	0	14.116	78.4941	0	6.72488	0.665028	0	0	0	91.3955
Powerhoning (230_S) #3	0	14.5635	73.6384	0	11.269	0.529111	0	0	0	86.1908
Powerhoning (230_S) #1	0	15.0808	73.7231	0	10.815	0.381157	0	0	0	86.8156
Powerhoning (230_S) #4	0	15.1529	72.8128	0	11.1979	0.836384	0	0	0	85.8165
Hob Helical Teeth 1st Speed (30_40_S) #1	0	15.2032	75.2527	0	8.48039	1.06371	0	0	0	88.7447
Grind Diameters and Length (190_S) #3	0	15.3302	76.6547	0	7.18444	0.830713	0	0	0	90.5336
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #2	0	16.585	75.6092	0	6.40319	1.40255	0	0	0	90.6423
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #8	0	16.5936	76.7436	0	6.40319	0.259595	0	0	0	92.0117
Grind+Hardturning Bore & Cone & Coneface (155_G) #5	0	16.8086	76.9596	0	5.57598	0.655806	0	0	0	92.5091
Grind Grooves (180_S) #2	0	17.1464	68.3284	0	13.4651	1.06013	0	0	0	82.4688
Gun Drill/Drill Cross Holes & Deburr (90_100_S) #1	0	17.6971	63.1321	0	18.6463	0.524542	0	0	0	76.707
Hob Helical Teeth 1st Speed (30_40_S) #3	0	18.8455	71.5882	0	8.61826	0.948025	0	0	0	88.2123
Grind Grooves (180_S) #3	0	19.6185	66.4658	0	13.0821	0.833536	0	0	0	82.688
Face, Center & Thread/Turn Profile Complete (10_20_S) #5	0	20.6177	75.7801	0	2.14461	1.4576	0	0	0	95.4622
Grind Diameters and Length (190_S) #2	0	21.3079	70.1255	0	6.75551	1.81112	0	0	0	89.1137
Grind Diameters and Length (190_S) #6	0	21.7429	70.3996	0	6.06618	1.79129	0	0	0	89.9594
Hard Finish Teeth (Prawema) (120_Prw_G) #3	0	22.6821	72.8983	0	3.46201	0.957501	0	0	0	94.284
Hard Finish Teeth (Prawema) (120_Prw_G) #1	0	23.1143	73.5965	0	2.26716	1.02196	0	0	0	95.7221
Hard Finish Teeth (Prawema) (120_Prw_G) #2	0	23.417	73.4241	0	2.57353	0.585374	0	0	0	95.8752
Hard Finish Teeth (Prawema) (120_Prw_G) #4	0	23.4818	72.85	0	3.18627	0.481911	0	0	0	95.2061
Face, Center & Thread/Turn Profile Complete (10_20_S) #3	0	23.5634	72.4581	0	2.69608	1.28242	0	0	0	94.795
Decant Gear For HT (DECH_G) #4	0	24.0096	73.3863	0	2.60417	0	0	0	0	96.573
Grind+Hardturning Bore & Cone & Coneface (155_G) #4	0	24.1411	69.4104	0	5.1011	1.34746	0	0	0	91.4993
Face, Center & Thread/Turn Profile Complete (10_20_S) #4	0	24.7776	71.6489	0	3.06373	0.509758	0	0	0	95.2494
Decant Gear For HT (DECH_G) #1	0	24.9412	72.4853	0	2.57353	0	0	0	0	96.5713
Face, Center & Thread/Turn Profile Complete (10_20_S) #2	0	24.9727	71.1709	0	3.21691	0.639495	0	0	0	94.86
Straighten 1 (140_S) #1	0	25.3969	69.7059	0	3.72449	1.17273	0	0	0	93.4356
Decant Gear For HT (DECH_G) #3	0	25.5844	71.8727	0	2.54289	0	0	0	0	96.5829
Straighten 1 (140_S) #3	0	25.7876	68.9029	0	4.35049	0.958983	0	0	0	92.8456

Hob Helical Teeth 1st Speed (30_40_S) #2	0	26.8971	64.808	0	7.32537	0.969568	0	0	0	88.6531
Grind Grooves (180_S) #1	0	26.9278	61.7647	0	11.152	0.155564	0	0	0	84.5256
Hard Finish Teeth (RZ400) (Ring Gear Only) (120_R) #2	0	27.1925	70.9093	0	0.903799	0.994363	0	0	0	97.3929
Decant Gear For HT (DECH_G) #2	0	27.3344	70.2146	0	2.45098	0	0	0	0	96.627
Gun Drill/Drill Cross Holes & Deburr (90_100_S) #2	0	27.3488	57.0348	0	15.1808	0.435666	0	0	0	78.5049
Hard Finish Teeth (RZ400) (Ring Gear Only) (120_R) #1	0	27.5401	70.8787	0	0.903799	0.677428	0	0	0	97.8178
Turn Grooves (120_S) #2	0	28.1713	65.049	0	5.91299	0.866655	0	0	0	90.5614
Face, Center & Thread/Turn Profile Complete (10_20_S) #1	0	31.4928	65.0294	0	2.19056	1.28727	0	0	0	94.9234
Assy/Laser Welding Green (60_70_G) #1	0	32.5484	65.5624	0	0.459559	1.42962	0	0	0	97.1992
Hob& Deburr/Chanmfer (Ring Gear only) (35_R) #1	0	33.1188	64.302	0	1.98223	0.596997	0	0	0	96.1436
Hob& Deburr/Chanmfer (Ring Gear only) (35_R) #2	0	34.7974	62.2224	0	1.93627	1.04389	0	0	0	95.4294
Turn (Ring Gear Only) (10_20_25_R) #1	0	36.168	59.9894	0	2.55821	1.28438	0	0	0	93.9801
Turn (Ring Gear Only) (10_20_25_R) #2	0	36.1887	60.0147	0	2.55821	1.23842	0	0	0	94.0502
Straighten 1 (140_S) #2	0	38.5402	57.0588	0	3.79902	0.601979	0	0	0	92.8392
Turn Grooves (120_S) #1	0	40.5577	55.1684	0	4.2739	0	0	0	0	92.81
Wash Final (200_B) #1	0	46.8608	52.4651	0.01	0					
Decant Gears (DEC_G) #2	0	52.8044	44.8059	0	2.38971	0	0	0	0	94.9366
Crack Detection (210_G) #2	0	56.5167	43.4833	0	0	0	0	0	0	100
Phosphation(210_B) #1	0	61.1803	38.7752	0	0	0.0445517	0	0	0	99.8852
Decant Ring Gear HT (DECH_R) #1	0	61.9826	37.0982	0	0.919118	0	0	0	0	97.5824
Load HT Fixture (125_S) #1	0	70.0564	29.2083	0	0.735294	0	0	0	0	97.5444
UnLoad HT Fixture (175_S) #1	0	71.0727	28.9273	0	0	0	0	0	0	100
Decant Shaft (DEC_S) #1	0	72.3248	26.7254	0	0.949755	0	0	0	0	96.5682
Decant Gears (DEC_G) #4	0	72.6654	25.9559	0	1.37868	0	0	0	0	94.9563
Load HT Fixture (125_S) #2	0	73.076	26.25	0	0.67402	0	0	0	0	97.4966
UnLoad HT Fixture (175_S) #2	0	73.4333	26.5667	0	0	0	0	0	0	100
Wash Green (45_B) #1	0	73.8805	26.1195	0	0					
Wash Hard (160_B) #1	0	74.6259	25.0816	0	0					
Decant Ring Gears (DEC_R) #1	0	80.9904	18.55	0	0.459559	0	0	0	0	97.5825
Decant Gears (DEC_G) #1	0	84.1593	15.0441	0	0.796569	0	0	0	0	94.9714
Wash For Laser (55_G) #2	0	85.8275	14.1725	0	0					
Decant Shaft (DEC_S) #2	0	87.0689	12.4716	0	0.459559	0	0	0	0	96.4461
Decant Gears (DEC_G) #3	0	89.8233	9.65588	0	0.520833	0	0	0	0	94.8821
Wash For Laser (55_G) #1	0	98.4726	1.52742	0	0					
Measure Gear (40_G) #1	0	100	0	0	0	0	0	0	0	0
Measure Gear (40_G) #2	0	100	0	0	0	0	0	0	0	0
Crack Detection (210_G) #1	0	100	0	0	0	0	0	0	0	0
Check Teeth (60_S) #1	0	100	0	0	0	0	0	0	0	0

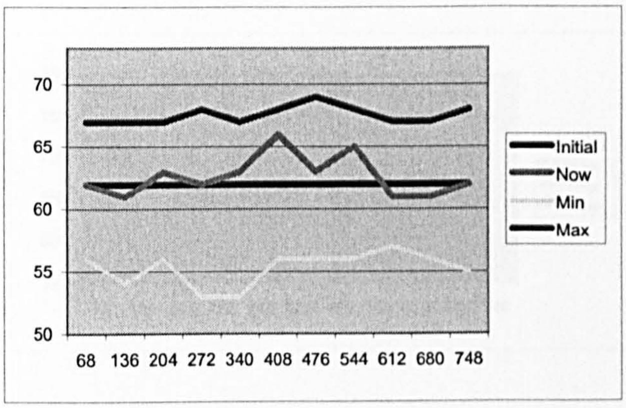
Green Market GEARS

Shift	Init	Now	Min	max
68	142	142	131	168
136	142	149	131	164
204	142	151	129	163
272	142	144	132	162
340	142	150	128	164
408	142	146	132	166
476	142	154	131	162
544	142	150	134	163
612	142	146	127	165
680	142	140	132	161
748	142	150	128	170
816	142	144	126	160



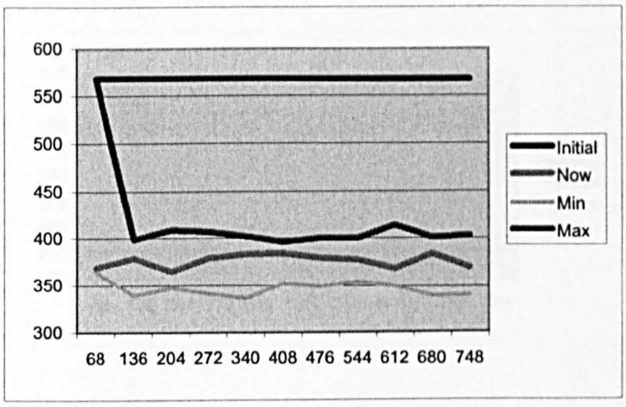
Green Market SHAFTS

Shift	Init	Now	Min	Max
68	62	62	56	67
136	62	61	54	67
204	62	63	56	67
272	62	62	53	68
340	62	63	53	67
408	62	66	56	68
476	62	63	56	69
544	62	65	56	68
612	62	61	57	67
680	62	61	56	67
748	62	62	55	68
816	62	59	54	67



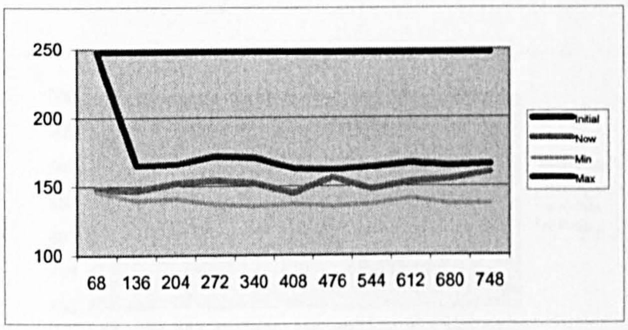
Hard Market GEARS

Shift	Init	Now	Min	Max
68	568	369	364	568
136	568	379	339	399
204	568	365	347	409
272	568	379	341	407
340	568	383	336	402
408	568	384	352	396
476	568	379	349	400
544	568	377	354	400
612	568	368	350	414
680	568	383	339	401
748	568	369	340	403
816	568	370	353	401



Hard Market SHAFTS

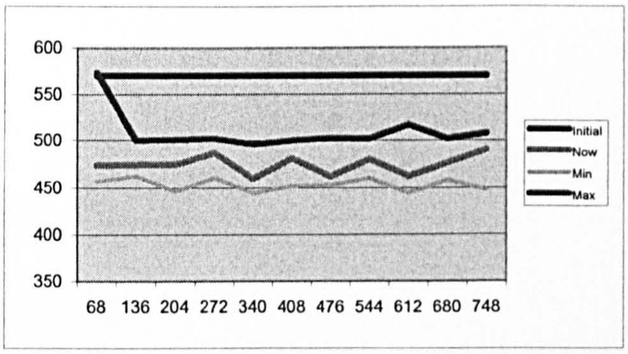
Shift	Init	Now	Min	Max
68	248	148	146	248
136	248	147	140	165
204	248	152	141	166
272	248	154	137	172
340	248	152	136	171
408	248	145	137	163
476	248	156	136	162
544	248	148	137	164
612	248	153	141	167
680	248	155	137	165
748	248	160	137	166
816	248	157	129	170



Changes in the Total Trolleys in Intermediate markets

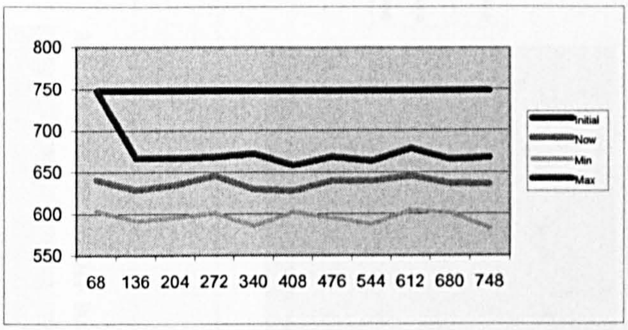
Finished Market

Shift	Init	Now	Min	Max
68	570	474	457	573
136	570	475	463	500
204	570	475	446	501
272	570	487	461	502
340	570	460	444	496
408	570	481	452	500
476	570	462	453	503
544	570	480	460	502
612	570	462	444	517
680	570	476	458	502
748	570	490	448	508
816	570	466	446	503



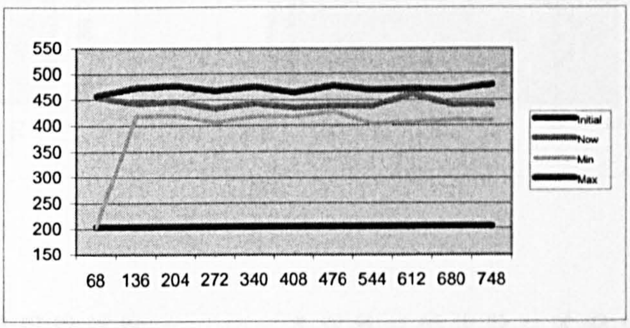
Empty trolleys Green Area

Shift	Init	Now	Min	Max
68	748	641	604	748
136	748	629	592	668
204	748	635	596	668
272	748	646	601	669
340	748	630	586	673
408	748	628	602	659
476	748	640	595	669
544	748	640	588	664
612	748	646	604	679
680	748	637	601	666
748	748	636	583	668
816	748	650	592	673



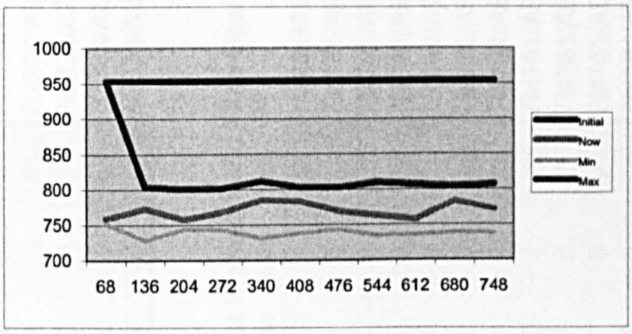
Empty trolleys Hard Area

Shift	Init	Now	Min	Max
68	204	455	204	459
136	204	442	418	474
204	204	446	419	478
272	204	433	406	468
340	204	442	417	476
408	204	434	417	465
476	204	438	426	477
544	204	438	403	469
612	204	462	406	472
680	204	440	410	469
748	204	440	410	479
816	204	456	415	476



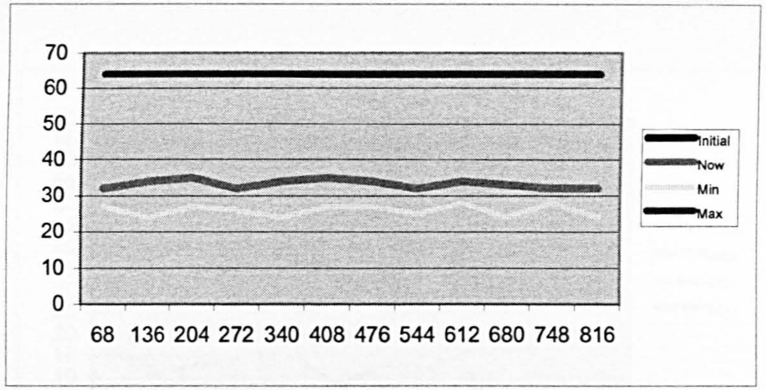
Empty racks

Shift	Init	Now	Min	Max
68	954	759	752	954
136	954	773	729	804
204	954	758	744	801
272	954	768	743	802
340	954	785	731	812
408	954	783	738	803
476	954	769	743	803
544	954	763	735	810
612	954	757	736	807
680	954	784	739	804
748	954	772	738	807
816	954	760	741	802



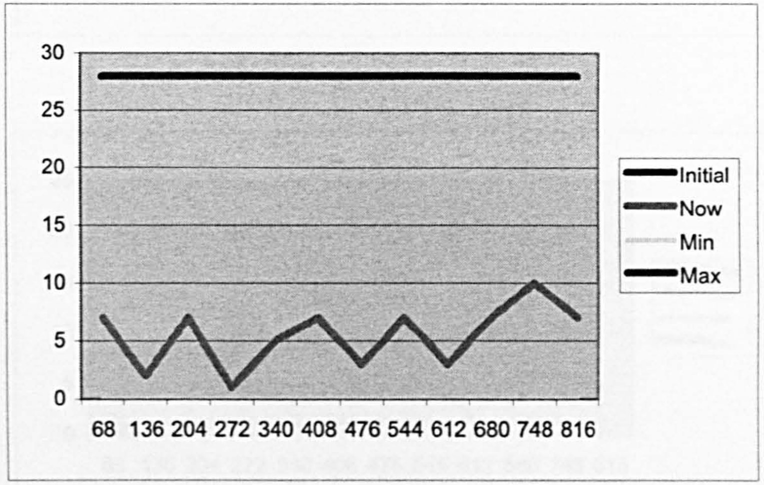
Hard Market Lowest Lead Time Gear

Shift	Init	Now	Min	max		
68	64	32	27	64	7G334/AB	20.37
136	64	34	24	64	7G334/AB	20.6
204	64	35	27	64	7G334/AB	20.63
272	64	32	26	64	7G334/AB	20.61
340	64	34	24	64	7G334/AB	20.6
408	64	35	27	64	7G334/AB	20.47
476	64	34	27	64	7G334/AB	20.54
544	64	32	25	64	7G334/AB	20.55
612	64	34	28	64	7G334/AB	20.43
680	64	33	24	64	7G334/AB	20.63
748	64	32	28	64	7G334/AB	20.62
816	64	32	24	64	7G334/AB	20.58



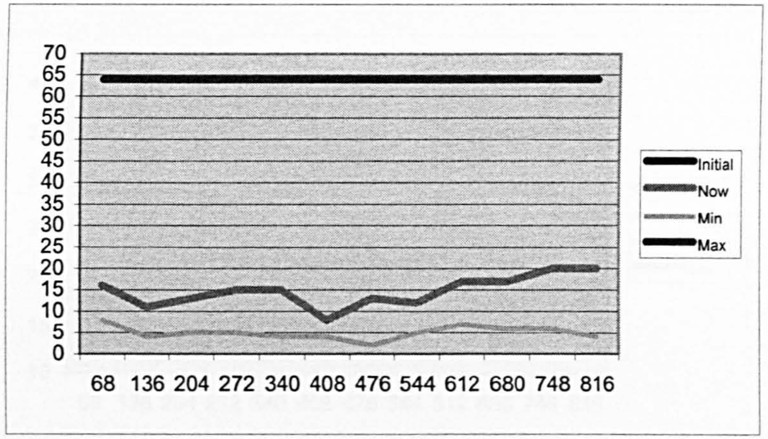
Hard Market Highest Lead Time Gear

Shift	Init	Now	Min	Max		
68	28	7	0	28	7M161/AB	34.64
136	28	2	0	28	7M161/AB	35.48
204	28	7	0	28	7M161/AB	34.48
272	28	1	0	28	7M161/AB	33.91
340	28	5	0	28	7M161/AB	35.56
408	28	7	0	28	7M161/AB	35.18
476	28	3	0	28	7M161/AB	34.68
544	28	7	0	28	7M161/AB	35.61
612	28	3	0	28	7M161/AB	35.04
680	28	7	0	28	7M161/AB	35.36
748	28	10	0	28	7M161/AB	34.51
816	28	7	0	28	7M161/AB	35.06



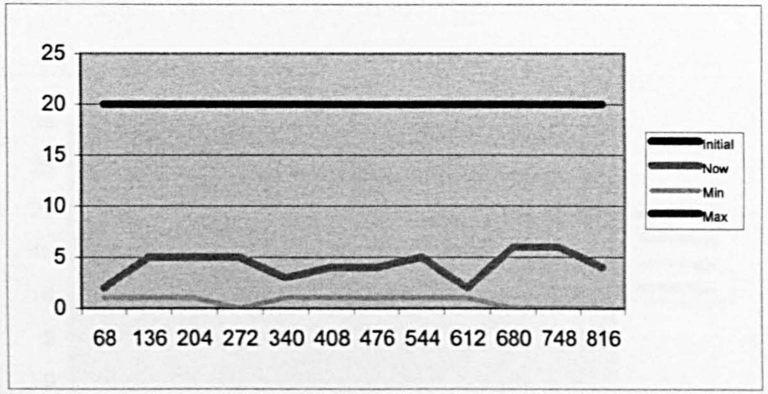
Hard Market Lowest Lead Time Shaft

Shift	Init	Now	Min	Max		
68	64	16	8	64	7L253/AB	26.59
136	64	11	4	64	7L253/AB	31.29
204	64	13	5	64	7L253/AB	31.03
272	64	15	5	64	7L253/AB	30.26
340	64	15	4	64	7L253/AB	30.13
408	64	8	4	64	7L253/AB	31.28
476	64	13	2	64	7L253/AB	30.75
544	64	12	5	64	7L253/AB	30.55
612	64	17	7	64	7L253/AB	30.33
680	64	17	6	64	7L253/AB	31.08
748	64	20	6	64	7L253/AB	30.5
816	64	20	4	64	7L253/AB	30.67



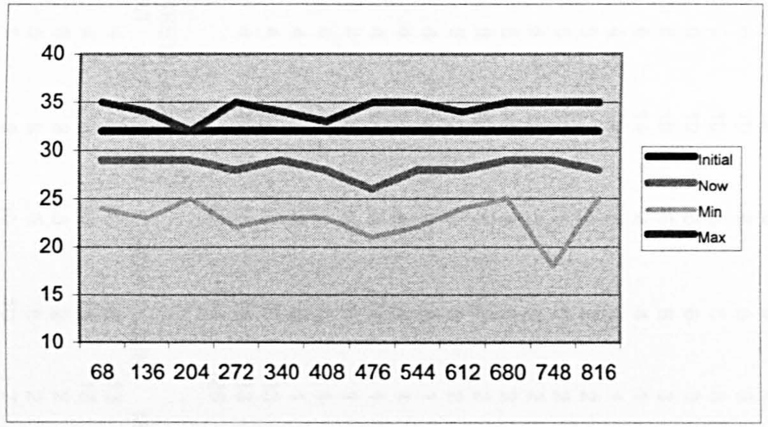
Hard Market Highest Lead Time Shaft

Shift	Init	Now	Min	Max		
68	20	2	1	20	7A356/AB	29.56
136	20	5	1	20	7A356/AB	30.92
204	20	5	1	20	7A356/AB	31.01
272	20	5	0	20	7A356/AB	31.85
340	20	3	1	20	7A356/AB	31.12
408	20	4	1	20	7A356/AB	30.55
476	20	4	1	20	7A356/AB	31.15
544	20	5	1	20	7A356/AB	30.86
612	20	2	1	20	7A356/AB	31.23
680	20	6	0	20	7A356/AB	31.28
748	20	6	0	20	7A356/AB	31.23
816	20	4	0	20	7A356/AB	31.13



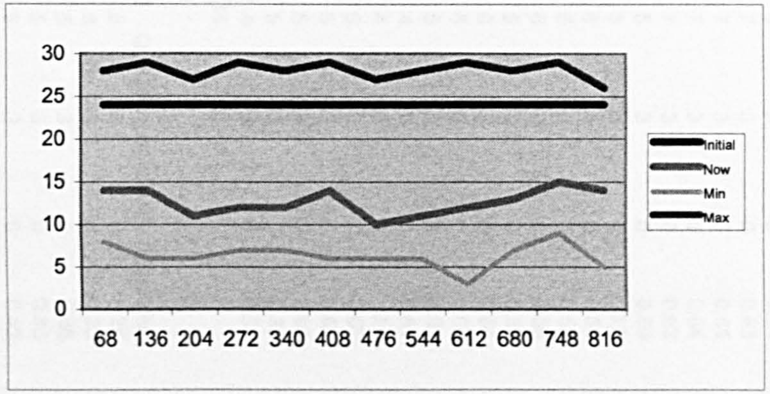
Finished Market Lowest LT

Shift	Init	Now	Min	Max		
68	32	29	24	35	7G334/AB	3.28
136	32	29	23	34	7G334/AB	3.41
204	32	29	25	32	7G334/AB	3.2
272	32	28	22	35	7G334/AB	3.38
340	32	29	23	34	7G334/AB	3.4
408	32	28	23	33	7G334/AB	3.36
476	32	26	21	35	7G334/AB	3.68
544	32	28	22	35	7G334/AB	3.71
612	32	28	24	34	7G334/AB	3.31
680	32	29	25	35	7G334/AB	3.18
748	32	29	18	35	7G334/AB	4.19
816	32	28	25	35	7G334/AB	3.14



Finished Market Highest LT

Shift	Init	Now	Min	Max		
68	24	14	8	28	7M003b/AE	24.88
136	24	14	6	29	7M003b/AE	26.48
204	24	11	6	27	7M003b/AE	26.97
272	24	12	7	29	7M003b/AE	26.64
340	24	12	7	28	7M003b/AE	26.73
408	24	14	6	29	7M003b/AE	25.79
476	24	10	6	27	7M003b/AE	26.35
544	24	11	6	28	7M003b/AE	26.78
612	24	12	3	29	7M003b/AE	27.65
680	24	13	7	28	7M003b/AE	23.56
748	24	15	9	29	7M003b/AE	23.2
816	24	14	5	26	7M003b/AE	24.99



TIME	391680
PRODUCED	404685
CURRENT SH	816
PLANNED OU	509

GEAR GREEN MARKETPLACE

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTIT	STKOUT	LEADTIME
7M161/AA	7	12	7	7	4	12	8	3	0	0.61
7M161/AB	7	12	7	7	4	12	8	3	0	0.57
7M162b/AA	5	12	5	6	2	9	7	3	0	0.63
7M162b/AB	5	12	5	5	2	8	6	3	0	0.64
7M003b/AA	6	10	6	6	3	10	7	3	0	0.63
7M003b/AB	6	10	6	6	3	10	7	3	0	0.61
7M004/AA	6	10	6	6	3	10	7	3	0	0.64
7M004/AB	6	10	6	6	3	10	7	3	0	0.63
7M005/AA	4	14	4	4	1	6	5	3	0	0.69
7M005/AB	4	14	4	4	1	7	6	3	0	0.6
7H518/AA	5	12	5	5	2	8	6	3	0	0.59
7H518/AB	5	12	5	5	2	7	5	3	0	0.59
7M006/AA	5	12	5	6	2	8	6	3	0	0.59
7M006/AB	5	12	5	5	2	7	5	3	0	0.59
7137/AA	5	12	5	5	2	8	6	3	0	0.64
7137/AB	5	12	5	5	2	7	5	3	0	0.59
7112/AA	4	14	4	4	1	6	5	3	0	0.61
7112/AB	4	14	4	4	1	5	4	3	0	0.61
7144/AA	4	14	4	4	1	5	4	3	0	0.6
7144/AB	4	14	4	4	1	6	5	3	0	0.67
7M202/AA	4	14	4	4	1	6	5	3	0	0.69
7M202/AB	4	14	4	4	1	6	5	3	0	0.64
7G334/AA	4	14	16	16	13	18	5	3	0	0.33
7G334/AB	4	14	16	16	13	17	4	3	0	0.33
TOTALS	-	-	142	144	126	160	34	16		

SHAFT GREEN MARKETPLACE

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTIT	STKOUT	LEADTIME
7L253/AA	4	8	16	16	13	18	5	3	0	0.26
7L253/AB	4	8	16	16	13	18	5	3	0	0.23
7A356/AA	5	8	5	2	2	7	5	3	0	0.86
7A356/AB	5	8	5	5	2	7	5	3	0	0.83
7061/AA	5	8	10	10	7	12	5	3	0	0.43
7061/AB	5	8	10	10	7	13	6	3	0	0.43
TOTALS	-	-	62	59	54	67	13	8		

GEAR HARD MARKETPLACE

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTIT	STKOUT	LEADTIME
7M161/AA	7	12	28	7	0	28	28	28	0	35.06
7M161/AB	7	12	28	28	0	28	28	28	1	36.33
7M162b/AA	5	12	20	1	0	20	20	20	0	34.41
7M162b/AB	5	12	20	20	1	20	19	19	0	34.32
7M003b/AA	6	10	24	6	2	24	22	22	0	30.6
7M003b/AB	6	10	24	24	2	24	22	22	0	29.66
7M004/AA	6	10	24	6	3	24	21	21	0	28.97
7M004/AB	6	10	24	24	2	24	22	22	0	31.51
7M005/AA	4	14	16	4	0	16	16	16	0	31.84
7M005/AB	4	14	16	16	0	16	16	16	0	31.38
7H518/AA	5	12	20	5	0	20	20	20	0	29.92
7H518/AB	5	12	20	20	2	20	18	18	0	29.77
7M006/AA	5	12	20	0	0	20	20	20	1	35.63
7M006/AB	5	12	20	20	0	20	20	20	0	34.48
7137/AA	5	12	20	5	0	20	20	20	0	30.99
7137/AB	5	12	20	20	2	20	18	18	0	28.65
7112/AA	4	14	16	4	0	16	16	16	0	30.45
7112/AB	4	14	16	16	0	16	16	16	0	29.1
7144/AA	4	14	16	8	0	16	16	16	0	29.01
7144/AB	4	14	16	16	0	16	16	16	0	32.89
7M202/AA	4	14	16	8	0	16	16	16	0	31.74
7M202/AB	4	14	16	16	0	16	16	16	0	31.19
7G334/AA	4	14	64	32	24	64	40	40	0	20.58

7G334/AB	4	14	64	64	28	64	36	36	0	20.59
TOTALS	-	-	568	370	353	401	48	215		

SHAFT HARD MARKETPLACE

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTIT	STKOUT	LEADTIME
7L253/AA	4	8	64	20	4	64	60	60	0	30.67
7L253/AB	4	8	64	64	0	64	64	64	1	32.07
7A356/AA	5	8	20	4	0	20	20	20	0	31.13
7A356/AB	5	8	20	20	0	20	20	20	0	32.09
7061/AA	5	8	40	9	3	40	37	37	0	30.15
7061/AB	5	8	40	40	0	40	40	40	1	31.47
TOTALS	-	-	248	157	129	170	41	119		

FINISHED MARKETPLACE

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTIT	STKOUT	LEADTIME
7M161/AA	7	12	21	16	9	26	17	12	0	10.77
7M161/AB	7	12	21	21	9	24	15	12	0	11.57
7M162b/AA	5	12	15	11	7	18	11	8	0	13.51
7M162b/AB	5	12	15	14	6	17	11	9	0	14.63
7M003b/AA	6	10	24	14	5	26	21	19	0	24.99
7M003b/AB	6	10	24	23	10	27	17	14	0	22.53
7M004/AA	6	10	24	14	9	30	21	15	0	23.33
7M004/AB	6	10	24	24	8	27	19	16	0	26.18
7M005/AA	4	14	16	8	4	18	14	12	0	24.89
7M005/AB	4	14	16	16	4	18	14	12	0	24.53
7H518/AA	5	12	20	11	2	23	21	18	0	24.57
7H518/AB	5	12	20	23	6	24	18	14	0	23.41
7M006/AA	5	12	15	11	6	18	12	9	0	13.43
7M006/AB	5	12	15	17	4	18	14	11	0	13.9
7137/AA	5	12	15	10	6	17	11	9	0	12.42
7137/AB	5	12	15	17	9	18	9	6	0	9.85
7112/AA	4	14	12	8	3	14	11	9	0	13.02
7112/AB	4	14	12	11	4	13	9	8	0	13.02
7144/AA	4	14	12	10	6	14	8	6	0	10.13
7144/AB	4	14	12	11	5	13	8	7	0	15.38
7M202/AA	4	14	12	8	4	14	10	8	0	14.04
7M202/AB	4	14	12	11	4	13	9	8	0	13.82
7G334/AA	4	14	32	28	25	35	10	7	0	3.14
7G334/AB	4	14	32	33	25	34	9	7	0	3.15
7L253/AA	4	8	32	13	8	34	26	24	0	11.61
7L253/AB	4	8	32	32	5	33	28	27	0	13.17
7A356/AA	5	8	15	8	5	19	14	10	0	16.28
7A356/AB	5	8	15	14	5	15	10	10	0	16.77
7061/AA	5	8	20	9	5	23	18	15	0	11.96
7061/AB	5	8	20	20	3	21	18	17	0	13.25
TOTALS	-	-	570	466	446	503	57	124		

FULL TROLLEYS (PRE GREEN MARKET ZONE)

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE
7M161/AA	7	12	0	0	0	1	1
7M161/AB	7	12	0	0	0	1	1
7M162b/AA	5	12	0	0	0	1	1
7M162b/AB	5	12	0	0	0	1	1
7M003b/AA	6	10	0	0	0	1	1
7M003b/AB	6	10	0	0	0	1	1
7M004/AA	6	10	0	0	0	1	1
7M004/AB	6	10	0	0	0	1	1
7M005/AA	4	14	0	0	0	1	1
7M005/AB	4	14	0	0	0	1	1
7H518/AA	5	12	0	0	0	1	1
7H518/AB	5	12	0	0	0	1	1
7M006/AA	5	12	0	0	0	1	1
7M006/AB	5	12	0	0	0	1	1
7137/AA	5	12	0	0	0	1	1
7137/AB	5	12	0	0	0	1	1
7112/AA	4	14	0	0	0	1	1
7112/AB	4	14	0	0	0	1	1
7144/AA	4	14	0	0	0	1	1
7144/AB	4	14	0	0	0	1	1
7M202/AA	4	14	0	0	0	1	1

7M202/AB	4	14	0	0	0	1	1
7G334/AA	4	14	0	0	0	1	1
7G334/AB	4	14	0	0	0	1	1
7L253/AA	4	8	0	0	0	1	1
7L253/AB	4	8	0	0	0	1	1
7A356/AA	5	8	0	0	0	1	1
7A356/AB	5	8	0	0	0	1	1
7061/AA	5	8	0	0	0	1	1
7061/AB	5	8	0	0	0	1	1
TOTALS	-	-	0	0	0	4	4

FULL TROLLEYS IN (GREEN ZONE)

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE
7M161/AA	7	12	0	7	0	17	17
7M161/AB	7	12	0	0	0	15	15
7M162b/AA	5	12	0	5	0	12	12
7M162b/AB	5	12	0	0	0	12	12
7M003b/AA	6	10	0	6	0	11	11
7M003b/AB	6	10	0	0	0	9	9
7M004/AA	6	10	0	2	0	11	11
7M004/AB	6	10	0	0	0	12	12
7M005/AA	4	14	0	4	0	9	9
7M005/AB	4	14	0	0	0	8	8
7H518/AA	5	12	0	5	0	10	10
7H518/AB	5	12	0	0	0	10	10
7M006/AA	5	12	0	9	0	13	13
7M006/AB	5	12	0	0	0	12	12
7137/AA	5	12	0	1	0	12	12
7137/AB	5	12	0	0	0	10	10
7112/AA	4	14	0	3	0	9	9
7112/AB	4	14	0	0	0	10	10
7144/AA	4	14	0	0	0	8	8
7144/AB	4	14	0	0	0	10	10
7M202/AA	4	14	0	4	0	10	10
7M202/AB	4	14	0	0	0	8	8
7G334/AA	4	14	0	5	0	13	13
7G334/AB	4	14	0	0	0	10	10
7L253/AA	4	8	0	21	0	33	33
7L253/AB	4	8	0	0	0	40	40
7A356/AA	5	8	0	9	0	11	11
7A356/AB	5	8	0	0	0	12	12
7061/AA	5	8	0	13	0	21	21
7061/AB	5	8	0	0	0	24	24
TOTALS	-	-	0	94	72	143	71

FULL RACKS ON SHOPFLOOR OR IN HEATTREAT

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE
7M161/AA	7	12	0	14	0	21	21
7M161/AB	7	12	0	0	0	21	21
7M162b/AA	5	12	0	14	0	15	15
7M162b/AB	5	12	0	0	0	15	15
7M003b/AA	6	10	0	12	0	18	18
7M003b/AB	6	10	0	0	0	18	18
7M004/AA	6	10	0	16	0	18	18
7M004/AB	6	10	0	0	0	18	18
7M005/AA	4	14	0	8	0	12	12
7M005/AB	4	14	0	0	0	12	12
7H518/AA	5	12	0	10	0	15	15
7H518/AB	5	12	0	0	0	15	15
7M006/AA	5	12	0	10	0	15	15
7M006/AB	5	12	0	0	0	15	15
7137/AA	5	12	0	14	0	15	15
7137/AB	5	12	0	0	0	15	15
7112/AA	4	14	0	9	0	12	12
7112/AB	4	14	0	0	0	12	12
7144/AA	4	14	0	8	0	12	12
7144/AB	4	14	0	0	0	12	12
7M202/AA	4	14	0	4	0	12	12
7M202/AB	4	14	0	0	0	12	12
7G334/AA	4	14	0	27	0	32	32

7G334/AB	4	14	0	0	0	32	32
7L253/AA	4	8	0	23	0	38	38
7L253/AB	4	8	0	0	0	37	37
7A356/AA	5	8	0	7	0	11	11
7A356/AB	5	8	0	0	0	11	11
7061/AA	5	8	0	18	0	23	23
7061/AB	5	8	0	0	0	25	25
TOTALS	-	-	0	194	152	213	61

FULL TROLLEYS IN (HARD ZONE)

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE
7M161/AA	7	12	0	6	0	12	12
7M161/AB	7	12	0	0	0	12	12
7M162b/AA	5	12	0	6	0	9	9
7M162b/AB	5	12	0	0	0	9	9
7M003b/AA	6	10	0	12	0	18	18
7M003b/AB	6	10	0	0	0	15	15
7M004/AA	6	10	0	12	0	17	17
7M004/AB	6	10	0	0	0	17	17
7M005/AA	4	14	0	8	0	12	12
7M005/AB	4	14	0	0	0	12	12
7H518/AA	5	12	0	11	0	19	19
7H518/AB	5	12	0	0	0	15	15
7M006/AA	5	12	0	7	0	10	10
7M006/AB	5	12	0	0	0	13	13
7137/AA	5	12	0	5	0	10	10
7137/AB	5	12	0	0	0	7	7
7112/AA	4	14	0	4	0	8	8
7112/AB	4	14	0	0	0	8	8
7144/AA	4	14	0	2	0	7	7
7144/AB	4	14	0	0	0	8	8
7M202/AA	4	14	0	4	0	8	8
7M202/AB	4	14	0	0	0	8	8
7G334/AA	4	14	0	6	0	7	7
7G334/AB	4	14	0	0	0	7	7
7L253/AA	4	8	0	19	0	25	25
7L253/AB	4	8	0	0	0	28	28
7A356/AA	5	8	0	9	0	11	11
7A356/AB	5	8	0	0	0	11	11
7061/AA	5	8	0	13	0	16	16
7061/AB	5	8	0	0	0	19	19
TOTALS	-	-	0	124	95	150	55

EMPTY TROLLEYS AT GREEN

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTITY
7M161/AA	7	12	21	14	0	21	21	14
7M161/AB	7	12	21	21	7	21	14	14
7M162b/AA	5	12	15	10	4	15	11	6
7M162b/AB	5	12	15	15	5	15	10	10
7M003b/AA	6	10	12	6	0	12	12	6
7M003b/AB	6	10	12	12	0	12	12	12
7M004/AA	6	10	12	10	0	12	12	10
7M004/AB	6	10	12	12	0	12	12	12
7M005/AA	4	14	8	4	0	8	8	4
7M005/AB	4	14	8	8	0	8	8	8
7H518/AA	5	12	10	5	0	10	10	5
7H518/AB	5	12	10	10	0	10	10	10
7M006/AA	5	12	15	5	0	15	15	5
7M006/AB	5	12	15	15	4	15	11	11
7137/AA	5	12	10	9	0	10	10	9
7137/AB	5	12	10	10	0	10	10	10
7112/AA	4	14	8	5	0	8	8	5
7112/AB	4	14	8	8	0	8	8	8
7144/AA	4	14	8	8	0	8	8	8
7144/AB	4	14	8	8	-2	8	10	10
7M202/AA	4	14	8	4	0	8	8	4
7M202/AB	4	14	8	8	0	8	8	8
7G334/AA	4	14	80	75	67	80	13	8
7G334/AB	4	14	80	80	69	80	11	11
7L253/AA	4	8	112	91	78	112	34	13

7L253/AB	4	8	112	112	72	112	40	40
7A356/AA	5	8	15	5	5	15	10	0
7A356/AB	5	8	15	15	3	15	12	12
7061/AA	5	8	40	25	20	40	20	5
7061/AB	5	8	40	40	15	40	25	25
TOTALS	-	-	748	650	592	673	81	156

EMPTY TROLLEYS AT HARD

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTITY
7M161/AA	7	12	7	27	2	34	32	25
7M161/AB	7	12	7	6	4	36	32	2
7M162b/AA	5	12	5	21	1	23	22	20
7M162b/AB	5	12	5	5	3	23	20	2
7M003b/AA	6	10	6	22	3	26	23	19
7M003b/AB	6	10	6	6	3	26	23	3
7M004/AA	6	10	6	22	0	24	24	22
7M004/AB	6	10	6	5	3	26	23	2
7M005/AA	4	14	4	16	1	19	18	15
7M005/AB	4	14	4	3	2	19	17	1
7H518/AA	5	12	5	18	1	24	23	17
7H518/AB	5	12	5	1	1	22	21	0
7M006/AA	5	12	5	22	2	26	24	20
7M006/AB	5	12	5	2	2	24	22	0
7137/AA	5	12	5	20	2	24	22	18
7137/AB	5	12	5	2	2	20	18	0
7112/AA	4	14	4	16	1	18	17	15
7112/AB	4	14	4	4	3	18	15	1
7144/AA	4	14	4	12	1	18	17	11
7144/AB	4	14	4	4	3	20	17	1
7M202/AA	4	14	4	12	2	20	18	10
7M202/AB	4	14	4	4	3	19	16	1
7G334/AA	4	14	16	46	13	54	41	33
7G334/AB	4	14	16	14	14	52	38	0
7L253/AA	4	8	16	60	14	74	60	46
7L253/AB	4	8	16	15	15	80	65	0
7A356/AA	5	8	5	18	1	22	21	17
7A356/AB	5	8	5	5	5	23	18	0
7061/AA	5	8	10	39	7	45	38	32
7061/AB	5	8	10	9	9	50	41	0
TOTALS	-	-	204	456	415	476	61	-211

EMPTY RACKS AT HARD

CODE	TR/BAT	BKTS/TR	INIT	NOW	MIN	MAX	RANGE	QUANTITY
7M161/AA	7	12	21	7	0	21	21	7
7M161/AB	7	12	21	21	0	21	21	21
7M162b/AA	5	12	15	1	0	15	15	1
7M162b/AB	5	12	15	15	0	15	15	15
7M003b/AA	6	10	18	6	0	18	18	6
7M003b/AB	6	10	18	18	0	18	18	18
7M004/AA	6	10	18	2	0	18	18	2
7M004/AB	6	10	18	18	0	18	18	18
7M005/AA	4	14	12	4	0	12	12	4
7M005/AB	4	14	12	12	0	12	12	12
7H518/AA	5	12	15	5	0	15	15	5
7H518/AB	5	12	15	15	0	15	15	15
7M006/AA	5	12	15	5	0	15	15	5
7M006/AB	5	12	15	15	0	15	15	15
7137/AA	5	12	15	1	0	15	15	1
7137/AB	5	12	15	15	0	15	15	15
7112/AA	4	14	12	3	0	12	12	3
7112/AB	4	14	12	12	0	12	12	12
7144/AA	4	14	12	4	0	12	12	4
7144/AB	4	14	12	12	0	12	12	12
7M202/AA	4	14	12	8	0	12	12	8
7M202/AB	4	14	12	12	0	12	12	12
7G334/AA	4	14	132	105	100	132	32	5
7G334/AB	4	14	132	132	100	132	32	32
7L253/AA	4	8	120	97	82	120	38	15
7L253/AB	4	8	120	120	83	120	37	37
7A356/AA	5	8	15	8	4	15	11	4

7A356/AB	5	8	15	15	4	15	11	11
7061/AA	5	8	45	27	22	45	23	5
7061/AB	5	8	45	45	20	45	25	25
TOTALS	-	-	954	760	741	802	61	213

TROLLEYS AT PROCESSES (CURRENT & MAXIMUM)

NAME/CODE												
Decant Gears	Current	0	0	0	0							
	Maximum	1	1	1	1							
	InQueue	0.01	0.01	0.01	0.01							
	OutQueue	0	0	0	0							
Decant Ring G	Current	0										
	Maximum	1										
	InQueue	0										
	OutQueue	0										
Marketplace G	Current	144										
	Maximum	160										
	InQueue	0										
	OutQueue											
Turn+Hob+Del	Current	0	3	2	1	3	3	3	0	1	3	1
	Maximum	3	3	3	3	3	3	3	3	3	3	3
	InQueue	1.3	1.36	1.25	1.29	1.31	1.34	1.25	1.33	1.31	1.4	1.3
	OutQueue	0	0	0	0	0	0	0	0	0	0	0
Turn (Ring Ge	Current	3	0									
	Maximum	3	3									
	InQueue	0.41	0.41									
	OutQueue	0	0									
Hob& Deburr/(	Current	1	1									
	Maximum	3	3									
	InQueue	0.01	0									
	OutQueue	0	0									
Measure Gear	Current	0	0									
	Maximum	0	0									
	InQueue	0	0									
	OutQueue	0	0									
Wash For Las	Current	0	0									
	Maximum	3	3									
	InQueue	0	0									
	OutQueue	0	0									
Assy/Laser W	Current	4										
	Maximum	13										
	InQueue	3.23										
	OutQueue	0										
Decant Gear F	Current	11	8	13	15							
	Maximum	22	23	22	21							
	InQueue	1.69	1.89	1.85	1.79							
	OutQueue	0	0	0	0							
Decant Ring G	Current	3										
	Maximum	13										
	InQueue	0.42										
	OutQueue	0										
Heat Treatmer	Current	165										
	Maximum	200										
	InQueue	0										
	OutQueue	0										
Market Place I	Current	370										
	Maximum	401										
	InQueue	0										
	OutQueue											
Grind + Hardtu	Current	0	3	3	0	3	3	2	3	2	0	1
	Maximum	3	3	3	3	3	3	3	3	3	3	3
	InQueue	1.33	1.38	1.41	1.48	1.38	1.43	1.41	1.42	1.46	1.4	1.3
	OutQueue	0	0	0	0	0	0	0	0	0	0	0
Grind + Hardtu	Current	3										
	Maximum	3										
	InQueue	0.31										
	OutQueue	0										
Hard Finish Te	Current	2	1									
	Maximum	3	3									
	InQueue	0.03	0.03									

	OutQueue	0	0					
Hard Finish Te	Current	3	4	4	4	1		
	Maximum	7	6	7	8	9		
	InQueue	2.25	2.25	2.23	2.11	2.07		
	OutQueue	0	0	0	0	0		
Hard Finish Te	Current	0	1	1	2			
	Maximum	3	4	3	3			
	InQueue	0.01	0.03	0.04	0.01			
	OutQueue	0	0	0	0			
Assy/Laser W	Current	15						
	Maximum	16						
	InQueue	4.11						
	OutQueue	0						
Grind+Hardtur	Current	0	1	3	2	0	4	3
	Maximum	6	6	6	6	11	7	10
	InQueue	2.41	2.4	2.67	2.77	2.87	2.64	2.94
	OutQueue	0	0	0	0	0	0	0
Wash Green/	Current	1						
	Maximum	13						
	InQueue	0						
	OutQueue	0						
Phosphation (	Current	4						
	Maximum	6						
	InQueue	0						
	OutQueue	0						
Wash Final (2	Current	1						
	Maximum	7						
	InQueue	0						
	OutQueue	0						
Crack Detectic	Current	5	0					
	Maximum	18	0					
	InQueue	0	3.03					
	OutQueue	0	0					
Market Place	Current	479						
	Maximum	511						
	InQueue	0						
	OutQueue							
Decant Shaft (	Current	0	0					
	Maximum	1	1					
	InQueue	0	0					
	OutQueue	0	0					
Market Place	Current	59						
	Maximum	67						
	InQueue	0						
	OutQueue							
Face, Center	Current	0	2	3	2	3		
	Maximum	3	3	3	3	3		
	InQueue	0.5	0.66	0.84	0.73	0.7		
	OutQueue	0	0	0	0	0		
Hob Helical Te	Current	1	0	0	3	2		
	Maximum	4	5	4	4	3		
	InQueue	0.08	0.13	0.07	0.08	0.07		
	OutQueue	0	0	0	0	0		
Deburr and Ch	Current	9	9					
	Maximum	19	22					
	InQueue	5.13	4.91					
	OutQueue	0	0					
Check Teeth (	Current	0						
	Maximum	0						
	InQueue	0						
	OutQueue	0						
Roll Splines (7	Current	1	2					
	Maximum	7	6					
	InQueue	0.17	0.19					
	OutQueue	0	0					
Gun Drill/Drill (	Current	3	0					
	Maximum	8	8					
	InQueue	0.52	0.41					
	OutQueue	0	0					
Wash Green (	Current							

	Maximum							
	InQueue							
	OutQueue							
Turn Grooves	Current	1	0					
	Maximum	5	4					
	InQueue	0.03	0.01					
	OutQueue	0	0					
Load HT Fixtu	Current	0	0					
	Maximum	6	4					
	InQueue	0.04	0.02					
	OutQueue	0	0					
UnLoad HT Fi	Current	1	0					
	Maximum	2	4					
	InQueue	0	0					
	OutQueue	0	0					
Market Place I	Current	157						
	Maximum	170						
	InQueue	0						
	OutQueue							
Straighten 1 (1	Current	3	0	3				
	Maximum	3	3	3				
	InQueue	0.41	0.43	0.36				
	OutQueue	0	0	0				
Grind Grooves	Current	0	4	2				
	Maximum	6	7	6				
	InQueue	0.47	0.42	0.54				
	OutQueue	0	0	0				
Grind Diamete	Current	1	2	4	0	3	0	2
	Maximum	5	6	5	5	5	5	5
	InQueue	1.03	1.18	0.73	0.85	0.83	1.02	1.1
	OutQueue	0	0	0	0	0	0	0
Profilegrinding	Current	1	1					
	Maximum	4	4					
	InQueue	0.1	0.05					
	OutQueue	0	0					
Powerhoning (	Current	2	5	1	1			
	Maximum	7	8	7	7			
	InQueue	1	1.01	0.92	0.95			
	OutQueue	0	0	0	0			
Grinding Diam	Current	4						
	Maximum	10						
	InQueue	0.59						
	OutQueue	0						
Assembly Line	Current	0						
	Maximum	0						
	InQueue	0						
	OutQueue							
() x 0	Current							
	Maximum							
	InQueue							
	OutQueue							
() x 0	Current							
	Maximum							
	InQueue							
	OutQueue							
() x 0	Current							
	Maximum							
	InQueue							
	OutQueue							

PROCESS UTILISATION

MACHINE

NAME	OFF-SHIF	IDLE	BUSY	BLOCKE	DOWN	BREAKC	LABW1	LABW2	LABW3	OEE
Assembly Mac	6.25	0	93.75	0	0	0	0	0	0	100
Decant Gears	0	84.1593	15.0441	0	0.7966	0	0	0	0	94.9714
Decant Gears	0	52.8044	44.8059	0	2.3897	0	0	0	0	94.9366
Decant Gears	0	89.8233	9.65588	0	0.5208	0	0	0	0	94.8821
Decant Gears	0	72.6654	25.9559	0	1.3787	0	0	0	0	94.9563
Decant Ring G	0	80.9904	18.55	0	0.4596	0	0	0	0	97.5825
Turn+Hob+Del	0	4.84341	86.618	0	7.9963	0.5422	0	0	0	91.0268
Turn+Hob+Del	0	10.7418	80.3988	0	8.2261	0.6333	0	0	0	90.0744

Turn+Hob+Del	0	6.47794	85.0482	0	7.0925	1.3813	0	0	0	90.9392
Turn+Hob+Del	0	5.75142	84.9643	0	7.6134	1.6709	0	0	0	90.1491
Turn+Hob+Del	0	8.94991	81.9244	0	8.3793	0.7464	0	0	0	89.9773
Turn+Hob+Del	0	7.07605	83.7794	0	8.1955	0.9491	0	0	0	90.1591
Turn+Hob+Del	0	4.02449	87.2219	0	7.3683	1.3853	0	0	0	90.8794
Turn+Hob+Del	0	11.4137	79.9651	0	7.9235	0.6977	0	0	0	90.268
Turn+Hob+Del	0	7.01815	83.3198	0	8.7469	0.9151	0	0	0	89.6086
Turn+Hob+Del	0	10.764	79.9864	0	8.2108	1.0388	0	0	0	89.6347
Turn+Hob+Del	0	8.50179	82.7181	0	7.5521	1.228	0	0	0	90.4041
Turn+Hob+Del	0	8.97097	81.7971	0	8.1036	1.1284	0	0	0	89.8582
Turn (Ring Ge:	0	36.168	59.9894	0	2.5582	1.2844	0	0	0	93.9801
Turn (Ring Ge:	0	36.1887	60.0147	0	2.5582	1.2384	0	0	0	94.0502
Hob& Deburr/(	0	33.1188	64.302	0	1.9822	0.597	0	0	0	96.1436
Hob& Deburr/(	0	34.7974	62.2224	0	1.9363	1.0439	0	0	0	95.4294
Measure Gear	0	100	0	0	0	0	0	0	0	0
Measure Gear	0	100	0	0	0	0	0	0	0	0
Assy/Laser We	0	32.5484	65.5624	0	0.4596	1.4296	0	0	0	97.1992
Decant Gear F	0	24.9412	72.4853	0	2.5735	0	0	0	0	96.5713
Decant Gear F	0	27.3344	70.2146	0	2.451	0	0	0	0	96.627
Decant Gear F	0	25.5844	71.8727	0	2.5429	0	0	0	0	96.5829
Decant Gear F	0	24.0096	73.3863	0	2.6042	0	0	0	0	96.573
Decant Ring G	0	61.9826	37.0982	0	0.9191	0	0	0	0	97.5824
Grind + Hardtu	0	6.08045	86.3993	0	6.633	0.8873	0	0	0	91.9929
Grind + Hardtu	0	16.585	75.6092	0	6.4032	1.4026	0	0	0	90.6423
Grind + Hardtu	0	9.63477	82.9486	0	7.0466	0.3701	0	0	0	91.7926
Grind + Hardtu	0	7.30094	84.7108	0	7.1538	0.8345	0	0	0	91.3826
Grind + Hardtu	0	9.80415	81.4366	0	6.97	1.7893	0	0	0	90.2886
Grind + Hardtu	0	8.3307	82.9917	0	7.0159	1.6617	0	0	0	90.5338
Grind + Hardtu	0	7.43024	84.578	0	7.1385	0.8533	0	0	0	91.3668
Grind + Hardtu	0	16.5936	76.7436	0	6.4032	0.2596	0	0	0	92.0117
Grind + Hardtu	0	6.38934	85.7503	0	7.3223	0.5381	0	0	0	91.6031
Grind + Hardtu	0	13.3469	79.173	0	6.6636	0.8165	0	0	0	91.3677
Grind + Hardtu	0	5.05849	88.0069	0	6.6023	0.3323	0	0	0	92.6959
Grind + Hardtu	0	14.116	78.4941	0	6.7249	0.665	0	0	0	91.3955
Grind + Hardtu	0	6.28136	87.277	0	5.6526	0.7891	0	0	0	93.1266
Hard Finish Te	0	27.5401	70.8787	0	0.9038	0.6774	0	0	0	97.8178
Hard Finish Te	0	27.1925	70.9093	0	0.9038	0.9944	0	0	0	97.3929
Hard Finish Te	0	8.47154	82.8884	0	7.3529	1.2871	0	0	0	90.5603
Hard Finish Te	0	9.38034	83.1643	0	6.6483	0.8071	0	0	0	91.7729
Hard Finish Te	0	9.12813	82.3393	0	7.1232	1.4094	0	0	0	90.6103
Hard Finish Te	0	7.63039	83.7637	0	7.3836	1.2223	0	0	0	90.6832
Hard Finish Te	0	10.5723	81.3754	0	7.0159	1.0363	0	0	0	90.9958
Hard Finish Te	0	23.1143	73.5965	0	2.2672	1.022	0	0	0	95.7221
Hard Finish Te	0	23.417	73.4241	0	2.5735	0.5854	0	0	0	95.8752
Hard Finish Te	0	22.6821	72.8983	0	3.462	0.9575	0	0	0	94.284
Hard Finish Te	0	23.4818	72.85	0	3.1863	0.4819	0	0	0	95.2061
Assy/Laser We	0	9.99317	87.0348	0	1.5165	1.4555	0	0	0	96.698
Grind+Hardtur	0	9.87503	83.4471	0	6.25	0.4278	0	0	0	92.5905
Grind+Hardtur	0	9.14887	83.6257	0	6.5821	0.6433	0	0	0	92.0469
Grind+Hardtur	0	13.6829	79.3407	0	5.7598	1.2166	0	0	0	91.9178
Grind+Hardtur	0	24.1411	69.4104	0	5.1011	1.3475	0	0	0	91.4993
Grind+Hardtur	0	16.8086	76.9596	0	5.576	0.6558	0	0	0	92.5091
Grind+Hardtur	0	8.49201	83.5407	0	6.4338	1.5335	0	0	0	91.2934
Grind+Hardtur	0	13.2972	79.6532	0	6.1275	0.9221	0	0	0	91.8693
Crack Detectic	0	100	0	0	0	0	0	0	0	0
Crack Detectic	0	56.5167	43.4833	0	0	0	0	0	0	100
Decant Shaft (	0	72.3248	26.7254	0	0.9498	0	0	0	0	96.5682
Decant Shaft (	0	87.0689	12.4716	0	0.4596	0	0	0	0	96.4461
Face, Center &	0	31.4928	65.0294	0	2.1906	1.2873	0	0	0	94.9234
Face, Center &	0	24.9727	71.1709	0	3.2169	0.6395	0	0	0	94.86
Face, Center &	0	23.5634	72.4581	0	2.6961	1.2824	0	0	0	94.795
Face, Center &	0	24.7776	71.6489	0	3.0637	0.5098	0	0	0	95.2494
Face, Center &	0	20.6177	75.7801	0	2.1446	1.4576	0	0	0	95.4622
Hob Helical Te	0	15.2032	75.2527	0	8.4804	1.0637	0	0	0	88.7447
Hob Helical Te	0	26.8971	64.808	0	7.3254	0.9696	0	0	0	88.6531
Hob Helical Te	0	18.8455	71.5882	0	8.6183	0.948	0	0	0	88.2123
Hob Helical Te	0	14.022	75.7557	0	9.0533	1.1691	0	0	0	88.1105
Hob Helical Te	0	14.0013	75.9297	0	9.0931	0.9758	0	0	0	88.2917
Deburr and Ch	0	6.31806	73.5662	0	19.738	0.378	0	0	0	78.5276
Deburr and Ch	0	6.65173	73.4248	0	19.565	0.3585	0	0	0	78.6569

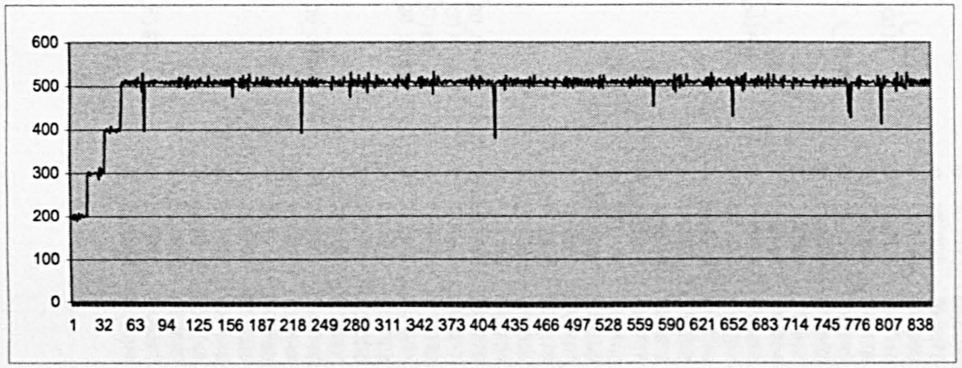
Check Teeth (	0	100	0	0	0	0	0	0	0	0
Roll Splines (7	0	10.2199	71.8438	0	16.912	1.0245	0	0	0	80.022
Roll Splines (7	0	11.5911	69.5621	0	17.387	1.4602	0	0	0	78.6822
Gun Drill/Drill (	0	17.6971	63.1321	0	18.646	0.5245	0	0	0	76.707
Gun Drill/Drill (	0	27.3488	57.0348	0	15.181	0.4357	0	0	0	78.5049
Turn Grooves	0	40.5577	55.1684	0	4.2739	0	0	0	0	92.81
Turn Grooves	0	28.1713	65.049	0	5.913	0.8667	0	0	0	90.5614
Load HT Fixtu	0	70.0564	29.2083	0	0.7353	0	0	0	0	97.5444
Load HT Fixtu	0	73.076	26.25	0	0.674	0	0	0	0	97.4966
UnLoad HT Fi	0	71.0727	28.9273	0	0	0	0	0	0	100
UnLoad HT Fi	0	73.4333	26.5667	0	0	0	0	0	0	100
Straighten 1 (1	0	25.3969	69.7059	0	3.7245	1.1727	0	0	0	93.4356
Straighten 1 (1	0	38.5402	57.0588	0	3.799	0.602	0	0	0	92.8392
Straighten 1 (1	0	25.7876	68.9029	0	4.3505	0.959	0	0	0	92.8456
Grind Grooves	0	26.9278	61.7647	0	11.152	0.1556	0	0	0	84.5256
Grind Grooves	0	17.1464	68.3284	0	13.465	1.0601	0	0	0	82.4688
Grind Grooves	0	19.6185	66.4658	0	13.082	0.8335	0	0	0	82.688
Grind Diamete	0	9.62191	83.2129	0	6.1734	0.9918	0	0	0	92.072
Grind Diamete	0	21.3079	70.1255	0	6.7555	1.8111	0	0	0	89.1137
Grind Diamete	0	15.3302	76.6547	0	7.1844	0.8307	0	0	0	90.5336
Grind Diamete	0	9.54227	82.6976	0	7.0925	0.6676	0	0	0	91.4212
Grind Diamete	0	10.0086	82.7019	0	6.3879	0.9017	0	0	0	91.8997
Grind Diamete	0	21.7429	70.3996	0	6.0662	1.7913	0	0	0	89.9594
Grind Diamete	0	13.8027	77.5485	0	7.2151	1.4338	0	0	0	89.9662
Profilegrinding	0	8.46003	89.244	0	1.3787	0.9173	0	0	0	97.4919
Profilegrinding	0	11.9517	85.6488	0	1.348	1.0515	0	0	0	97.2748
Powerhoning (	0	15.0808	73.7231	0	10.815	0.3812	0	0	0	86.8156
Powerhoning (	0	12.9239	73.1708	0	12.638	1.2675	0	0	0	84.0308
Powerhoning (	0	14.5635	73.6384	0	11.269	0.5291	0	0	0	86.1908
Powerhoning (	0	15.1529	72.8128	0	11.198	0.8364	0	0	0	85.8165
Grinding Diam	0	9.84154	87.2055	0	2.0221	0.9309	0	0	0	96.7247
Phosphation(2	0	61.1803	38.7752	0	0	0.0446	0	0	0	99.8852

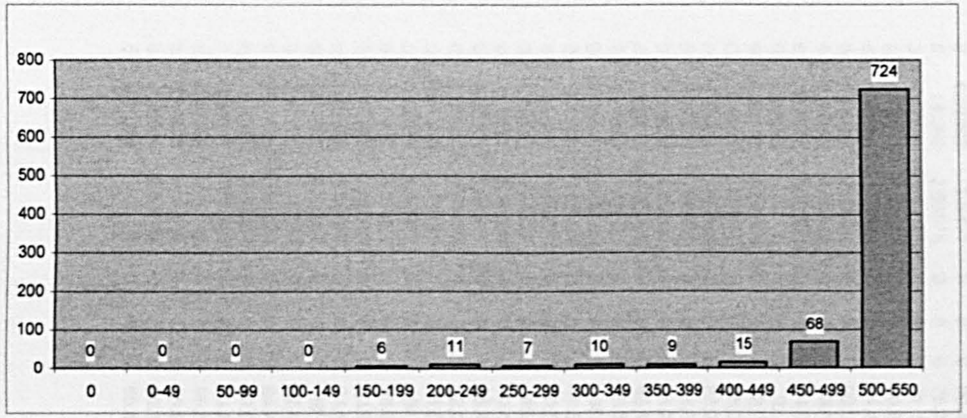
CONVEYOURS

NAME	OFF-SHIF	EMPTY	MOVING	BLOCKE	QUEUED
Wash For Las	0	90.9398	9.0602	0	0
Wash For Las	0	93.3242	6.63588	0	0
Wash Green/	0	54.6054	44.8576	0	0
Wash Final (2	0	46.748	53.1614	0	0

	Freq	%	Cumulative	%
0	0	0.00%	0	0.0%
0-49	0	0.00%	0	0.0%
50-99	0	0.00%	0	0.0%
100-149	0	0.00%	0	0.0%
150-199	6	0.71%	6	0.7%
200-249	11	1.29%	17	2.0%
250-299	7	0.82%	24	2.8%
300-349	10	1.18%	34	4.0%
350-399	9	1.06%	43	5.1%
400-449	15	1.76%	58	6.8%
450-499	68	8.00%	126	14.8%
500-550	724	85.18%	850	100.0%
	850			

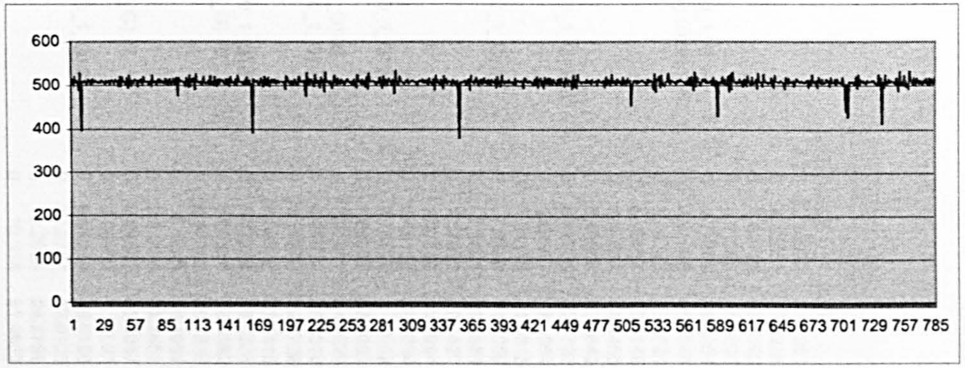
Total	*421170*	
Av	495.4941	
StndDev	54.60338	
Rate/Shift	509	
Shifts	799	from 66 forward
Planned	421991	
	821	
	0.19%	

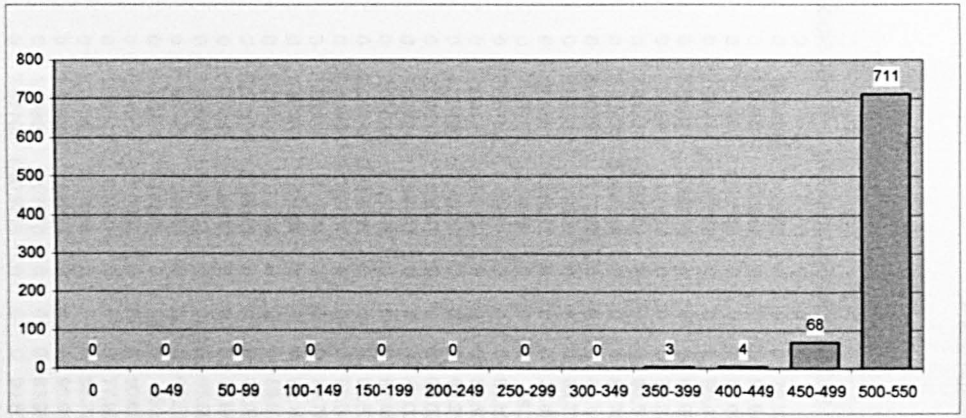




	Freq	%	Cumulative	%
0	0	0.00%	0	0.0%
0-49	0	0.00%	0	0.0%
50-99	0	0.00%	0	0.0%
100-149	0	0.00%	0	0.0%
150-199	0	0.00%	0	0.0%
200-249	0	0.00%	0	0.0%
250-299	0	0.00%	0	0.0%
300-349	0	0.00%	0	0.0%
350-399	3	0.35%	3	0.4%
400-449	4	0.47%	7	0.8%
450-499	68	8.00%	75	8.8%
500-550	711	83.65%	786	92.5%
	786			

Total	399257
Av	507.9606
StndDev	12.1674
Rate/Shift	509
Shifts	786
Planned	400074
	817
	0.20%





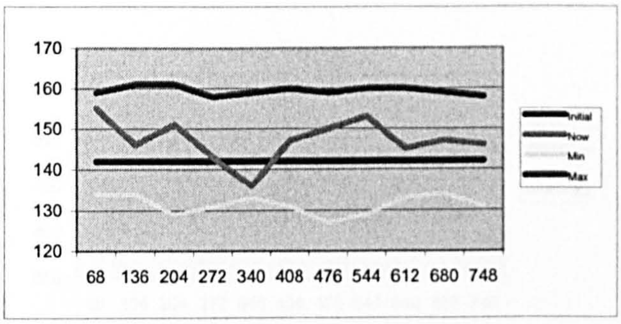
PROCESS UTILISATION

MACHINE NAME	OFF-S	IDLE	BUSY	BLOCKI	DOWN	BREAKDO	LAB	LAB'	LAB	OEE
Assembly Machine(ASSEM) #1	6.25	0.713943	93.0361	0	0	0	0	0	0	100
Deburr and Chamfer (Shaft) (50_S) #1	0	4.10651	73.6238	0	19.8468	2.42283	0	0	0	76.7767
Turn+Hob+Deburr (10_20_30_35_G) #9	0	4.39727	86.6592	0	7.93505	1.00847	0	0	0	90.6451
Turn+Hob+Deburr (10_20_30_35_G) #7	0	4.61278	84.604	0	7.91973	2.86348	0	0	0	88.6953
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #1	0	4.77906	86.0951	0	7.00418	2.12166	0	0	0	90.4161
Grind + Hardturning Bore & Cone & Coneface(Ring Gear) (110_1	0	4.81503	86.6047	0	5.68321	2.89703	0	0	0	90.9857
Hard Finish Teeth (RZ150) (120_RZ150_G) #4	0	5.44773	83.4621	0	7.01593	4.07428	0	0	0	88.2708
Turn+Hob+Deburr (10_20_30_35_G) #6	0	5.95017	83.8146	0	7.84314	2.39204	0	0	0	89.1173
Turn+Hob+Deburr (10_20_30_35_G) #8	0	6.24537	84.1455	0	8.62439	0.984718	0	0	0	89.7508
Turn+Hob+Deburr (10_20_30_35_G) #2	0	6.48606	83.3642	0	8.40993	1.7398	0	0	0	89.1463
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #10	0	6.62303	83.7737	0	6.87806	2.72521	0	0	0	89.7156
Deburr and Chamfer (Shaft) (50_S) #2	0	6.62377	72.364	0	19.1321	1.88011	0	0	0	77.4972
Hard Finish Teeth (RZ150) (120_RZ150_G) #2	0	7.24178	81.9315	0	7.07721	3.74951	0	0	0	88.328
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #6	0	7.2636	84.2059	0	7.06189	1.46861	0	0	0	90.8013
Turn+Hob+Deburr (10_20_30_35_G) #12	0	7.3691	83.1854	0	7.90441	1.54109	0	0	0	89.8031
Profilegrinding Gear Teeth (220_S) #1	0	7.37023	89.1427	0	1.37868	2.10839	0	0	0	96.2355
Turn+Hob+Deburr (10_20_30_35_G) #10	0	7.37046	83.984	0	7.50613	1.13941	0	0	0	90.6665
Hard Finish Teeth (RZ150) (120_RZ150_G) #3	0	7.45158	81.5234	0	7.07721	3.94781	0	0	0	88.0873
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #5	0	7.78627	82.52	0	7.23039	2.46337	0	0	0	89.4877
Turn+Hob+Deburr (10_20_30_35_G) #4	0	7.86725	83.4081	0	8.24142	0.483247	0	0	0	90.5303
Grind+Hardturning Bore & Cone & Coneface (155_G) #2	0	7.92289	84.6629	0	6.46446	0.949751	0	0	0	91.9478
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #3	0	8.00633	83.5016	0	6.95466	1.5374	0	0	0	90.7689
Hard Finish Teeth (RZ150) (120_RZ150_G) #1	0	8.19616	82.7736	0	7.38358	1.64669	0	0	0	90.1635
Grind Diameters and Length (190_S) #7	0	8.39908	82.1416	0	6.54105	2.91824	0	0	0	89.6734
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #8	0	8.72283	81.231	0	6.52574	3.52045	0	0	0	88.9938
Grind+Hardturning Bore & Cone & Coneface (155_G) #6	0	9.06134	82.4682	0	6.51042	1.96007	0	0	0	90.6855
Turn+Hob+Deburr (10_20_30_35_G) #1	0	9.16069	78.7235	0	7.88909	4.22673	0	0	0	86.6624
Grinding Diameters (255_S) #1	0	9.1622	86.4969	0	1.99142	2.34943	0	0	0	95.2213
Hard Finish Teeth (RZ150) (120_RZ150_G) #5	0	9.64664	81.7852	0	7.04295	1.52525	0	0	0	90.517
Grind+Hardturning Bore & Cone & Coneface (155_G) #7	0	9.65682	81.9247	0	6.44914	1.9693	0	0	0	90.6817
Roll Splines (70_80_S) #2	0	9.84902	70.21	0	17.0343	2.9067	0	0	0	77.8804
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #2	0	9.99174	79.9198	0	6.77083	3.31766	0	0	0	88.7916
Assy/Laser Welding Hard (140_150_G) #1	0	10.2777	87.0129	0	1.51654	1.19281	0	0	0	96.9803
Profilegrinding Gear Teeth (220_S) #2	0	10.2965	84.2788	0	1.34804	4.07673	0	0	0	93.9526
Turn+Hob+Deburr (10_20_30_35_G) #3	0	10.314	81.4837	0	7.52705	0.675218	0	0	0	90.8545
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #12	0	10.369	81.8314	0	6.98529	0.814241	0	0	0	91.2982
Turn+Hob+Deburr (10_20_30_35_G) #11	0	10.4107	79.2094	0	8.62439	1.75553	0	0	0	88.4139
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #7	0	10.6605	79.0296	0	6.72488	3.58502	0	0	0	88.4599
Turn+Hob+Deburr (10_20_30_35_G) #5	0	10.7091	77.7699	0	7.55208	3.96895	0	0	0	87.0972
Grind Diameters and Length (190_S) #3	0	10.754	81.7367	0	6.54105	0.968234	0	0	0	91.5859
Grind Diameters and Length (190_S) #4	0	10.7771	80.6998	0	6.67892	1.8441	0	0	0	90.4475
Roll Splines (70_80_S) #1	0	10.7975	70.3377	0	16.299	2.56574	0	0	0	78.8518
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #4	0	11.3386	80.8555	0	6.81679	0.989063	0	0	0	91.1959
Grind+Hardturning Bore & Cone & Coneface (155_G) #3	0	12.6628	79.2044	0	6.11213	2.02064	0	0	0	90.6881
Grind Diameters and Length (190_S) #1	0	12.7968	79.7176	0	6.70956	0.776046	0	0	0	91.4159
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #9	0	13.1563	78.1743	0	6.64828	2.02104	0	0	0	90.0173
Hob Helical Teeth 1st Speed (30_40_S) #2	0	13.4997	72.2652	0	9.54963	4.68542	0	0	0	83.5433
Powerhoning (230_S) #2	0	13.551	72.957	0	10.7016	2.79039	0	0	0	84.3931
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #11	0	13.7207	79.6004	0	6.67892	0	0	0	0	92.259
Grind+Hardturning Bore & Cone & Coneface (155_G) #4	0	14.0428	77.0287	0	5.82108	3.10743	0	0	0	89.6128
Powerhoning (230_S) #4	0	14.1188	73.0707	0	10.8915	1.91897	0	0	0	85.0834
Hob Helical Teeth 1st Speed (30_40_S) #4	0	14.5234	75.2224	0	8.09436	2.15985	0	0	0	88.0035
Hob Helical Teeth 1st Speed (30_40_S) #1	0	14.5669	75.202	0	9.57414	0.656966	0	0	0	88.0244
Grind Diameters and Length (190_S) #5	0	14.8056	75.1853	0	6.81679	3.19239	0	0	0	88.2514
Powerhoning (230_S) #3	0	15.1384	73.0767	0	11.0819	0.703062	0	0	0	86.1127
Powerhoning (230_S) #1	0	15.2436	72.5442	0	10.5852	1.62701	0	0	0	85.5914
Hob Helical Teeth 1st Speed (30_40_S) #3	0	15.5267	74.5105	0	9.38419	0.578584	0	0	0	88.206
Gun Drill/Drill Cross Holes & Deburr (90_100_S) #1	0	16.3662	64.0464	0	18.0289	1.55854	0	0	0	76.5796
Grind Grooves (180_S) #2	0	17.3452	66.6176	0	14.185	1.85214	0	0	0	80.5974
Grind Diameters and Length (190_S) #2	0	18.6351	73.0535	0	7.16912	1.14227	0	0	0	89.785
Grind Grooves (180_S) #3	0	18.8769	64.5724	0	11.3817	5.16894	0	0	0	79.5981
Face, Center & Thread/Turn Profile Complete (10_20_S) #5	0	19.8998	76.8776	0	2.02206	1.20057	0	0	0	95.9767
Grind+Hardturning Bore & Cone & Coneface (155_G) #1	0	19.9348	73.7317	0	5.31556	1.01793	0	0	0	92.0896
Grind+Hardturning Bore & Cone & Coneface (155_G) #5	0	20.9924	72.349	0	4.91728	1.74135	0	0	0	91.5722
Face, Center & Thread/Turn Profile Complete (10_20_S) #1	0	21.0122	74.3583	0	3.09436	1.53509	0	0	0	94.139
Hard Finish Teeth (Prawema) (120_Prw_G) #2	0	21.3012	73.8522	0	3.21691	1.62971	0	0	0	93.8416
Hard Finish Teeth (Prawema) (120_Prw_G) #4	0	22.7174	72.5333	0	2.78331	1.96591	0	0	0	93.8547
Hard Finish Teeth (Prawema) (120_Prw_G) #1	0	22.8363	72.6582	0	2.81863	1.68683	0	0	0	94.1612
Face, Center & Thread/Turn Profile Complete (10_20_S) #4	0	23.0351	70.8346	0	3.17096	2.95927	0	0	0	92.035
Hard Finish Teeth (Prawema) (120_Prw_G) #3	0	23.6018	70.6489	0	3.24755	2.50174	0	0	0	92.4746
Grind Grooves (180_S) #1	0	24.1711	64.0689	0	11.1433	0.616728	0	0	0	84.4914
Grind Diameters and Length (190_S) #6	0	24.6761	67.1039	0	5.8364	2.38353	0	0	0	89.0872
Straighten 1 (140_S) #1	0	24.7638	70.1516	0	5.00919	0.075387	0	0	0	93.2418
Decant Gear For HT (DECH_G) #4	0	24.9816	72.4448	0	2.57353	0	0	0	0	96.5695
Decant Gear For HT (DECH_G) #3	0	25.0692	72.3879	0	2.54289	0	0	0	0	96.6063
Hard Finish Teeth (RZ400) (Ring Gear Only) (120_R) #1	0	25.8916	71.4242	0	1.05699	1.62715	0	0	0	96.3781
Decant Gear For HT (DECH_G) #1	0	25.9684	71.5194	0	2.51225	0	0	0	0	96.6065

Straighten 1 (140_S) #3	0	26.1576	67.8982	0	4.16351	1.78065	0	0	0	91.9502
Face, Center & Thread/Turn Profile Complete (10_20_S) #3	0	26.4068	69.7379	0	3.24755	0.607717	0	0	0	94.7614
Turn Grooves (120_S) #2	0	27.7498	64.4593	0	5.91299	1.87799	0	0	0	89.2167
Decant Gear For HT (DECH_G) #2	0	28.2755	69.2735	0	2.45098	0	0	0	0	96.5828
Hob Helical Teeth 1st Speed (30_40_S) #5	0	28.4608	63.3885	0	7.45429	0.696379	0	0	0	88.6067
Gun Drill/Drill Cross Holes & Deburr (90_100_S) #2	0	28.7418	55.3464	0	14.1697	1.74203	0	0	0	77.6703
Hard Finish Teeth (RZ400) (Ring Gear Only) (120_R) #2	0	28.9047	69.2751	0	0.903799	0.916436	0	0	0	97.4397
Hob& Deburr/Chanmfer (Ring Gear only) (35_R) #2	0	33.5789	63.3023	0	2.25184	0.866976	0	0	0	95.3045
Assy/Laser Welding Green (60_70_G) #1	0	33.9389	64.9869	0	0.459559	0.614644	0	0	0	98.3739
Face, Center & Thread/Turn Profile Complete (10_20_S) #2	0	34.4696	61.6227	0	2.23652	1.67126	0	0	0	94.0367
Hob& Deburr/Chanmfer (Ring Gear only) (35_R) #1	0	34.9742	62.216	0	1.93627	0.87355	0	0	0	95.6789
Turn (Ring Gear Only) (10_20_25_R) #1	0	35.3754	60.7279	0	2.65012	1.24651	0	0	0	93.9704
Turn Grooves (120_S) #1	0	37.6235	54.8485	0	4.16667	3.36128	0	0	0	87.9314
Turn (Ring Gear Only) (10_20_25_R) #2	0	37.8641	58.425	0	2.48162	1.22928	0	0	0	94.0278
Straighten 1 (140_S) #2	0	39.1734	56.7549	0	3.80568	0.265998	0	0	0	93.3061
Wash Final (200_B) #1	0	46.8608	52.4651	0.0119	0					
Decant Gears (DEC_G) #2	0	53.1431	44.4978	0	2.35907	0	0	0	0	94.9654
Crack Detection (210_G) #1	0	57.0859	42.9141	0	0	0	0	0	0	100
Phosphation(210_B) #1	0	60.8372	38.5444	0	0	0.618439	0	0	0	98.4208
Decant Ring Gear HT (DECH_R) #1	0	62.309	36.7719	0	0.919118	0	0	0	0	97.5614
UnLoad HT Fixture (175_S) #1	0	71.5122	28.4878	0	0	0	0	0	0	100
Load HT Fixture (125_S) #1	0	71.7745	27.5209	0	0.704657	0	0	0	0	97.5035
Load HT Fixture (125_S) #2	0	71.8162	27.4792	0	0.704657	0	0	0	0	97.4998
Decant Gears (DEC_G) #4	0	72.2525	26.3382	0	1.40931	0	0	0	0	94.9209
Decant Shaft (DEC_S) #1	0	72.5384	26.5119	0	0.949755	0	0	0	0	96.5415
UnLoad HT Fixture (175_S) #2	0	73.2906	26.7094	0	0	0	0	0	0	100
Wash Green (45_B) #1	0	73.8805	26.1195	0	0					
Wash Hard (160_B) #1	0	74.6259	25.0816	0	0					
Decant Ring Gears (DEC_R) #1	0	81.088	18.4525	0	0.459559	0	0	0	0	97.57
Wash For Laser (55_G) #2	0	85.8275	14.1725	0	0					
Decant Gears (DEC_G) #3	0	86.923	12.4029	0	0.67402	0	0	0	0	94.8457
Decant Gears (DEC_G) #1	0	87.1507	12.2059	0	0.643382	0	0	0	0	94.9928
Decant Shaft (DEC_S) #2	0	87.1847	12.3864	0	0.428922	0	0	0	0	96.6531
Wash For Laser (55_G) #1	0	98.4726	1.52742	0	0					
Measure Gear (40_G) #1	0	100	0	0	0	0	0	0	0	0
Measure Gear (40_G) #2	0	100	0	0	0	0	0	0	0	0
Crack Detection (210_G) #2	0	100	0	0	0	0	0	0	0	0
Check Teeth (60_S) #1	0	100	0	0	0	0	0	0	0	0

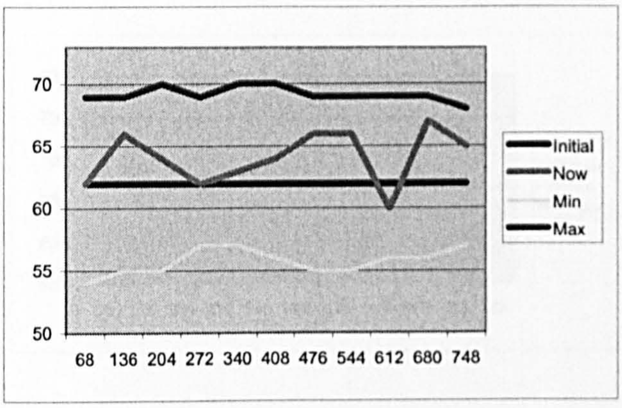
Green Market GEARS

Shift	Init	Now	Min	max
68	142	155	134	159
136	142	146	134	161
204	142	151	129	161
272	142	143	131	158
340	142	136	133	159
408	142	147	131	160
476	142	150	127	159
544	142	153	129	160
612	142	145	133	160
680	142	147	134	159
748	142	146	131	158
816	142	145	130	161



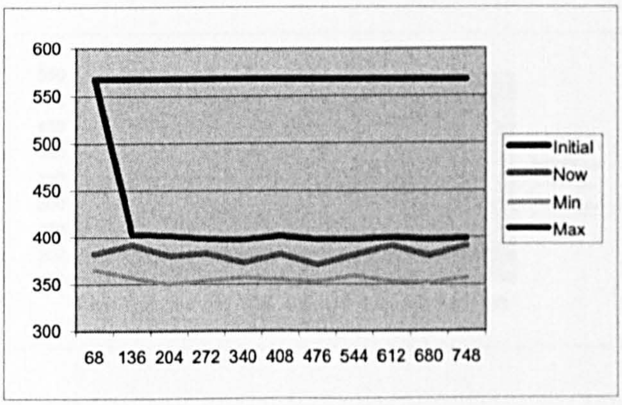
Green Market SHAFTS

Shift	Init	Now	Min	Max
68	62	62	54	69
136	62	66	55	69
204	62	64	55	70
272	62	62	57	69
340	62	63	57	70
408	62	64	56	70
476	62	66	55	69
544	62	66	55	69
612	62	60	56	69
680	62	67	56	69
748	62	65	57	68
816	62	62	57	71



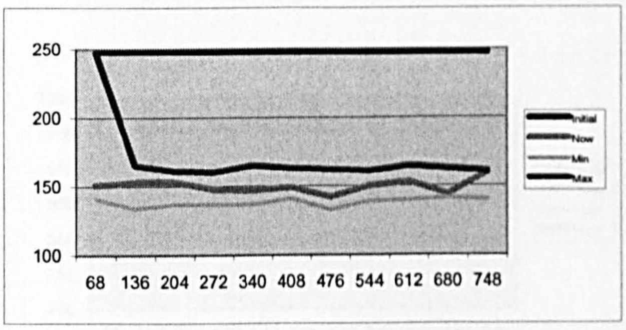
Hard Market GEARS

Shift	Init	Now	Min	Max
68	568	382	365	568
136	568	392	357	404
204	568	380	350	402
272	568	383	354	399
340	568	373	357	398
408	568	382	355	402
476	568	371	353	398
544	568	381	359	398
612	568	391	353	400
680	568	380	352	398
748	568	391	357	399
816	568	379	354	401



Hard Market SHAFTS

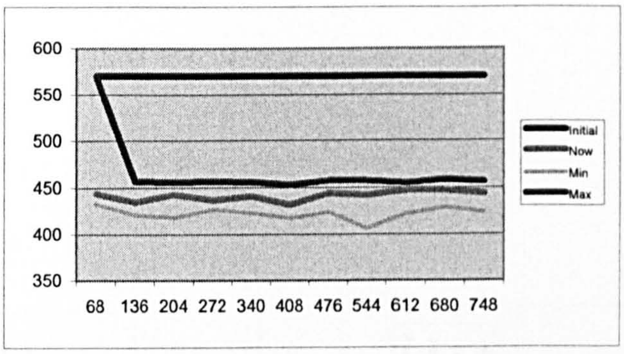
Shift	Init	Now	Min	Max
68	248	151	141	248
136	248	153	134	165
204	248	153	137	161
272	248	148	137	160
340	248	147	137	165
408	248	149	141	163
476	248	142	133	162
544	248	150	139	161
612	248	153	140	165
680	248	144	141	163
748	248	160	140	161
816	248	153	134	161



Changes in the Total Trolleys in Intermediate markets

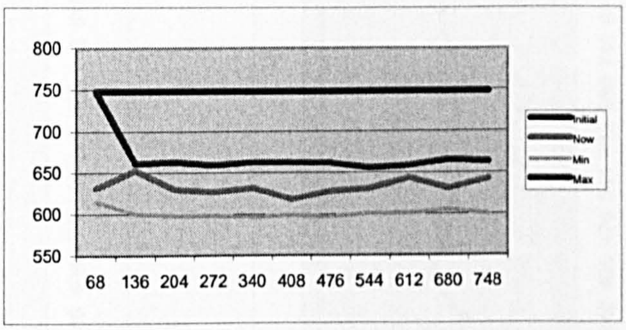
Finished Market

Shift	Init	Now	Min	Max
68	570	444	433	570
136	570	435	421	457
204	570	443	418	456
272	570	437	427	457
340	570	441	423	456
408	570	432	417	453
476	570	444	424	458
544	570	442	406	458
612	570	447	422	455
680	570	447	429	459
748	570	444	424	457
816	570	437	419	457



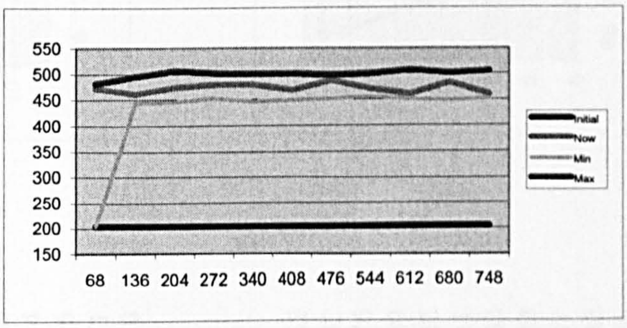
Empty trolleys Green Area

Shift	Init	Now	Min	Max
68	748	632	615	748
136	748	653	600	661
204	748	630	598	663
272	748	627	598	659
340	748	632	597	663
408	748	618	599	663
476	748	628	597	662
544	748	631	601	656
612	748	644	601	659
680	748	631	605	666
748	748	643	600	664
816	748	637	595	659



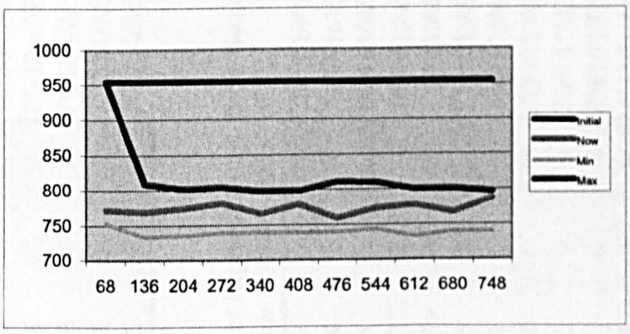
Empty trolleys Hard Area

Shift	Init	Now	Min	Max
68	204	473	204	482
136	204	461	444	496
204	204	475	446	507
272	204	480	452	502
340	204	480	446	500
408	204	469	448	501
476	204	488	452	498
544	204	472	456	500
612	204	461	451	507
680	204	483	449	501
748	204	460	452	505
816	204	478	454	505



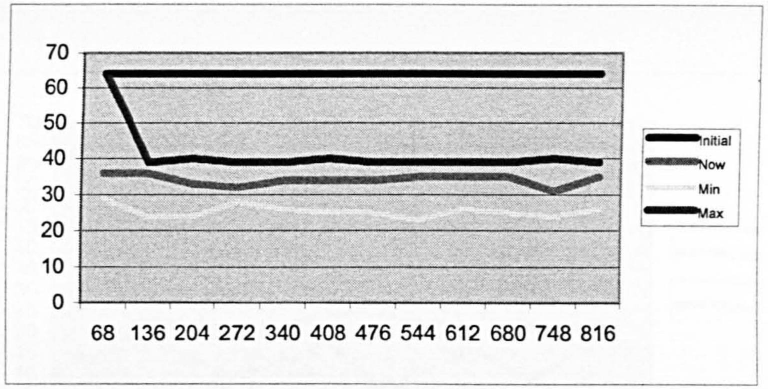
Empty racks

Shift	Init	Now	Min	Max
68	954	772	753	954
136	954	769	734	809
204	954	774	736	802
272	954	781	740	804
340	954	766	740	798
408	954	779	739	798
476	954	759	740	811
544	954	773	743	810
612	954	777	733	800
680	954	767	740	801
748	954	787	740	797
816	954	781	748	810



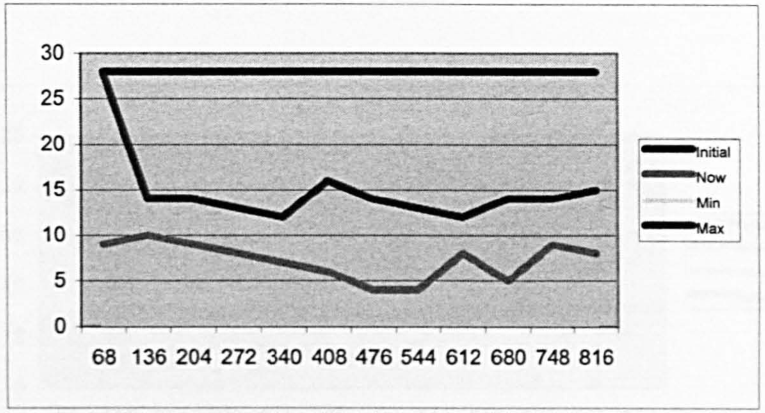
Hard Market Lowest Lead Time Gear

Shift	Init	Now	Min	max		
68	64	36	29	64	7G334/AB	20.27
136	64	36	24	39	7G334/AB	20.6
204	64	33	24	40	7G334/AB	20.7
272	64	32	28	39	7G334/AB	20.36
340	64	34	26	39	7G334/AB	20.54
408	64	34	25	40	7G334/AB	20.58
476	64	34	25	39	7G334/AB	20.7
544	64	35	23	39	7G334/AB	20.53
612	64	35	26	39	7G334/AB	20.44
680	64	35	25	39	7G334/AB	20.5
748	64	31	24	40	7G334/AB	20.71
816	64	35	26	39	7G334/AB	20.6



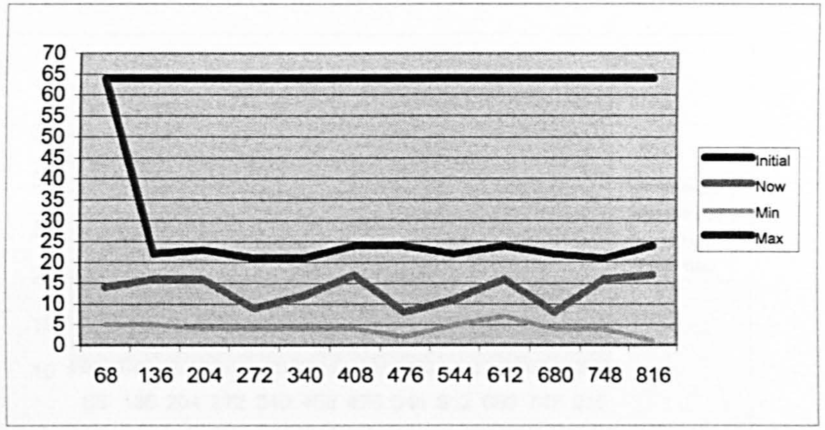
Hard Market Highest Lead Time Gear

Shift	Init	Now	Min	Max		
68	28	9	0	28	7M161/AB	32.52
136	28	10	0	14	7M161/AB	34.62
204	28	9	0	14	7M161/AB	34.75
272	28	8	0	13	7M161/AB	35.89
340	28	7	0	12	7M161/AB	35.35
408	28	6	0	16	7M161/AB	34.11
476	28	4	0	14	7M161/AB	34.53
544	28	4	0	13	7M161/AB	35.89
612	28	8	0	12	7M161/AB	35.07
680	28	5	0	14	7M161/AB	35.32
748	28	9	0	14	7M161/AB	34.55
816	28	8	0	15	7M161/AB	34.01



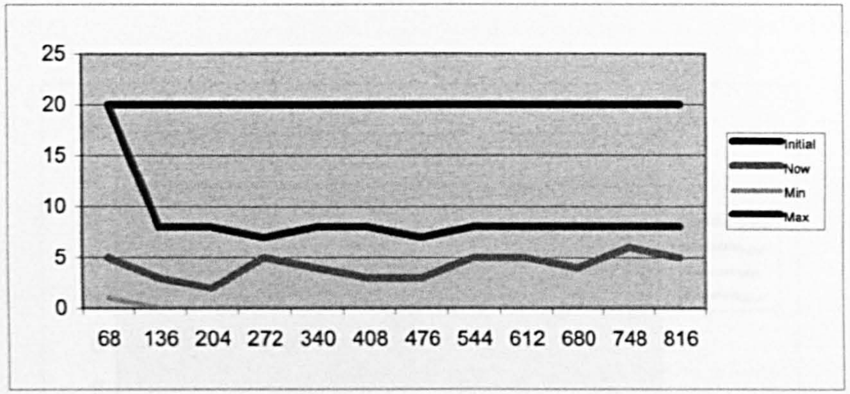
Hard Market Lowest Lead Time Shaft

Shift	Init	Now	Min	Max		
68	64	14	5	64	7L253/AB	25.95
136	64	16	5	22	7L253/AB	30.63
204	64	16	4	23	7L253/AB	31.05
272	64	9	4	21	7L253/AB	31.64
340	64	12	4	21	7L253/AB	31.02
408	64	17	4	24	7L253/AB	30.35
476	64	8	2	24	7L253/AB	31.39
544	64	11	5	22	7L253/AB	30.9
612	64	16	7	24	7L253/AB	29.88
680	64	8	4	22	7L253/AB	30.72
748	64	16	4	21	7L253/AB	30.79
816	64	17	1	24	7L253/AB	30.88



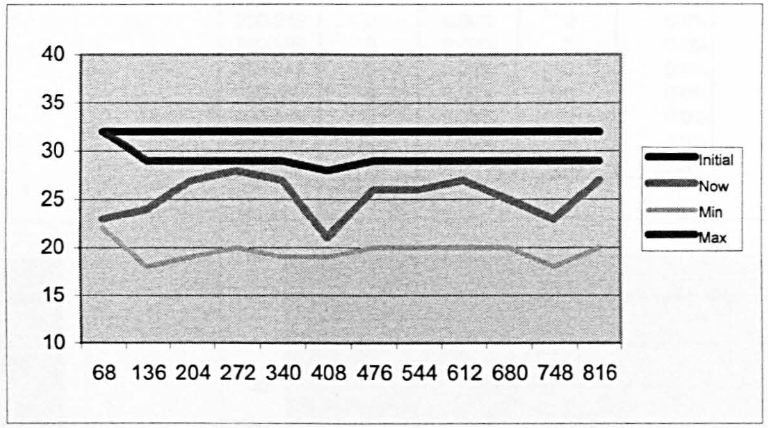
Hard Market Highest Lead Time Shaft

Shift	Init	Now	Min	Max		
68	20	5	1	20	7A356/AB	29.41
136	20	3	0	8	7A356/AB	31.69
204	20	2	0	8	7A356/AB	31.15
272	20	5	0	7	7A356/AB	32.17
340	20	4	0	8	7A356/AB	32.18
408	20	3	0	8	7A356/AB	31.67
476	20	3	0	7	7A356/AB	32.49
544	20	5	0	8	7A356/AB	31.2
612	20	5	0	8	7A356/AB	31.17
680	20	4	0	8	7A356/AB	31
748	20	6	0	8	7A356/AB	30.83
816	20	5	0	8	7A356/AB	31.68



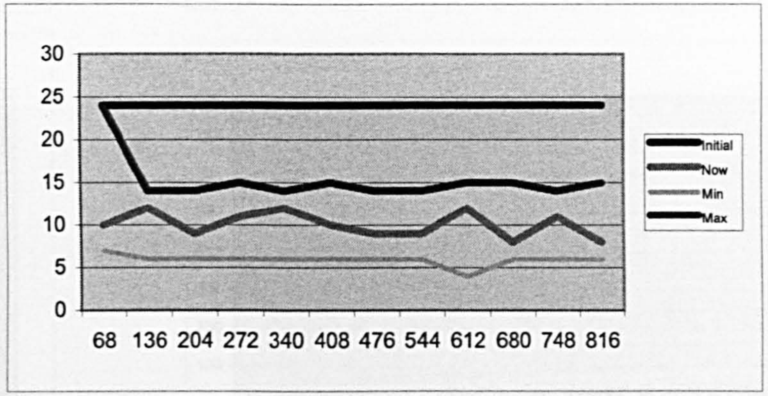
Finished Market Lowest LT

Shift	Init	Now	Min	Max		
68	32	23	22	32	7G334/AB	3.48
136	32	24	18	29	7G334/AB	4.64
204	32	27	19	29	7G334/AB	5.03
272	32	28	20	29	7G334/AB	4.54
340	32	27	19	29	7G334/AB	4.88
408	32	21	19	28	7G334/AB	5.27
476	32	26	20	29	7G334/AB	4.73
544	32	26	20	29	7G334/AB	4.58
612	32	27	20	29	7G334/AB	5.02
680	32	25	20	29	7G334/AB	4.41
748	32	23	18	29	7G334/AB	4.82
816	32	27	20	29	7G334/AB	4.82



Finished Market HIghest LT

Shift	Init	Now	Min	Max		
68	24	10	7	24	7M003b/AE	24.76
136	24	12	6	14	7M003b/AE	27.66
204	24	9	6	14	7M003b/AE	26.83
272	24	11	6	15	7M003b/AE	26.43
340	24	12	6	14	7M003b/AE	27.29
408	24	10	6	15	7M003b/AE	26.94
476	24	9	6	14	7M003b/AE	27.14
544	24	9	6	14	7M003b/AE	27.1
612	24	12	4	15	7M003b/AE	27.35
680	24	8	6	15	7M003b/AE	26.11
748	24	11	6	14	7M003b/AE	26.55
816	24	8	6	15	7M003b/AE	26.88



	Freq	%	Cumulative	%
0	0	0.00%	0	0.0%
0-49	0	0.00%	0	0.0%
50-99	0	0.00%	0	0.0%
100-149	0	0.00%	0	0.0%
150-199	6	0.71%	6	0.7%
200-249	11	1.29%	17	2.0%
250-299	8	0.94%	25	2.9%
300-349	9	1.06%	34	4.0%
350-399	8	0.94%	42	4.9%
400-449	9	1.06%	51	6.0%
450-499	68	8.00%	119	14.0%
500-550	731	86.00%	850	100.0%
	850			

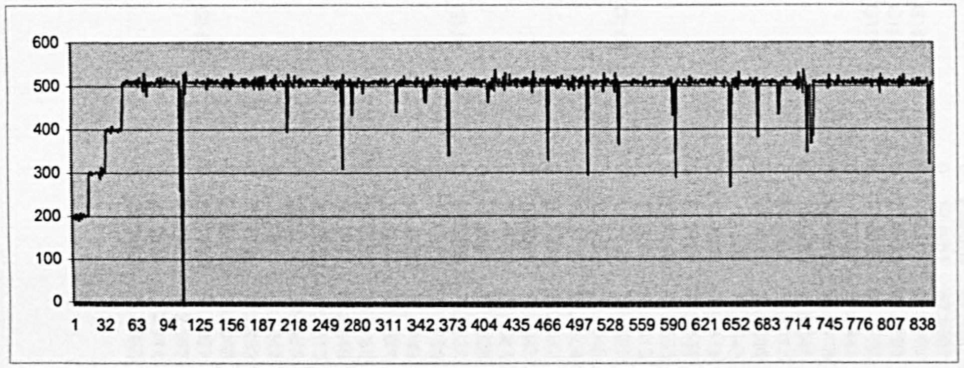
Total	*418055*
Av	491.8294
StndDev	214.9605

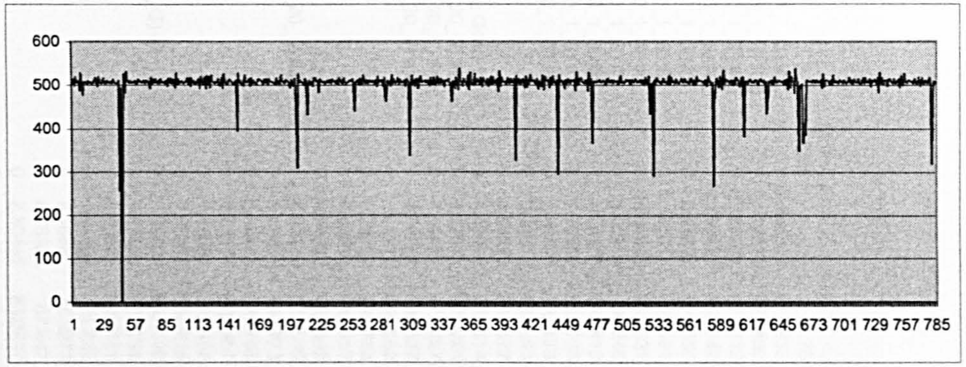
Rate/Shift	509	
Shifts	799	from 66 forward
Planned	421991	
	3936	
	0.93%	

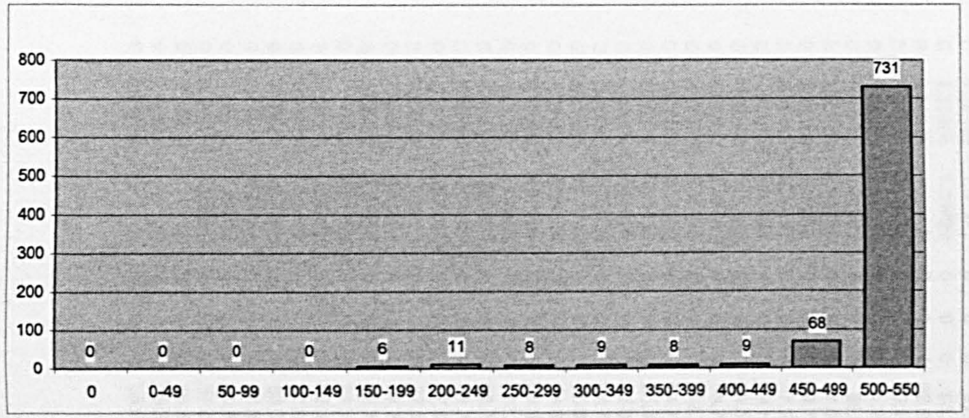
	Freq	%	Cumulative	%
0	0	0.00%	0	0.0%
0-49	0	0.00%	0	0.0%
50-99	0	0.00%	0	0.0%
100-149	0	0.00%	0	0.0%
150-199	0	0.00%	0	0.0%
200-249	0	0.00%	0	0.0%
250-299	0	0.00%	0	0.0%
300-349	0	0.00%	0	0.0%
350-399	0	0.00%	0	0.0%
400-449	0	0.00%	0	0.0%
450-499	66	7.76%	66	7.8%
500-550	720	84.71%	786	92.5%
	786			

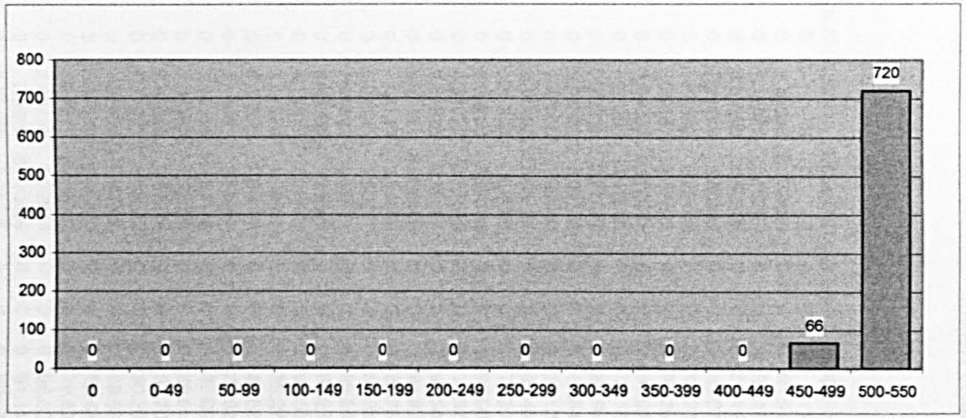
Total	396142
Av	503.9975
StndDev	32.00513

Rate/Shift	509
Shifts	786
Planned	400074
	3932
	0.98%









PROCESS UTILISATION

MACHINE NAME	OFF-S	IDLE	BUSY	BLOCKI	DOWN	BREAKDO	LAB'	LAB'	LAB	OEE
Assembly Machine(ASSEM) #1	6.25	0	93.75	0	0	0	0	0	0	100
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #1	0	0.349502	91.4935	0	7.38358	0.773424	0	0	0	91.8144
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #10	0	0.519095	90.6489	0	7.19975	1.63224	0	0	0	91.1219
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #11	0	0.596754	87.6312	0	6.87806	4.89395	0	0	0	88.1573
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #9	0	0.790453	88.3742	0	7.03125	3.80405	0	0	0	89.0784
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #2	0	0.83808	89.4856	0	7.4563	2.22002	0	0	0	90.2419
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #8	0	0.865417	90.4691	0	7.29167	1.37379	0	0	0	91.2589
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #6	0	0.930643	91.0831	0	7.61336	0.372871	0	0	0	91.9387
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #5	0	1.00936	90.248	0	7.55208	1.19051	0	0	0	91.1683
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #4	0	1.24958	88.7413	0	7.23039	2.77877	0	0	0	89.8642
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #7	0	1.25985	88.4123	0	6.98529	3.34258	0	0	0	89.5404
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #3	0	1.44849	89.8173	0	7.42953	1.30466	0	0	0	91.1374
Turn+Hob+Deburr (10_20_30_35_G) #9	0	3.46513	86.3643	0	8.11887	2.05174	0	0	0	89.4643
Deburr and Chamfer (Shaft) (50_S) #1	0	3.99223	74.2672	0	20.242	1.4985	0	0	0	77.3554
Grind + Hardturning Bore & Cone & Coneface(Ring Gear) (110_	0	4.09416	87.2814	0	5.65257	2.97186	0	0	0	91.0074
Face, Center & Thread/Turn Profile Complete (10_20_S) #2	0	4.27911	89.9024	0	4.24326	1.57519	0	0	0	93.9214
Face, Center & Thread/Turn Profile Complete (10_20_S) #4	0	4.30451	87.8527	0	4.24326	3.59954	0	0	0	91.8044
Face, Center & Thread/Turn Profile Complete (10_20_S) #1	0	4.70261	90.367	0	4.29181	0.638603	0	0	0	94.8263
Turn+Hob+Deburr (10_20_30_35_G) #7	0	5.1314	84.2062	0	7.8125	2.84985	0	0	0	88.7609
Turn+Hob+Deburr (10_20_30_35_G) #12	0	5.29468	84.3683	0	8.73121	1.60577	0	0	0	89.0851
Turn+Hob+Deburr (10_20_30_35_G) #6	0	5.43082	84.9652	0	7.99632	1.60771	0	0	0	89.8444
Turn+Hob+Deburr (10_20_30_35_G) #11	0	5.79232	83.7802	0	8.44056	1.98696	0	0	0	88.9313
Face, Center & Thread/Turn Profile Complete (10_20_S) #3	0	5.94112	87.9519	0	4.12071	1.98626	0	0	0	93.5073
Turn+Hob+Deburr (10_20_30_35_G) #1	0	6.49491	83.4773	0	8.08824	1.93958	0	0	0	89.2756
Turn+Hob+Deburr (10_20_30_35_G) #8	0	6.60231	82.7768	0	8.07292	2.54798	0	0	0	88.6283
Turn+Hob+Deburr (10_20_30_35_G) #10	0	6.72174	82.9451	0	8.14951	2.18367	0	0	0	88.9222
Hard Finish Teeth (RZ150) (120_RZ150_G) #2	0	7.43051	82.467	0	7.26103	2.84148	0	0	0	89.0866
Hard Finish Teeth (RZ150) (120_RZ150_G) #5	0	7.65548	83.0326	0	7.38358	1.92829	0	0	0	89.9162
Grind+Hardturning Bore & Cone & Coneface (155_G) #4	0	7.92024	84.4426	0	6.46446	1.17274	0	0	0	91.7059
Hard Finish Teeth (RZ150) (120_RZ150_G) #1	0	7.97498	83.0098	0	7.07721	1.93802	0	0	0	90.2035
Turn+Hob+Deburr (10_20_30_35_G) #5	0	8.00992	82.7811	0	7.27635	1.93266	0	0	0	89.9891
Turn+Hob+Deburr (10_20_30_35_G) #3	0	8.1464	81.232	0	8.19547	2.42613	0	0	0	88.4364
Deburr and Chamfer (Shaft) (50_S) #2	0	8.16662	73.3073	0	18.1213	0.404804	0	0	0	79.8264
Grinding Diameters (255_S) #1	0	8.78588	87.847	0	2.03738	1.32974	0	0	0	96.3086
Hard Finish Teeth (RZ150) (120_RZ150_G) #3	0	8.80445	83.0927	0	7.3989	0.703956	0	0	0	91.1149
Grind Diameters and Length (190_S) #3	0	9.0225	81.9163	0	6.72488	2.33635	0	0	0	90.0401
Powerhoning (230_S) #1	0	9.17456	74.1114	0	12.9749	3.7392	0	0	0	81.5976
Hard Finish Teeth (RZ150) (120_RZ150_G) #4	0	9.20719	81.4965	0	6.7402	2.55614	0	0	0	89.7609
Grind Diameters and Length (190_S) #4	0	9.24402	82.4931	0	6.35723	1.90563	0	0	0	90.8955
Roll Splines (70_80_S) #1	0	9.51479	71.8015	0	17.1875	1.49622	0	0	0	79.3516
Profilegrinding Gear Teeth (220_S) #1	0	9.89078	87.4321	0	1.36336	1.31377	0	0	0	97.029
Profilegrinding Gear Teeth (220_S) #2	0	10.1061	87.1602	0	1.37868	1.35499	0	0	0	96.959
Grind+Hardturning Bore & Cone & Coneface (155_G) #3	0	10.151	83.2007	0	6.64828	0	0	0	0	92.6006
Grind+Hardturning Bore & Cone & Coneface (155_G) #7	0	10.2879	80.8793	0	6.31127	2.52154	0	0	0	90.1543
Grind+Hardturning Bore & Cone & Coneface (155_G) #5	0	10.6849	81.5439	0	6.18873	1.58251	0	0	0	91.2991
Grind Diameters and Length (190_S) #1	0	10.707	79.5449	0	7.78186	1.96623	0	0	0	89.083
Assy/Laser Welding Hard (140_150_G) #1	0	10.7679	86.6413	0	1.50123	1.08959	0	0	0	97.0965
Turn+Hob+Deburr (10_20_30_35_G) #2	0	10.773	80.0841	0	7.78186	1.36099	0	0	0	89.7533
Hob Helical Teeth 1st Speed (30_40_S) #2	0	11.2382	77.7077	0	8.75919	2.29492	0	0	0	87.5463
Roll Splines (70_80_S) #2	0	11.2575	70.2206	0	16.682	1.83988	0	0	0	79.1285
Turn+Hob+Deburr (10_20_30_35_G) #4	0	12.205	78.9243	0	7.85846	1.01226	0	0	0	89.8961
Grind Diameters and Length (190_S) #2	0	12.7955	79.1676	0	6.67892	1.35792	0	0	0	90.7839
Grind Diameters and Length (190_S) #7	0	12.9793	76.7836	0	7.21507	3.02205	0	0	0	88.236
Powerhoning (230_S) #3	0	12.9946	73.2353	0	11.7373	2.03282	0	0	0	84.1732
Powerhoning (230_S) #4	0	13.0432	74.1913	0	10.6311	2.13434	0	0	0	85.3198
Grind+Hardturning Bore & Cone & Coneface (155_G) #6	0	13.1622	79.9521	0	6.09681	0.788883	0	0	0	92.0706
Powerhoning (230_S) #2	0	13.6052	73.1846	0	11.5043	1.70595	0	0	0	84.7095
Gun Drill/Drill Cross Holes & Deburr (90_100_S) #1	0	16.3739	64.3554	0	18.1373	1.13342	0	0	0	76.9561
Hob Helical Teeth 1st Speed (30_40_S) #1	0	16.7344	70.6881	0	8.31189	4.26569	0	0	0	84.8946
Grind Diameters and Length (190_S) #6	0	16.8558	71.7647	0	6.77415	4.60531	0	0	0	86.3136
Grind Grooves (180_S) #2	0	17.1663	68.1564	0	13.1281	1.5492	0	0	0	82.281
Hob Helical Teeth 1st Speed (30_40_S) #3	0	17.2934	73.4328	0	8.48346	0.790309	0	0	0	88.7871
Grind+Hardturning Bore & Cone & Coneface (155_G) #1	0	17.5399	75.6232	0	5.95895	0.877957	0	0	0	91.7088
Grind Diameters and Length (190_S) #5	0	17.871	72.1606	0	7.3223	2.6461	0	0	0	87.8625
Hob Helical Teeth 1st Speed (30_40_S) #4	0	18.3233	71.3488	0	8.68566	1.6423	0	0	0	87.3551
Hob Helical Teeth 1st Speed (30_40_S) #5	0	19.1845	70.9327	0	7.43873	2.44401	0	0	0	87.7712
Hard Finish Teeth (Prawema) (120_Prw_G) #1	0	19.8188	74.3762	0	3.06373	2.74126	0	0	0	92.7602
Grind Grooves (180_S) #1	0	20.9767	64.4118	0	12.5	2.11158	0	0	0	81.5098
Hard Finish Teeth (Prawema) (120_Prw_G) #3	0	21.7855	72.3413	0	3.06373	2.8095	0	0	0	92.4909
Grind Grooves (180_S) #3	0	22.3214	63.6475	0	10.7996	3.2315	0	0	0	81.9369
Hard Finish Teeth (Prawema) (120_Prw_G) #4	0	22.501	72.1242	0	3.18627	2.1885	0	0	0	93.0647
Hard Finish Teeth (Prawema) (120_Prw_G) #2	0	22.7925	72.8832	0	3.40074	0.923596	0	0	0	94.3991
Straighten 1 (140_S) #3	0	22.8068	70.6343	0	4.9326	1.62629	0	0	0	91.5033
Grind+Hardturning Bore & Cone & Coneface (155_G) #2	0	25.1138	68.8657	0	4.76409	1.25645	0	0	0	91.9604
Decant Gear For HT (DECH_G) #2	0	25.2901	72.167	0	2.54289	0	0	0	0	96.5963
Decant Gear For HT (DECH_G) #4	0	25.3431	72.114	0	2.54289	0	0	0	0	96.5939
Decant Gear For HT (DECH_G) #3	0	25.5183	71.9388	0	2.54289	0	0	0	0	96.5859

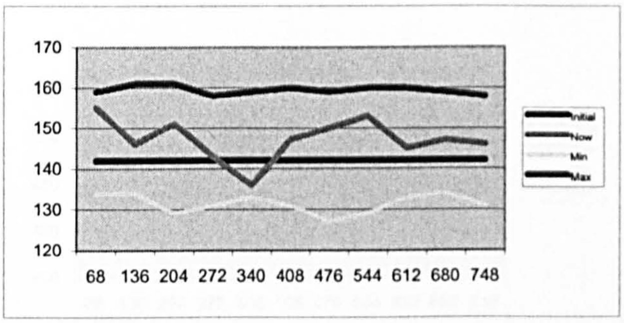
Decant Gear For HT (DECH_G) #1	0	25.8793	71.6084	0	2.51225	0	0	0	0	96.6106
Hard Finish Teeth (RZ400) (Ring Gear Only) (120_R) #1	0	25.9576	72.7295	0	0.873162	0.439753	0	0	0	98.2268
Turn Grooves (120_S) #2	0	25.9753	66.7036	0	5.69853	1.62256	0	0	0	90.1099
Straighten 1 (140_S) #1	0	26.1803	66.1765	0	4.83466	2.80861	0	0	0	89.646
Gun Drill/Drill Cross Holes & Deburr (90_100_S) #2	0	26.9065	56.7371	0	14.4608	1.8956	0	0	0	77.6227
Hard Finish Teeth (RZ400) (Ring Gear Only) (120_R) #2	0	27.7627	69.0801	0	0.903799	2.2534	0	0	0	95.6294
Assy/Laser Welding Green (60_70_G) #1	0	33.2929	65.8381	0	0.459559	0.409446	0	0	0	98.6973
Hob& Deburr/Chanmfer (Ring Gear only) (35_R) #1	0	33.6045	63.7505	0	1.98223	0.662769	0	0	0	96.0163
Hob& Deburr/Chanmfer (Ring Gear only) (35_R) #2	0	33.6312	62.8431	0	1.98223	1.54348	0	0	0	94.6877
Straighten 1 (140_S) #2	0	34.4301	58.8504	0	4.65686	2.06262	0	0	0	89.7522
Turn (Ring Gear Only) (10_20_25_R) #1	0	35.9736	60.5809	0	2.58885	0.856654	0	0	0	94.6186
Turn (Ring Gear Only) (10_20_25_R) #2	0	36.5823	59.4657	0	2.51225	1.4398	0	0	0	93.7682
Turn Grooves (120_S) #1	0	39.2902	54.5601	0	4.59559	1.55414	0	0	0	89.8703
Decant Gears (DEC_G) #3	0	51.8179	45.7618	0	2.42034	0	0	0	0	94.9767
Crack Detection (210_G) #1	0	59.0179	40.9821	0	0	0	0	0	0	100
Phosphation(210_B) #1	0	59.8319	38.8572	0	0	1.31089	0	0	0	96.7365
Decant Ring Gear HT (DECH_R) #1	0	62.0237	37.0572	0	0.919118	0	0	0	0	97.5798
Decant Gears (DEC_G) #2	0	70.3371	28.1616	0	1.50123	0	0	0	0	94.939
Load HT Fixture (125_S) #1	0	70.9203	28.375	0	0.704657	0	0	0	0	97.5768
UnLoad HT Fixture (175_S) #1	0	71.0257	28.9743	0	0	0	0	0	0	100
Decant Shaft (DEC_S) #1	0	71.3853	27.6343	0	0.980392	0	0	0	0	96.5738
Load HT Fixture (125_S) #2	0	72.012	27.2833	0	0.704657	0	0	0	0	97.4823
UnLoad HT Fixture (175_S) #2	0	73.1946	26.8054	0	0	0	0	0	0	100
Decant Ring Gears (DEC_R) #1	0	80.9904	18.55	0	0.459559	0	0	0	0	97.5825
Decant Gears (DEC_G) #1	0	85.2851	13.9796	0	0.735294	0	0	0	0	95.0031
Decant Shaft (DEC_S) #2	0	88.0181	11.5836	0	0.398284	0	0	0	0	96.6759
Decant Gears (DEC_G) #4	0	91.061	8.47941	0	0.459559	0	0	0	0	94.8589
Crack Detection (210_G) #2	0	97.6334	2.36659	0	0	0	0	0	0	100
Measure Gear (40_G) #1	0	100	0	0	0	0	0	0	0	0
Measure Gear (40_G) #2	0	100	0	0	0	0	0	0	0	0
Check Teeth (60_S) #1	0	100	0	0	0	0	0	0	0	0

CONVEYOURS

NAME	OFF-S	EMPTY	MOVING	BLOCKI	QUEUED
Wash For Laser (55_G) #1	0	98.102	1.89798	0	0
Wash For Laser (55_G) #2	0	85.6411	13.663	0	0
Wash Green/Hard (160_B) #1	0	68.0525	31.3246	0	0
Wash Final (200_B) #1	0	36.9596	62.5948	0.0205	0

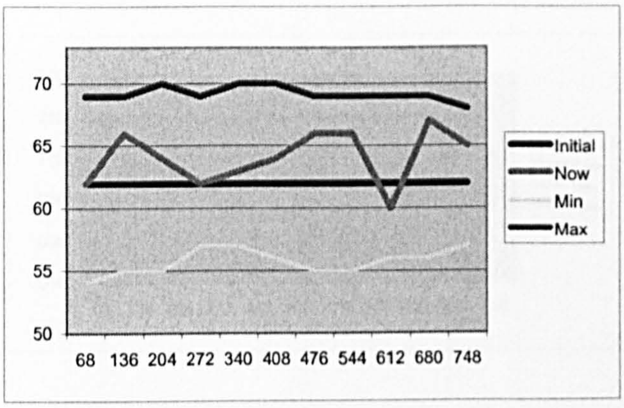
Green Market GEARS

Shift	Init	Now	Min	max
68	142	155	134	159
136	142	146	134	161
204	142	151	129	161
272	142	143	131	158
340	142	136	133	159
408	142	147	131	160
476	142	150	127	159
544	142	153	129	160
612	142	145	133	160
680	142	147	134	159
748	142	146	131	158
816	142	145	130	161



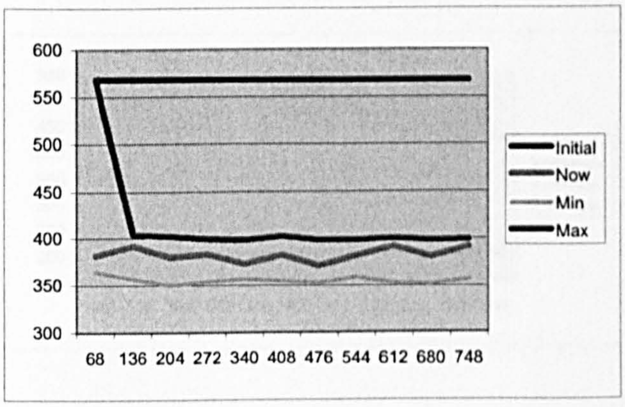
Green Market SHAFTS

Shift	Init	Now	Min	Max
68	62	62	54	69
136	62	66	55	69
204	62	64	55	70
272	62	62	57	69
340	62	63	57	70
408	62	64	56	70
476	62	66	55	69
544	62	66	55	69
612	62	60	56	69
680	62	67	56	69
748	62	65	57	68
816	62	62	57	71



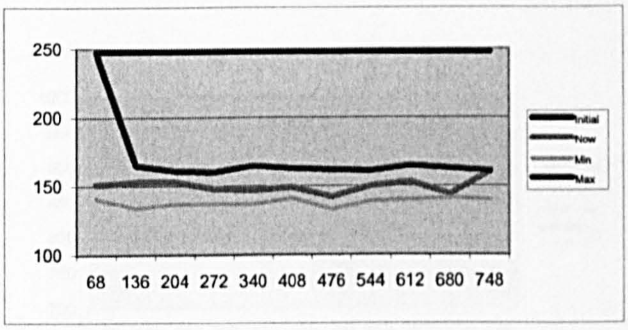
Hard Market GEARS

Shift	Init	Now	Min	Max
68	568	382	365	568
136	568	392	357	404
204	568	380	350	402
272	568	383	354	399
340	568	373	357	398
408	568	382	355	402
476	568	371	353	398
544	568	381	359	398
612	568	391	353	400
680	568	380	352	398
748	568	391	357	399
816	568	379	354	401



Hard Market SHAFTS

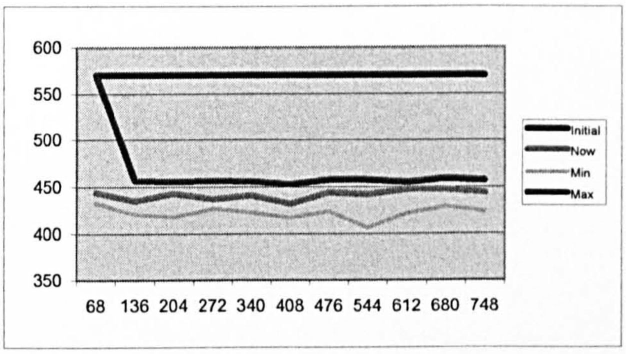
Shift	Init	Now	Min	Max
68	248	151	141	248
136	248	153	134	165
204	248	153	137	161
272	248	148	137	160
340	248	147	137	165
408	248	149	141	163
476	248	142	133	162
544	248	150	139	161
612	248	153	140	165
680	248	144	141	163
748	248	160	140	161
816	248	153	134	161



Changes in the Total Trolleys in Intermediate markets

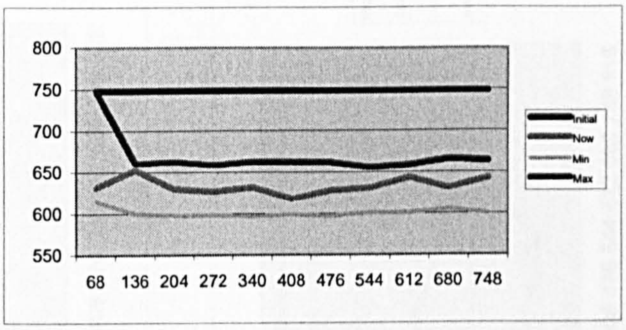
Finished Market

Shift	Init	Now	Min	Max
68	570	444	433	570
136	570	435	421	457
204	570	443	418	456
272	570	437	427	457
340	570	441	423	456
408	570	432	417	453
476	570	444	424	458
544	570	442	406	458
612	570	447	422	455
680	570	447	429	459
748	570	444	424	457
816	570	437	419	457



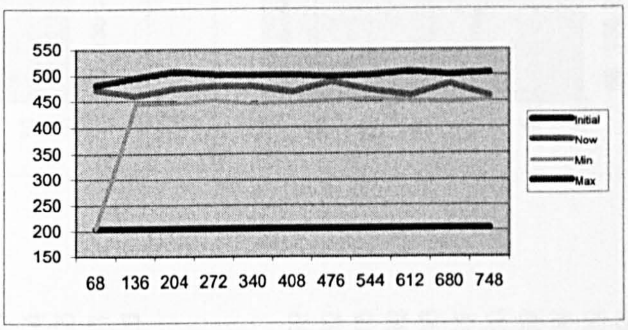
Empty trolleys Green Area

Shift	Init	Now	Min	Max
68	748	632	615	748
136	748	653	600	661
204	748	630	598	663
272	748	627	598	659
340	748	632	597	663
408	748	618	599	663
476	748	628	597	662
544	748	631	601	656
612	748	644	601	659
680	748	631	605	666
748	748	643	600	664
816	748	637	595	659



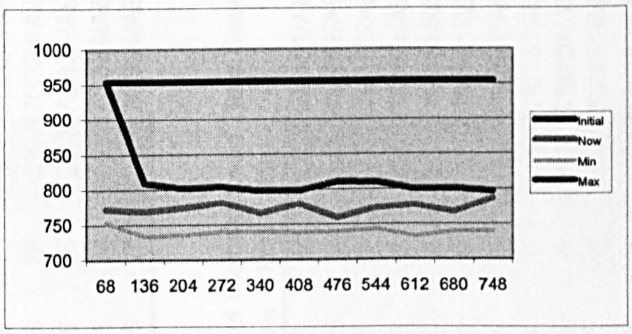
Empty trolleys Hard Area

Shift	Init	Now	Min	Max
68	204	473	204	482
136	204	461	444	496
204	204	475	446	507
272	204	480	452	502
340	204	480	446	500
408	204	469	448	501
476	204	488	452	498
544	204	472	456	500
612	204	461	451	507
680	204	483	449	501
748	204	460	452	505
816	204	478	454	505



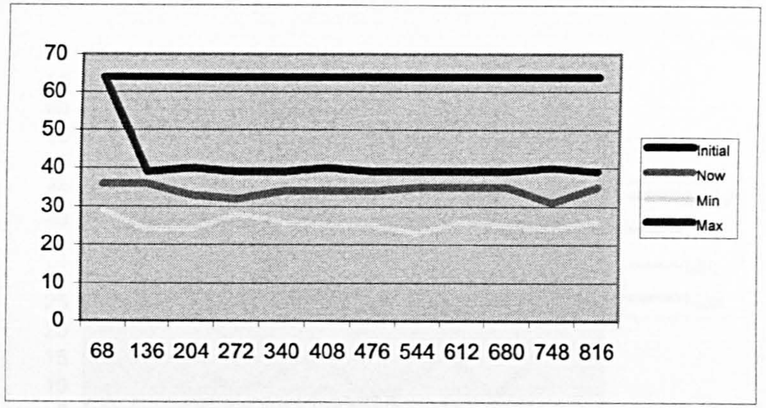
Empty racks

Shift	Init	Now	Min	Max
68	954	772	753	954
136	954	769	734	809
204	954	774	736	802
272	954	781	740	804
340	954	766	740	798
408	954	779	739	798
476	954	759	740	811
544	954	773	743	810
612	954	777	733	800
680	954	767	740	801
748	954	787	740	797
816	954	781	748	810



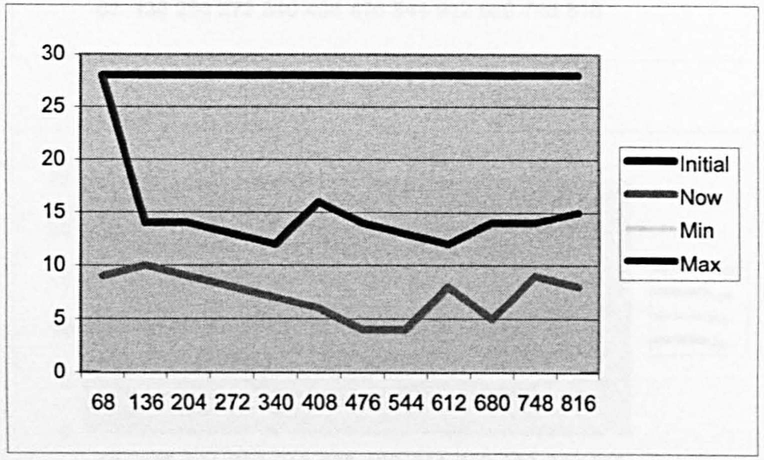
Hard Market Lowest Lead Time Gear

Shift	Init	Now	Min	max		
68	64	36	29	64	7G334/AB	20.27
136	64	36	24	39	7G334/AB	20.6
204	64	33	24	40	7G334/AB	20.7
272	64	32	28	39	7G334/AB	20.36
340	64	34	26	39	7G334/AB	20.54
408	64	34	25	40	7G334/AB	20.58
476	64	34	25	39	7G334/AB	20.7
544	64	35	23	39	7G334/AB	20.53
612	64	35	26	39	7G334/AB	20.44
680	64	35	25	39	7G334/AB	20.5
748	64	31	24	40	7G334/AB	20.71
816	64	35	26	39	7G334/AB	20.6



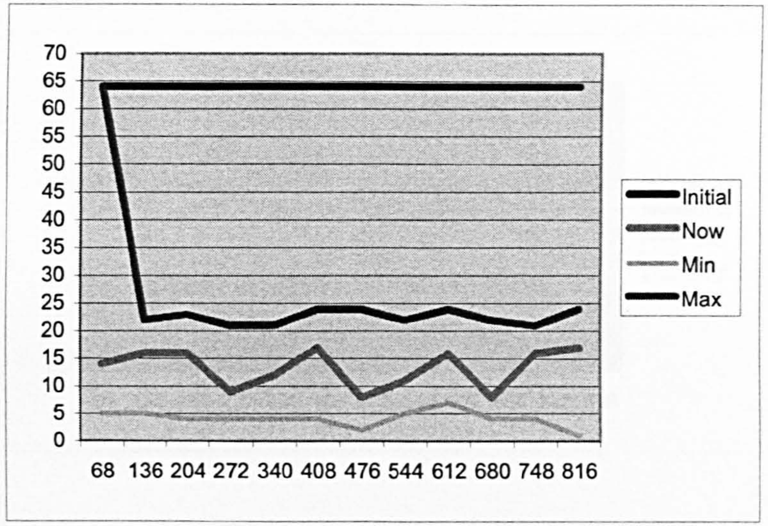
Hard Market Highest Lead Time Gear

Shift	Init	Now	Min	Max		
68	28	9	0	28	7M161/AB	32.52
136	28	10	0	14	7M161/AB	34.62
204	28	9	0	14	7M161/AB	34.75
272	28	8	0	13	7M161/AB	35.89
340	28	7	0	12	7M161/AB	35.35
408	28	6	0	16	7M161/AB	34.11
476	28	4	0	14	7M161/AB	34.53
544	28	4	0	13	7M161/AB	35.89
612	28	8	0	12	7M161/AB	35.07
680	28	5	0	14	7M161/AB	35.32
748	28	9	0	14	7M161/AB	34.55
816	28	8	0	15	7M161/AB	34.01



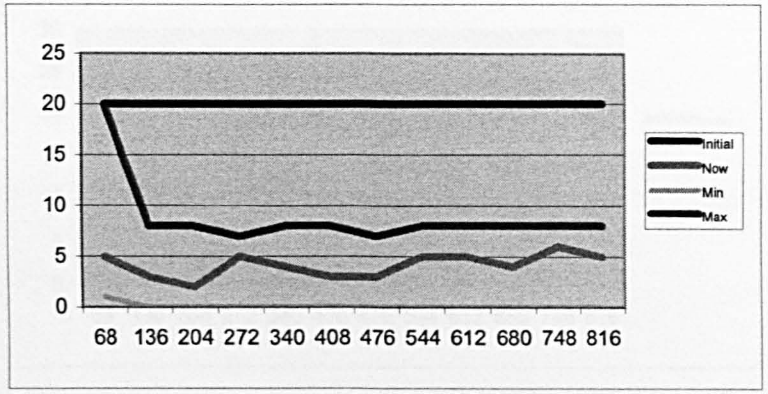
Hard Market Lowest Lead Time Shaft

Shift	Init	Now	Min	Max		
68	64	14	5	64	7L253/AB	25.95
136	64	16	5	22	7L253/AB	30.63
204	64	16	4	23	7L253/AB	31.05
272	64	9	4	21	7L253/AB	31.64
340	64	12	4	21	7L253/AB	31.02
408	64	17	4	24	7L253/AB	30.35
476	64	8	2	24	7L253/AB	31.39
544	64	11	5	22	7L253/AB	30.9
612	64	16	7	24	7L253/AB	29.88
680	64	8	4	22	7L253/AB	30.72
748	64	16	4	21	7L253/AB	30.79
816	64	17	1	24	7L253/AB	30.88



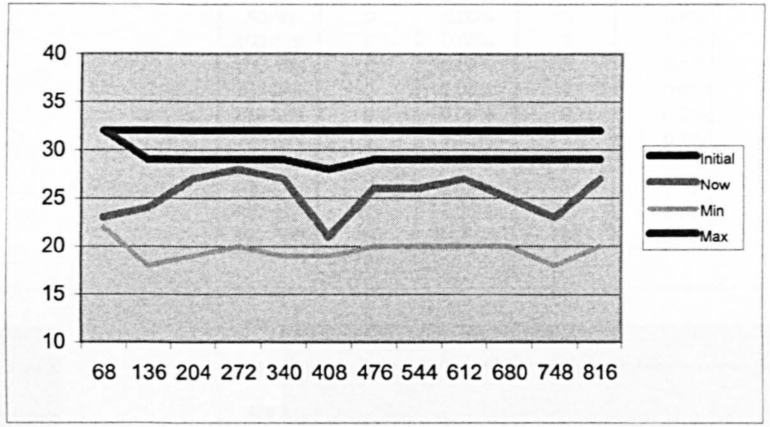
Hard Market Highest Lead Time Shaft

Shift	Init	Now	Min	Max		
68	20	5	1	20	7A356/AB	29.41
136	20	3	0	8	7A356/AB	31.69
204	20	2	0	8	7A356/AB	31.15
272	20	5	0	7	7A356/AB	32.17
340	20	4	0	8	7A356/AB	32.18
408	20	3	0	8	7A356/AB	31.67
476	20	3	0	7	7A356/AB	32.49
544	20	5	0	8	7A356/AB	31.2
612	20	5	0	8	7A356/AB	31.17
680	20	4	0	8	7A356/AB	31
748	20	6	0	8	7A356/AB	30.83
816	20	5	0	8	7A356/AB	31.68



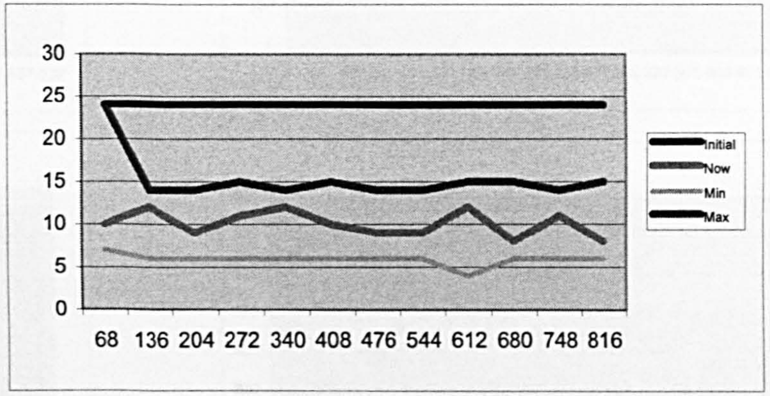
Finished Market Lowest LT

Shift	Init	Now	Min	Max		
68	32	23	22	32	7G334/AB	3.48
136	32	24	18	29	7G334/AB	4.64
204	32	27	19	29	7G334/AB	5.03
272	32	28	20	29	7G334/AB	4.54
340	32	27	19	29	7G334/AB	4.88
408	32	21	19	28	7G334/AB	5.27
476	32	26	20	29	7G334/AB	4.73
544	32	26	20	29	7G334/AB	4.58
612	32	27	20	29	7G334/AB	5.02
680	32	25	20	29	7G334/AB	4.41
748	32	23	18	29	7G334/AB	4.82
816	32	27	20	29	7G334/AB	4.82



Finished Market HIghest LT

Shift	Init	Now	Min	Max		
68	24	10	7	24	7M003b/AE	24.76
136	24	12	6	14	7M003b/AE	27.66
204	24	9	6	14	7M003b/AE	26.83
272	24	11	6	15	7M003b/AE	26.43
340	24	12	6	14	7M003b/AE	27.29
408	24	10	6	15	7M003b/AE	26.94
476	24	9	6	14	7M003b/AE	27.14
544	24	9	6	14	7M003b/AE	27.1
612	24	12	4	15	7M003b/AE	27.35
680	24	8	6	15	7M003b/AE	26.11
748	24	11	6	14	7M003b/AE	26.55
816	24	8	6	15	7M003b/AE	26.88



	Freq	%	Cumulative	%
0	0	0.00%	0	0.0%
0-49	0	0.00%	0	0.0%
50-99	0	0.00%	0	0.0%
100-149	0	0.00%	0	0.0%
150-199	6	0.71%	6	0.7%
200-249	11	1.29%	17	2.0%
250-299	7	0.82%	24	2.8%
300-349	11	1.29%	35	4.1%
350-399	6	0.71%	41	4.8%
400-449	11	1.29%	52	6.1%
450-499	65	7.65%	117	13.8%
500-550	733	86.24%	850	100.0%
	850			

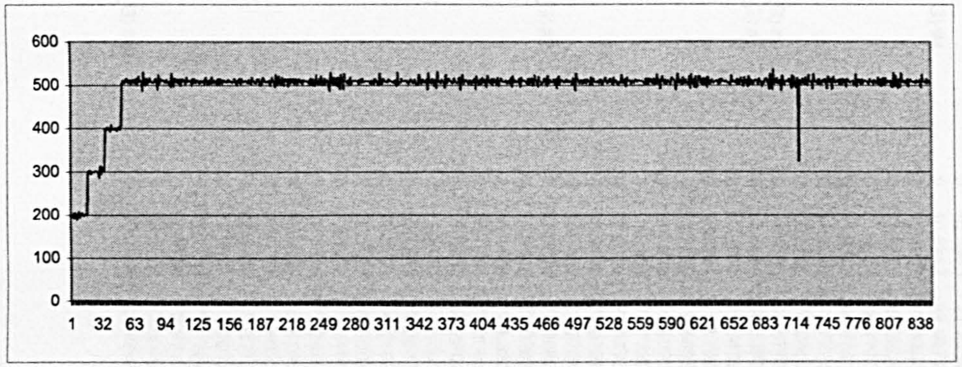
Total	*421804*
Av	496.24
StndDev	54.34234

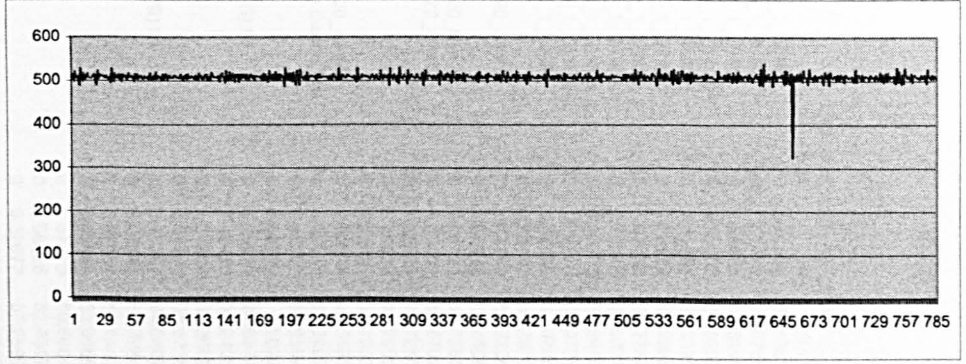
Rate/Shift	509	
Shifts	799	from 66 forward
Planned	421991	
	187	
	0.04%	

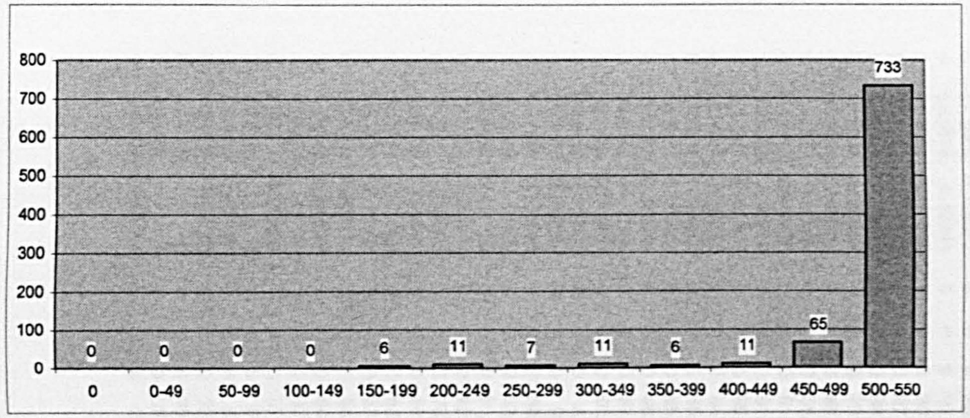
	Freq	%	Cumulative	%
0	0	0.00%	0	0.0%
0-49	0	0.00%	0	0.0%
50-99	0	0.00%	0	0.0%
100-149	0	0.00%	0	0.0%
150-199	0	0.00%	0	0.0%
200-249	0	0.00%	0	0.0%
250-299	0	0.00%	0	0.0%
300-349	1	0.12%	1	0.1%
350-399	0	0.00%	1	0.1%
400-449	0	0.00%	1	0.1%
450-499	65	7.65%	66	7.8%
500-550	720	84.71%	786	92.5%
	786			

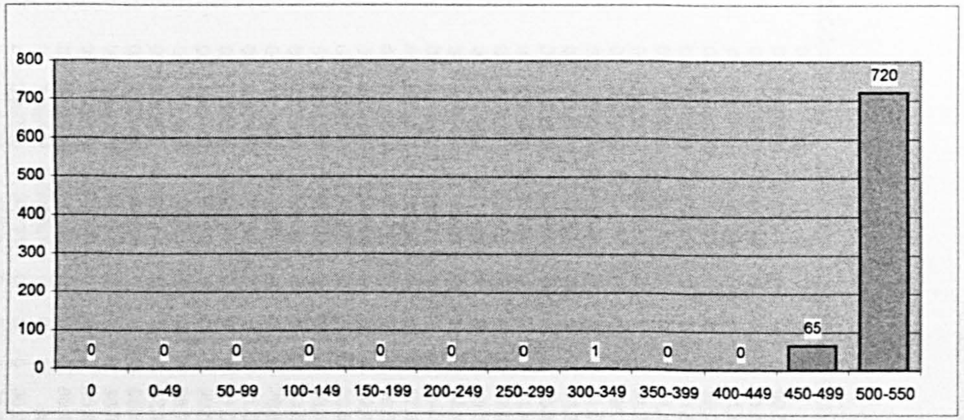
Total	399891
Av	508.7672
StndDev	9.853991

Rate/Shift	509
Shifts	786
Planned	400074
	183
	0.05%









PROCESS UTILISATION

MACHINE NAME	OFF-SHIF	IDLE	BUSY	BLOCKI	DOWN	BREAKDO	LAB'	LAB'	LAB	OEE
Assembly Machine(ASSEM) #1	6.25	0	93.75	0	0	0	0	0	0	100
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #6	0	1.05865	89.5981	0	7.10784	2.23541	0	0	0	90.5568
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #5	0	1.1414	90.0759	0	7.3354	1.44732	0	0	0	91.1159
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #7	0	1.24023	90.3145	0	7.33762	1.10766	0	0	0	91.4487
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #2	0	1.33257	89.5607	0	7.38995	1.71681	0	0	0	90.7702
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #3	0	1.41834	90.3831	0	7.16912	1.02945	0	0	0	91.6835
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #9	0	1.62419	89.9996	0	7.61336	0.762816	0	0	0	91.4855
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #8	0	1.62688	90.2714	0	7.48582	0.61593	0	0	0	91.7643
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #1	0	1.70628	89.8031	0	7.34992	1.14071	0	0	0	91.362
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #10	0	1.85703	89.9916	0	7.3989	0.752488	0	0	0	91.6944
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #11	0	2.0228	89.0731	0	7.23039	1.67367	0	0	0	90.9121
Grind + Hardturning Bore & Cone & Coneface (110_1_G) #4	0	2.07481	88.9786	0	7.30699	1.63961	0	0	0	90.8638
Turn+Hob+Deburr (10_20_30_35_G) #3	0	3.8477	88.2971	0	6.95466	0.90052	0	0	0	91.8305
Face, Center & Thread/Turn Profile Complete (10_20_S) #1	0	3.9753	89.2224	0	4.36581	2.4365	0	0	0	92.9161
Turn+Hob+Deburr (10_20_30_35_G) #7	0	4.60323	85.2608	0	7.41422	2.72174	0	0	0	89.3749
Face, Center & Thread/Turn Profile Complete (10_20_S) #2	0	4.69134	89.7285	0	4.42708	1.15306	0	0	0	94.1452
Face, Center & Thread/Turn Profile Complete (10_20_S) #3	0	4.72207	89.6709	0	4.31985	1.28721	0	0	0	94.115
Deburr and Chamfer (Shaft) (50_S) #1	0	4.80386	73.7255	0	20.1317	1.33895	0	0	0	77.4458
Turn+Hob+Deburr (10_20_30_35_G) #10	0	5.29573	84.7813	0	8.31801	1.60496	0	0	0	89.5221
Turn+Hob+Deburr (10_20_30_35_G) #1	0	5.59665	84.1388	0	8.62439	1.64018	0	0	0	89.1269
Face, Center & Thread/Turn Profile Complete (10_20_S) #4	0	5.93292	88.0491	0	4.22794	1.79001	0	0	0	93.6025
Grind + Hardturning Bore & Cone & Coneface(Ring Gear) (110	0	6.32843	87.2669	0	5.65257	0.752149	0	0	0	93.1626
Turn+Hob+Deburr (10_20_30_35_G) #9	0	6.42232	84.8154	0	8.02696	0.73534	0	0	0	90.6363
Deburr and Chamfer (Shaft) (50_S) #2	0	6.68959	73.027	0	19.7978	0.48562	0	0	0	78.2624
Grind+Hardturning Bore & Cone & Coneface (155_G) #3	0	6.98651	84.6874	0	6.57169	1.75437	0	0	0	91.0485
Hard Finish Teeth (RZ150) (120_RZ150_G) #2	0	7.48415	84.2425	0	7.38358	0.88981	0	0	0	91.0573
Hard Finish Teeth (RZ150) (120_RZ150_G) #3	0	7.7206	83.3562	0	7.43158	1.49162	0	0	0	90.3302
Profilegrinding Gear Teeth (220_S) #1	0	8.04107	88.9716	0	1.394	1.5933	0	0	0	96.7515
Grind+Hardturning Bore & Cone & Coneface (155_G) #1	0	8.10767	84.6492	0	6.55637	0.686772	0	0	0	92.1178
Turn+Hob+Deburr (10_20_30_35_G) #4	0	8.20468	82.3984	0	7.95037	1.44652	0	0	0	89.7632
Hard Finish Teeth (RZ150) (120_RZ150_G) #5	0	8.57064	82.1443	0	6.86275	2.42229	0	0	0	89.8446
Turn+Hob+Deburr (10_20_30_35_G) #6	0	8.69186	82.9966	0	7.72059	0.590922	0	0	0	90.8973
Turn+Hob+Deburr (10_20_30_35_G) #12	0	8.87275	80.6064	0	8.10355	2.41733	0	0	0	88.4547
Turn+Hob+Deburr (10_20_30_35_G) #2	0	8.98625	82.4312	0	7.99632	0.586267	0	0	0	90.57
Grinding Diameters (255_S) #1	0	9.32677	87.2886	0	2.03738	1.34721	0	0	0	96.2673
Turn+Hob+Deburr (10_20_30_35_G) #5	0	9.36535	80.8647	0	8.0576	1.71238	0	0	0	89.2205
Hard Finish Teeth (RZ150) (120_RZ150_G) #1	0	9.49579	83.0741	0	7.01146	0.418669	0	0	0	91.7903
Grind Diameters and Length (190_S) #2	0	9.65604	82.9961	0	6.35723	0.990598	0	0	0	91.8668
Hard Finish Teeth (RZ150) (120_RZ150_G) #4	0	9.7803	81.9129	0	7.02593	1.28089	0	0	0	90.7927
Grind Diameters and Length (190_S) #4	0	10.2989	82.0373	0	6.9087	0.755057	0	0	0	91.4563
Roll Splines (70_80_S) #1	0	10.5803	71.7035	0	17.3866	0.329577	0	0	0	80.1876
Grind+Hardturning Bore & Cone & Coneface (155_G) #4	0	10.6913	82.4572	0	6.44914	0.40241	0	0	0	92.3282
Turn+Hob+Deburr (10_20_30_35_G) #8	0	11.0927	80.4257	0	7.68995	0.791695	0	0	0	90.4601
Assy/Laser Welding Hard (140_150_G) #1	0	11.2429	86.9251	0	1.50123	0.330816	0	0	0	97.9359
Profilegrinding Gear Teeth (220_S) #2	0	11.38	85.7776	0	1.37868	1.46376	0	0	0	96.7926
Roll Splines (70_80_S) #2	0	11.8663	69.6331	0	17.8462	0.654381	0	0	0	79.0085
Turn+Hob+Deburr (10_20_30_35_G) #11	0	12.2959	78.7779	0	8.40993	0.516237	0	0	0	89.8224
Hob Helical Teeth 1st Speed (30_40_S) #2	0	12.3166	77.2562	0	9.12071	1.30648	0	0	0	88.1081
Grind+Hardturning Bore & Cone & Coneface (155_G) #5	0	12.4698	80.4725	0	6.11213	0.945486	0	0	0	91.9369
Grind+Hardturning Bore & Cone & Coneface (155_G) #7	0	12.5814	80.3373	0	5.95895	1.12232	0	0	0	91.8996
Grind Diameters and Length (190_S) #5	0	13.3817	77.8431	0	8.14951	0.625694	0	0	0	89.8691
Powerhoning (230_S) #2	0	13.6271	72.799	0	12.4837	1.09023	0	0	0	84.2845
Grind Diameters and Length (190_S) #7	0	13.7556	76.4898	0	7.21507	2.53953	0	0	0	88.6896
Powerhoning (230_S) #4	0	14.989	72.8021	0	11.8873	0.321684	0	0	0	85.6384
Powerhoning (230_S) #3	0	15.106	73.7732	0	10.7308	0.390034	0	0	0	86.9003
Powerhoning (230_S) #1	0	15.2778	74.0771	0	10.0797	0.56541	0	0	0	87.4353
Grind Diameters and Length (190_S) #3	0	15.9649	77.0701	0	6.1504	0.814644	0	0	0	91.7118
Hob Helical Teeth 1st Speed (30_40_S) #1	0	16.1853	73.9761	0	8.93967	0.898926	0	0	0	88.2615
Grind+Hardturning Bore & Cone & Coneface (155_G) #2	0	17.6705	75.9687	0	5.71101	0.649764	0	0	0	92.274
Hob Helical Teeth 1st Speed (30_40_S) #3	0	17.9353	73.0265	0	8.97824	0.059928	0	0	0	88.9865
Grind Diameters and Length (190_S) #6	0	18.4628	73.303	0	6.96998	1.26421	0	0	0	89.9013
Grind Diameters and Length (190_S) #1	0	18.7946	74.0589	0	6.26532	0.881139	0	0	0	91.1995
Grind Grooves (180_S) #1	0	19.2839	66.2624	0	13.6183	0.835477	0	0	0	82.0931
Gun Drill/Drill Cross Holes & Deburr (90_100_S) #1	0	19.685	61.0791	0	16.9271	2.30887	0	0	0	76.0494
Hob Helical Teeth 1st Speed (30_40_S) #5	0	20.0662	70.3677	0	8.31189	1.25415	0	0	0	88.0325
Grind Grooves (180_S) #2	0	20.5224	66.3168	0	12.1477	1.01308	0	0	0	83.4409
Hob Helical Teeth 1st Speed (30_40_S) #4	0	21.2013	69.3164	0	8.70404	0.77824	0	0	0	87.9664
Hard Finish Teeth (Prawema) (120_Prw_G) #1	0	22.52	73.3197	0	3.15564	1.00475	0	0	0	94.6304
Hard Finish Teeth (Prawema) (120_Prw_G) #2	0	22.7378	73.3896	0	3.06373	0.808854	0	0	0	94.9877
Grind Grooves (180_S) #3	0	22.9014	63.9706	0	11.5503	1.57766	0	0	0	82.9725
Hard Finish Teeth (Prawema) (120_Prw_G) #3	0	23.5375	72.9021	0	2.91054	0.649815	0	0	0	95.3437
Decant Gear For HT (DECH_G) #3	0	23.9491	73.4774	0	2.57353	0	0	0	0	96.616
Hard Finish Teeth (Prawema) (120_Prw_G) #4	0	24.0107	72.5668	0	2.60417	0.818355	0	0	0	95.496
Straighten 1 (140_S) #3	0	24.1136	71.0124	0	4.74877	0.12529	0	0	0	93.5772
Decant Gear For HT (DECH_G) #2	0	25.0355	72.4216	0	2.54289	0	0	0	0	96.6079
Decant Gear For HT (DECH_G) #1	0	25.4629	71.9942	0	2.54289	0	0	0	0	96.5884
Grind+Hardturning Bore & Cone & Coneface (155_G) #6	0	26.3848	68.0264	0	4.91728	0.671564	0	0	0	92.408

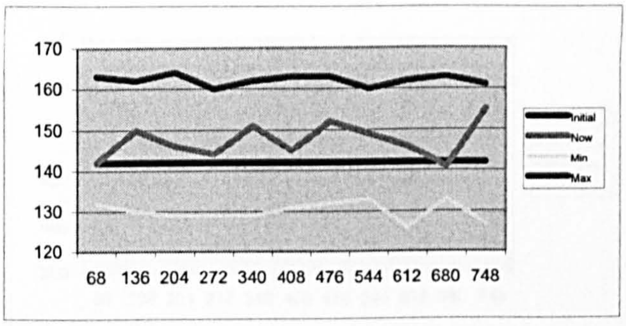
Gun Drill/Drill Cross Holes & Deburr (90_100_S) #2	0	26.4754	58.848	0	14.0165	0.659967	0	0	0	80.0386
Hard Finish Teeth (RZ400) (Ring Gear Only) (120_R) #2	0	26.7046	70.879	0	0.873162	1.54321	0	0	0	96.7032
Straighten 1 (140_S) #2	0	26.8044	68.8443	0	4.21262	0.138658	0	0	0	94.0553
Hard Finish Teeth (RZ400) (Ring Gear Only) (120_R) #1	0	27.4593	70.8992	0	0.903799	0.737734	0	0	0	97.7371
Decant Gear For HT (DECH_G) #4	0	27.5179	70.0311	0	2.45098	0	0	0	0	96.6185
Turn Grooves (120_S) #2	0	28.1314	64.6514	0	5.63725	1.57991	0	0	0	89.9578
Assy/Laser Welding Green (60_70_G) #1	0	32.95	65.5006	0	0.459559	1.08988	0	0	0	97.6891
Hob& Deburr/Chanmfer (Ring Gear only) (35_R) #1	0	33.9133	63.3028	0	2.02819	0.755724	0	0	0	95.7875
Hob& Deburr/Chanmfer (Ring Gear only) (35_R) #2	0	34.431	63.2821	0	1.95159	0.335279	0	0	0	96.5123
Turn (Ring Gear Only) (10_20_25_R) #1	0	36.8819	59.9894	0	2.57353	0.555156	0	0	0	95.0431
Turn (Ring Gear Only) (10_20_25_R) #2	0	37.2938	60.0139	0	2.55821	0.134054	0	0	0	95.7065
Turn Grooves (120_S) #1	0	39.1209	55.2451	0	4.54963	1.08435	0	0	0	90.7456
Straighten 1 (140_S) #1	0	39.8335	55.9297	0	3.99816	0.238647	0	0	0	92.9582
Decant Gears (DEC_G) #4	0	53.3633	44.2776	0	2.35907	0	0	0	0	94.9416
Crack Detection (210_G) #2	0	56.2588	43.7412	0	0	0	0	0	0	100
Phosphation(210_B) #1	0	60.4366	38.8235	0	0	0.739918	0	0	0	98.1298
Decant Ring Gear HT (DECH_R) #1	0	61.9809	37.1	0	0.919118	0	0	0	0	97.5825
Load HT Fixture (125_S) #1	0	69.7049	29.5598	0	0.735294	0	0	0	0	97.5729
UnLoad HT Fixture (175_S) #1	0	71.1047	28.8953	0	0	0	0	0	0	100
Decant Gears (DEC_G) #3	0	72.1066	26.5147	0	1.37868	0	0	0	0	95.0573
Decant Shaft (DEC_S) #1	0	72.1091	26.9412	0	0.949755	0	0	0	0	96.5948
UnLoad HT Fixture (175_S) #2	0	73.5	26.5	0	0	0	0	0	0	100
Load HT Fixture (125_S) #2	0	73.5066	25.85	0	0.643382	0	0	0	0	97.5715
Decant Ring Gears (DEC_R) #1	0	80.9904	18.55	0	0.459559	0	0	0	0	97.5825
Decant Gears (DEC_G) #2	0	84.7605	14.4735	0	0.765931	0	0	0	0	94.974
Decant Shaft (DEC_S) #2	0	87.3946	12.1765	0	0.428922	0	0	0	0	96.5973
Decant Gears (DEC_G) #1	0	89.1074	10.3412	0	0.551471	0	0	0	0	94.9372
Measure Gear (40_G) #1	0	100	0	0	0	0	0	0	0	0
Measure Gear (40_G) #2	0	100	0	0	0	0	0	0	0	0
Crack Detection (210_G) #1	0	100	0	0	0	0	0	0	0	0
Check Teeth (60_S) #1	0	100	0	0	0	0	0	0	0	0

CONVEYOURS

NAME	OFF-SHIF	EMPTY	MOVING	BLOCKI	QUEUED
Wash For Laser (55_G) #1	0	97.5411	2.45895	0	0
Wash For Laser (55_G) #2	0	86.6775	13.2033	0	0
Wash Green/Hard (160_B) #1	0	68.4953	31.4572	0	0
Wash Final (200_B) #1	0	37.2544	62.6602	0.015	0
Wash Green (45_B) #1	0	73.8805	26.1195	0	0

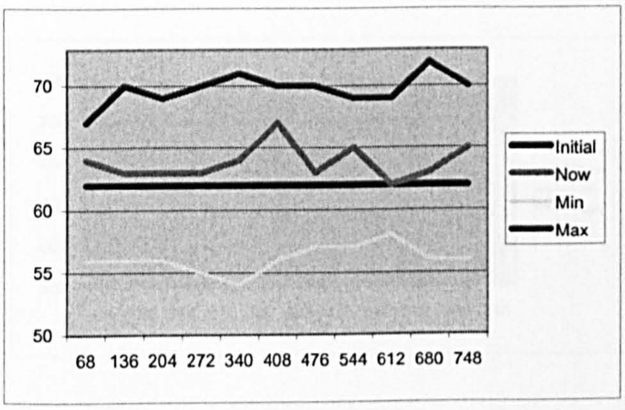
Green Market GEARS

Shift	Init	Now	Min	max
68	142	142	132	163
136	142	150	130	162
204	142	146	129	164
272	142	144	129	160
340	142	151	129	162
408	142	145	131	163
476	142	152	132	163
544	142	149	133	160
612	142	146	126	162
680	142	141	133	163
748	142	155	127	161
816	142	153	128	159



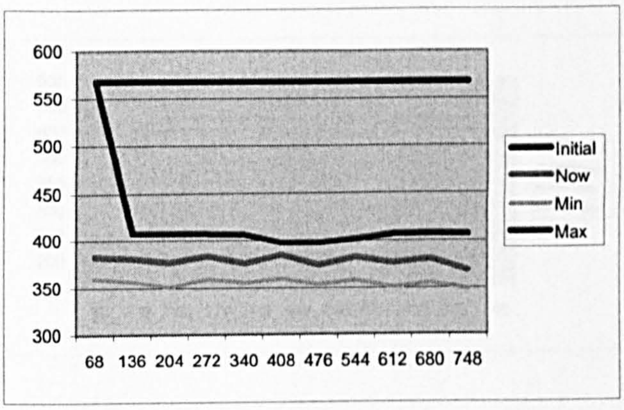
Green Market SHAFTS

Shift	Init	Now	Min	Max
68	62	64	56	67
136	62	63	56	70
204	62	63	56	69
272	62	63	55	70
340	62	64	54	71
408	62	67	56	70
476	62	63	57	70
544	62	65	57	69
612	62	62	58	69
680	62	63	56	72
748	62	65	56	70
816	62	63	56	72



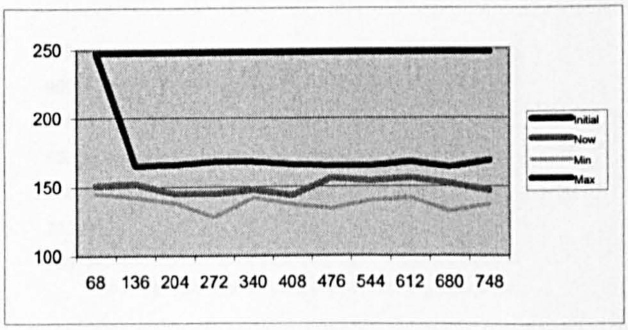
Hard Market GEARS

Shift	Init	Now	Min	Max
68	568	383	360	568
136	568	381	357	408
204	568	377	351	408
272	568	384	360	408
340	568	376	356	407
408	568	385	360	398
476	568	374	354	398
544	568	382	358	402
612	568	376	351	407
680	568	380	355	408
748	568	368	349	407
816	568	381	355	405



Hard Market SHAFTS

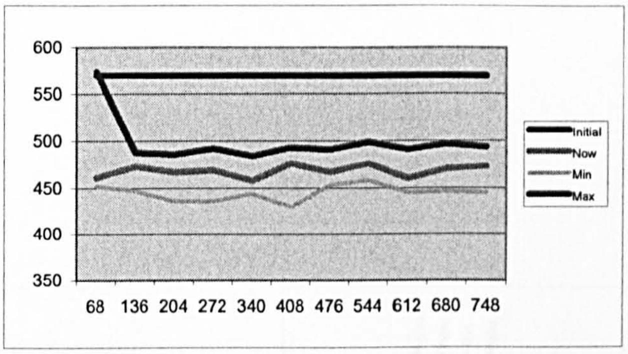
Shift	Init	Now	Min	Max
68	248	151	145	248
136	248	152	142	165
204	248	145	138	166
272	248	145	128	168
340	248	148	142	168
408	248	144	137	166
476	248	156	134	165
544	248	154	140	165
612	248	156	142	168
680	248	152	132	164
748	248	147	137	169
816	248	146	132	166



Changes in the Total Trolleys in Intermediate markets

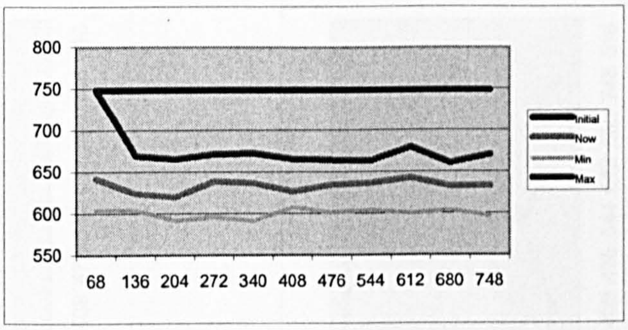
Finished Market

Shift	Init	Now	Min	Max
68	570	461	452	574
136	570	473	447	488
204	570	467	436	486
272	570	469	436	492
340	570	458	444	484
408	570	476	430	493
476	570	467	453	491
544	570	476	458	499
612	570	460	445	491
680	570	470	446	497
748	570	473	445	494
816	570	464	431	494



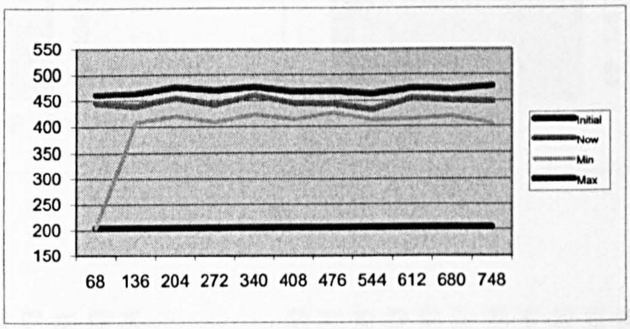
Empty trolleys Green Area

Shift	Init	Now	Min	Max
68	748	642	604	748
136	748	624	604	670
204	748	620	592	666
272	748	639	596	672
340	748	637	591	673
408	748	627	607	666
476	748	635	601	665
544	748	637	604	664
612	748	643	600	680
680	748	633	603	661
748	748	634	597	671
816	748	637	606	668



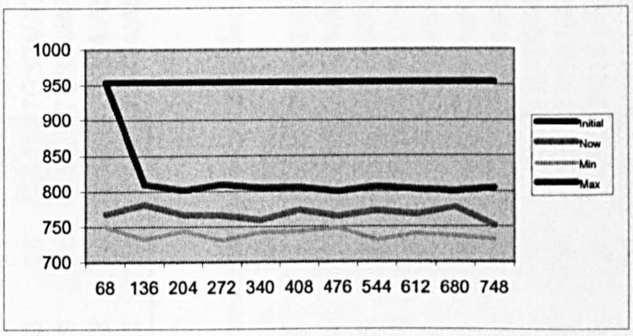
Empty trolleys Hard Area

Shift	Init	Now	Min	Max
68	204	445	204	462
136	204	439	408	465
204	204	456	420	477
272	204	442	409	471
340	204	461	423	477
408	204	445	414	468
476	204	444	426	469
544	204	432	413	464
612	204	455	414	474
680	204	451	420	472
748	204	448	405	478
816	204	454	418	474



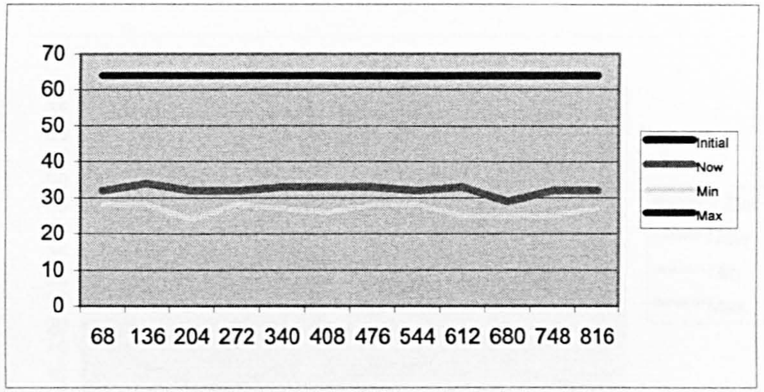
Empty racks

Shift	Init	Now	Min	Max
68	954	768	750	954
136	954	781	733	810
204	954	767	744	802
272	954	766	731	810
340	954	759	742	805
408	954	773	743	806
476	954	764	748	800
544	954	772	731	807
612	954	767	740	803
680	954	777	737	801
748	954	752	732	805
816	954	766	745	800



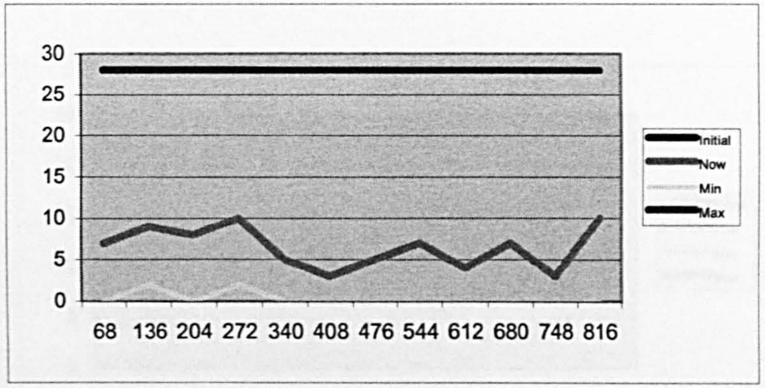
Hard Market Lowest Lead Time Gear

Shift	Init	Now	Min	max		
68	64	32	28	64	7G334/AB	20.55
136	64	34	28	64	7G334/AB	20.41
204	64	32	24	64	7G334/AB	20.83
272	64	32	28	64	7G334/AB	20.64
340	64	33	27	64	7G334/AB	20.54
408	64	33	26	64	7G334/AB	20.45
476	64	33	28	64	7G334/AB	20.37
544	64	32	28	64	7G334/AB	20.52
612	64	33	25	64	7G334/AB	20.73
680	64	29	25	64	7G334/AB	20.51
748	64	32	25	64	7G334/AB	20.43
816	64	32	27	64	7G334/AB	20.34



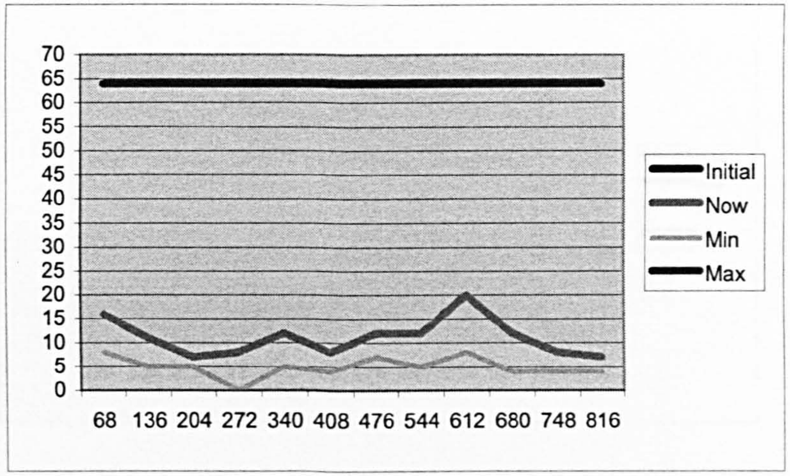
Hard Market Highest Lead Time Gear

Shift	Init	Now	Min	Max		
68	28	7	0	28	7M161/AB	34.29
136	28	9	2	28	7M161/AB	34.01
204	28	8	0	28	7M161/AB	35.98
272	28	10	2	28	7M161/AB	34.43
340	28	5	0	28	7M161/AB	36.09
408	28	3	0	28	7M161/AB	35.57
476	28	5	0	28	7M161/AB	35.26
544	28	7	0	28	7M161/AB	34.65
612	28	4	0	28	7M161/AB	36.43
680	28	7	0	28	7M161/AB	35
748	28	3	0	28	7M161/AB	34.25
816	28	10	0	28	7M161/AB	35.32



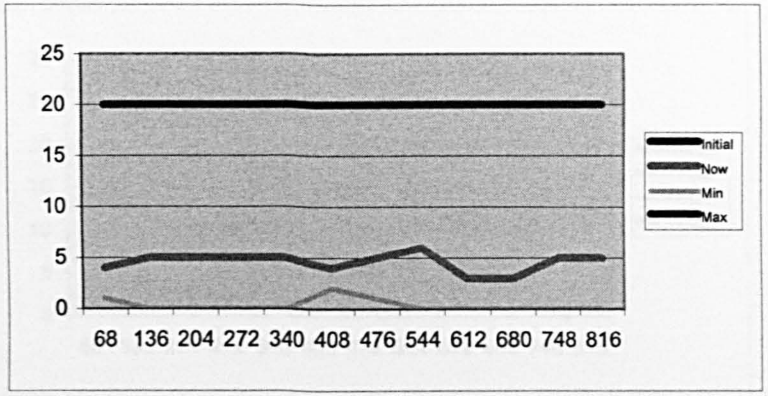
Hard Market Lowest Lead Time Shaft

Shift	Init	Now	Min	Max		
68	64	16	8	64	7L253/AB	26.68
136	64	11	5	64	7L253/AB	30.1
204	64	7	5	64	7L253/AB	31.39
272	64	8	0	64	7L253/AB	32.35
340	64	12	5	64	7L253/AB	30.21
408	64	8	4	64	7L253/AB	30.01
476	64	12	7	64	7L253/AB	31.18
544	64	12	5	64	7L253/AB	30.71
612	64	20	8	64	7L253/AB	29.38
680	64	12	4	64	7L253/AB	30.99
748	64	8	4	64	7L253/AB	30.9
816	64	7	4	64	7L253/AB	30.57



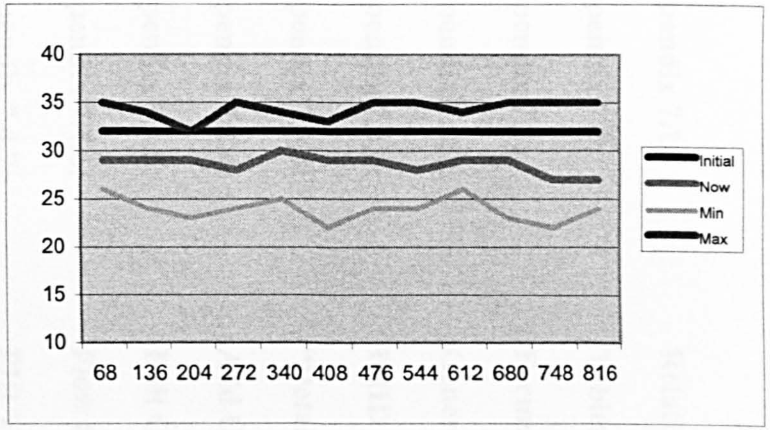
Hard Market Highest Lead Time Shaft

Shift	Init	Now	Min	Max		
68	20	4	1	20	7A356/AB	30.41
136	20	5	0	20	7A356/AB	31.34
204	20	5	0	20	7A356/AB	31.92
272	20	5	0	20	7A356/AB	33.58
340	20	5	0	20	7A356/AB	31.21
408	20	4	2	20	7A356/AB	30.49
476	20	5	1	20	7A356/AB	30.69
544	20	6	0	20	7A356/AB	31.89
612	20	3	0	20	7A356/AB	30.74
680	20	3	0	20	7A356/AB	31.81
748	20	5	0	20	7A356/AB	32.14
816	20	5	0	20	7A356/AB	31.2



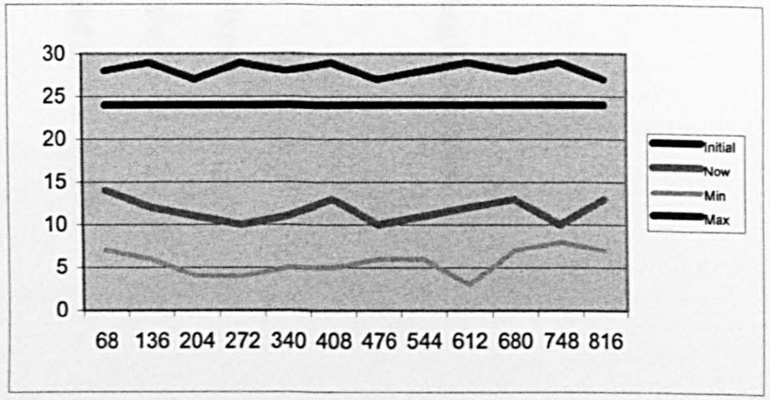
Finished Market Lowest LT

Shift	Init	Now	Min	Max		
68	32	29	26	35	7G334/AB	3.15
136	32	29	24	34	7G334/AB	3.23
204	32	29	23	32	7G334/AB	3.48
272	32	28	24	35	7G334/AB	3.22
340	32	30	25	34	7G334/AB	3.22
408	32	29	22	33	7G334/AB	3.4
476	32	29	24	35	7G334/AB	3.22
544	32	28	24	35	7G334/AB	3.19
612	32	29	26	34	7G334/AB	3.16
680	32	29	23	35	7G334/AB	3.56
748	32	27	22	35	7G334/AB	3.4
816	32	27	24	35	7G334/AB	3.22



Finished Market HIghest LT

Shift	Init	Now	Min	Max		
68	24	14	7	28	7M003b/AE	25.81
136	24	12	6	29	7M003b/AE	27.45
204	24	11	4	27	7M003b/AE	28.91
272	24	10	4	29	7M003b/AE	29.27
340	24	11	5	28	7M003b/AE	29.25
408	24	13	5	29	7M003b/AE	28.07
476	24	10	6	27	7M003b/AE	27.68
544	24	11	6	28	7M003b/AE	28.22
612	24	12	3	29	7M003b/AE	28.43
680	24	13	7	28	7M003b/AE	26.05
748	24	10	8	29	7M003b/AE	24.7
816	24	13	7	27	7M003b/AE	26.24



Appendix H

Appendix 7.1:	**Relationships**
Appendix 7.2:	**Tables**
Appendix 7.3:	**Forms**
Appendix 7.4.1:	**General code using in macros**
Appendix 7.4.2:	**PRID VBA code**
Appendix 7.4.3:	**“Details” button**
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Appendix 7.6.1:	**Excel - Main VBA code**
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Appendix 7.6.4:	**Excel – Operations Functions**
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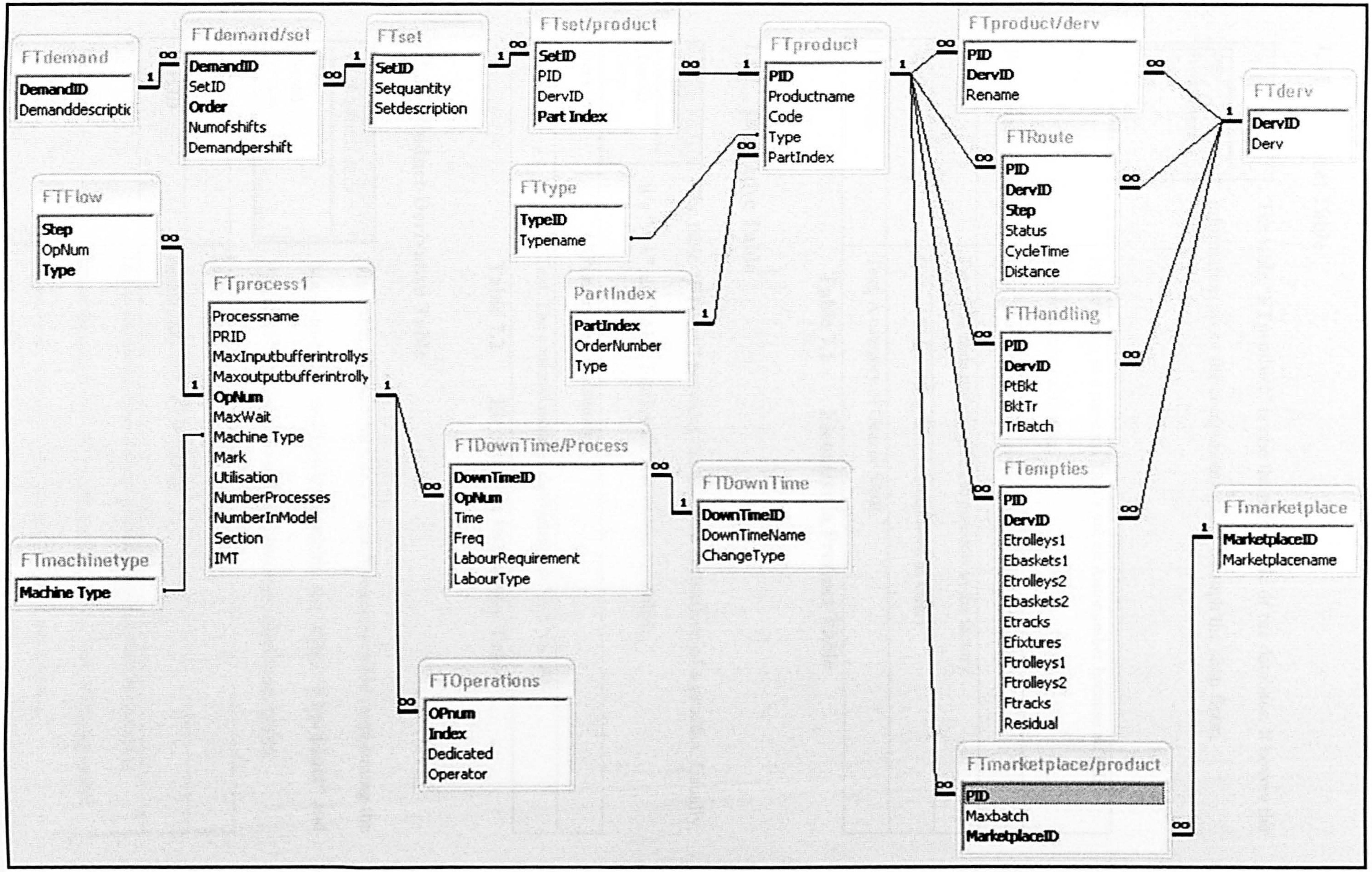
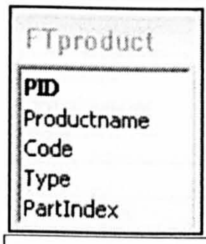
Appendix 7.1: Relationships



Appendix 7.2

7.3.1 Product Table

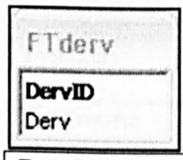


The table **"FTproduct"** is one the main table of the database. It covers the information about the components going through the shop floor.

PID	Primary key, as a number. That's not an Autonumber because all PID have to follow each other.
Productname	Text. The name usually given to products in the factory.
Code	Text. The code usually given to products in the factory.
Type	Gear or Shaft. (Ring Gear is considered as Gear)
PartIndex	Text. A category of Gear or Shaft.

Table 7.1 Elements in Product Table

7.3.2 Derivative Table

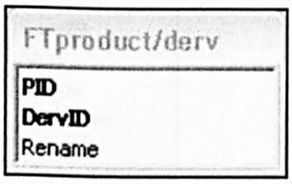


The table **"FTderv"** provides the different derivatives of a product. Usually, it's "AA" and "AB". Further derivative can be added.

DervID	Primary key, as a number.
Derv	Text. The common name of derivatives, as "AA" or "AB"

Table 7.2 Elements in Derivative Table

7.3.3 Product-Derivative Table

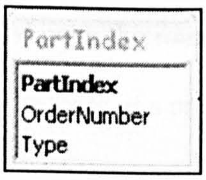


The table **"FTproduct/derv"** is a connection table representing the Many-to-Many relationship between the tables **"FTproduct"** and **"FTderv"**. PID and DervID are derived from these tables.

PID	Primary key of "FTproduct" table.
DervID	Primary key of "FTderv" table.
Rename	Due to the spreadsheets design, a unique number must be created to define the uniqueness of each product-derivative. This field is generated automatically when opening the export form in the database.

Table 7.3 Elements in Product/Derivative Table

7.3.4 Part Index Table


PartIndex

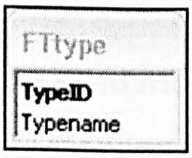
PartIndex
OrderNumber
Type

The table "**PartIndex**" compiles the order of products in different spreadsheets. This order is crucial for the simulation model.

PartIndex	Primary key, as text. A category of Gear or Shaft.
OrderNumber	Unique Number. That number gives the order of products according to PartIndex.
Type	Gear or Shaft. (Ring Gear is considered as Gear)

Table 7.4 Elements in Part Index Table

7.3.5 Type Table


FTtype

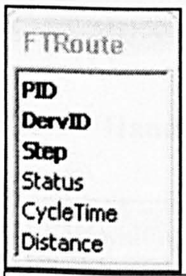
TypeID
Typename

The table "**FTtype**" defines the two mains types of products: gears and shafts. This table is necessary for queries to search component.

TypeID	Primary key, as number.
Typename	"Gear" or "Shaft".

Table 7.5 Elements in Type Table

7.3.6 Route Table


FTRoute

PID
DervID
Step
Status
CycleTime
Distance

The table "**FTroute**" defines the route that each product goes through, and the properties of the route (status, cycle time and distance).

PID	Primary Key. Defines which route's product is edited
DervID	Primary Key. Defines which route's derivative is edited
Step	Number. Step's number in the Gear Flow or Shaft Flow
Status	Yes or No. Yes if this product go to a specific machine
CycleTime	Number. Cycle time of this step

Distance	Number. Distance to next machine

Table 7.6 Elements in Route Table

This table has a multiple-field primary key. **PID** and **DervID** are also the primary keys because the route of each product-derivative must be unique. **Step** is a primary key as well; the route of a product cannot include twice the same step.

7.3.7 Marketplace Table

FTmarketplace

MarketplaceID
Marketplacename

The table **"FTmarketplace"** is a singular table defining the 3 marketplaces of the shop floor.

MarketplaceID	Primary key, as number.
Marketplacename	"MatplaceGreen" or "MatplaceHard" or "MatplaceFinished"

Table 7.7 Elements in Marketplace Table

7.3.8 Marketplace-Product Table

FTmarketplace/product

PID
Maxbatch
MarketplaceID

The table **"FTmarketplace/product"** is a connection table representing the Many-to-Many relationship between the tables **"FTproduct"** and **"FTmarketplace"**.

PID	Primary key of "FTproduct" table.
MarketplaceID	Primary key of "FTmarketplace" table.
Maxbatch	Number. Maximum batch allocated for that market.

Table 7.8 Elements in Marketplace/Product Table

7.3.9 Handling Table

FTHandling

PID
DervID
PtBkt
BktTr
TrBatch

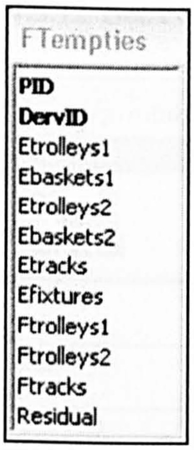
This table is a connection table between **"FTproduct"** and **"FTderv"** tables. It contains the composition of handling used in each product type.

PID	Primary key of "FTproduct" table.
DervID	Primary key of "FTderv" table.
PtBkt	Number. Parts per Basket

BktTr	Number. Basket per Trolley
TrBatch	Number. Trolleys per Batch.

Table 7.9 Elements in Handling Table

7.3.10 Empties Table

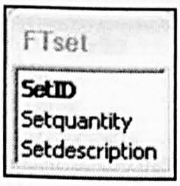

FTempties
PID
DervID
Etrolleys1
Ebaskets1
Etrolleys2
Ebaskets2
Etracks
Efixtures
Ftrolleys1
Ftrolleys2
Ftracks
Residual

The empties table consists of number of empty trolleys, baskets, racks and fixture to fill each marketplace. Elements in the table are described in Table 30. This table is a middle table between **"FTproduct"** and **"FTderv"** tables and defines the configurations of full and empties material handling containers (i.e. trolleys, baskets, etc.) of the shop floor.

PID	Primary key of "FTproduct" table.
DervID	Primary key of "FTderv" table.
Etrolleys1	Number. Empty trolleys in Green Marketplace
Ebaskets1	Number. Empty baskets in Green Marketplace
Etrolleys2	Number. Empty trolleys in Hard Marketplace
Ebaskets2	Number. Empty baskets in Hard Marketplace
Etracks	Number. Empty tracks
Efixtures	Number. Empty fixtures
Ftrolleys1	Number. Full trolleys in Green Marketplace
Ftrolleys2	Number. Full trolleys in Hard Marketplace
Ftracks	Number. Full tracks
Residual	Number. Trolleys leftover from an order

Table 7.10 Elements in Empties Table

7.3.11 Set Table

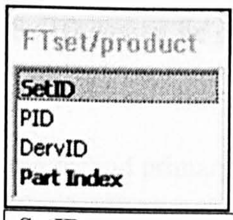

FTset
SetID
Setquantity
Setdescription

The Set table defines the set properties. A set is a group of products. Orders are placed using sets.

SetID	Primary key, as text. That is the set name.
Setquantity	Number. Number of products making up a set.
Setdescription	Text. Description to help the user to remember what that set is.

Table 7.11 Elements in Set Table

7.3.12 Set/Product Table


FTset/product
SetID
PID
DervID
Part Index

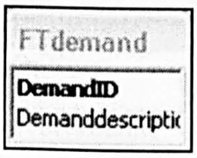
The table **"FTset/product"** is a connection table representing the Many-to-Many relationship between the tables **"FTproduct"** and **"FTset"**.

SetID	Primary key of "FTset" table.
PID	Field of "FTproduct" table.
DervID	Field of "FTderv" table.
PartIndex	Field of "FTproduct" table.

Table 7.12 Elements in Set/Product Table

SetID and **PartIndex** are defined to be the primary keys due to a property of a set: a set can only contain a unique product with the same part index.

7.3.13 Demand Table

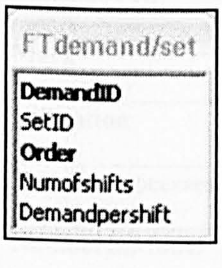

FTdemand
DemandID
Demanddescriptic

The demand table consists a group of sets for an order. A demand may have several repetition of the same set, with different quantities and number of shifts allocated.

DemandID	Primary key, as number.
Demanddescription	Text. This text helps the user to add comments to a specified set.

Table 7.13 Elements in Demand Table

7.3.14 Demand/Set Table


FTdemand/set
DemandID
SetID
Order
Numofshifts
Demandpershift

The table **"FTdemand/set"** is a connection table representing the Many-to-Many relationship between the tables **"FTdemand"** and **"FTset"**. This table also display details of shifts.

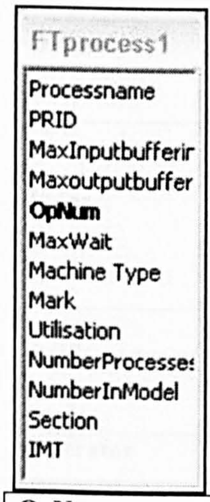
DemandID	Primary Key of "FTdemand" table.
SetID	Field of "FTset" table.
Order	Number. It defines the order of different sets in the demand.
Numofshifts	Number. Number of shift for that demand.
Demandpershift	Number. Number of sets produced for that shift.

Table 7.14 Elements in Demand/Set Table

SetID cannot be defined as a primary key there because a demand may contain repetition of the same set. But it's important to define an order between sets of a demand, so **"Order"** is the second primary key of this table.

7.3.15 Process1 Table

The Process 1 table defines the machines and the properties. All processes created in the database are not always in the model. The number of machine in the model is based on the value of **"NumberInModel"**. **PRID** is not the primary key of this table, due to the design of the others tables, linked with this one. Also, **PRID** is not a useful field for the user, because it is not descriptive. Hence **OpNum** is used as the primary key of the table.

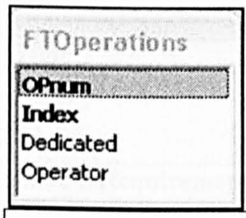

FTprocess1
Processname
PRID
MaxInputbufferir
Maxoutputbuffer
OpNum
MaxWait
Machine Type
Mark
Utilisation
NumberProcesse:
NumberInModel
Section
IMT

OpNum	Primary Key. Specific codes of the process.
Processname	Text. Name of the process.
PRID	Number. Process ID in the table.
MaxInputBuffering	Number. Number of maximum of available buffers before the process.
MaxOutputBuffering	Number. Number of maximum of available buffers after the process.
MaxWait	Number. Maximum wait time before the process continue to process another batch
MachineType	Text. Category of the machine.
Mark	Number: 0 or 1. 1 if the process is used in the model, 0 otherwise.
Utilisation	Text. Gear or Shaft.
NumberProcesses	Number. The number of process created in the database.
NumberInModel	Number. The number of process really used in the model. This field

	permits to test different scenarios.
Section	Text. From the list of the different areas of the manufacturing system.
IMT	Yes or No. Yes if an IMT is affected to the area of this process in case of breakdown; No otherwise. IMT is either a mechanical or electrical technician.

Table 7.15 Elements in Process 1 Table

7.3.16 Operations Table



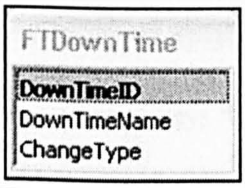
FTOperations
OPnum
Index
Dedicated
Operator

The **"FTOperations"** table is complementary to the **"FTprocess1"** table. This table store the number of machines for each process and the properties of each.

OPnum	Primary key as text. That is the ID of the "FTprocess1" table, due to the One-To-Many relationship between thee tables.
Index	Primary key as number. List of number to index the different machine of a process. The last number of the list for a particular process is the number of machines for this process.
Dedicated	Yes or No. Yes if this machine is dedicated to a particular product. No if the machine is "opened" to all products.
Operator	A,B,C,D,E, or F. The staff category operating in this machine.

Table 7.16 Elements in Operations Table

7.3.17 Downtime Table



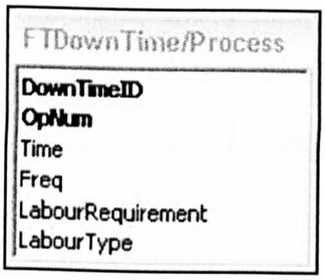
FTDownTime
DownTimeID
DownTimeName
ChangeType

This table lists the downtimes managing the behaviour of machines and also displays the different types of downtimes.

DownTimeID	Primary key, as number.
DownTimeName	Text. Common name of downtimes.
ChangeType	1, 2 or 3 or according to the type of the downtime.

Table 7.17 Elements in Downtime Table

7.3.18 Downtime-Process Table


FTDownTime/Process

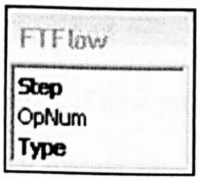
DownTimeID
OpNum
Time
Freq
LabourRequirement
LabourType

This table is the connection table between "FTproocess1" and "FTDowntime" due to its Many-To-Many relationship. It manages downtimes (and its properties) of each process.

DownTimeID	Primary Key of "FTDowntime"
OpNum	Primary Key of "FTprocess1"
Time	Number. Time of no production because of the downtime.
Freq	Number. Frequency of appearance of the downtime cause.
LabourRequirement	Number. The number of staff necessary for this downtime.
LabourType	The staff category intervening for this downtime.

Table 7.18 Elements in of Downtime/Process Table

7.3.19 Flow Table


FTFlow

Step
OpNum
Type

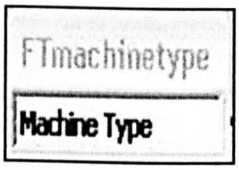
"**FTFlow**" table determines the flow of each component (Gear or Shaft) through the system. It creates two lists separating Gear and Shaft (Gear Flow and Shaft Flow) to reduce redundancy in data.

Step	Primary Key as number. 1, 2, 3, etc to the last process. Numbers have to follow.
OpNum	Field from the "FTprocess1" table.
Type	Second primary key. Gear or Shaft. To edit both lists.

Table 7.19 Elements in Flow Table

The primary keys "**Step**" – "**Type**" defines two lists in a same table: a list for the Gear Flow and another for the Shaft Flow. Each list is fixed but products do not have to go through all these processes. The user has to select the processes required only according to the type of the product (Gear or Shaft).

7.3.20 Type of Machine Table



FTmachinetype

Machine Type

The "**FTmachinetype**" is a list of different types of machines in the simulation model. Examples of machine type are general machine, continuous machine, chemical treatment machine, etc.

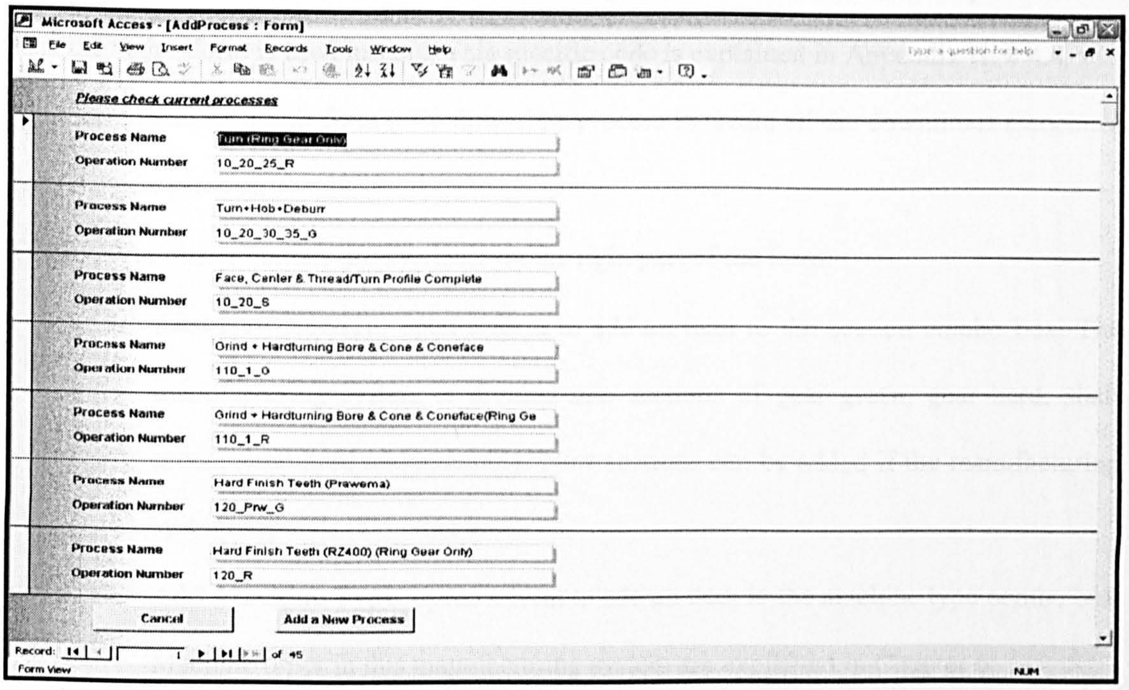
Appendix 7.3

7.3.1 Process

In the process section, the users have the option to add a new process, edit an existing process and generating a new flow for the component. The add process action consists of three other sub-forms to be filled before exiting the action. Downtime, machine type and new section can be created in these forms. The edit process option can be editing general properties, the machine and the downtimes. New process to the flow can also be added and rearranged according to the sequence of process.

7.3.1.1 Add a new process

The "Add Process" form (Figure 7.1) is the first form displaying current process for users to check if new process needs to be created. Before adding a new process, the user has to check the current processes to make sure it is not identical to an existing process. The subsequent form, the "Add Process1" form (Figure 7.2) is where the new process details needs to be filled.



Please check current processes

Process Name	Turn (Ring Gear Only)
Operation Number	10_20_25_R
Process Name	Turn+Hob+Deburr
Operation Number	10_20_30_35_G
Process Name	Face, Center & Thread/Turn Profile Complete
Operation Number	10_20_S
Process Name	Grind + Hardturning Bore & Cone & Coneface
Operation Number	110_1_G
Process Name	Grind + Hardturning Bore & Cone & Coneface(Ring Ge
Operation Number	110_1_R
Process Name	Hard Finish Teeth (Prawema)
Operation Number	120_Prw_G
Process Name	Hard Finish Teeth (RZ400) (Ring Gear Only)
Operation Number	120_R

Figure 7.1 Check Current Processes Form

Details of the Add Process Form are shown in Table 7.20.

Source	FTproduct1 (read only)
Subform	None
Buttons (Macros)	BackProcessSwitchboard, OpenAddProcess1
Code VBA	None

Table 7.20 Details of Add Process Form

7.3.1.1.a Add Process1 Form (Figure 7.2):

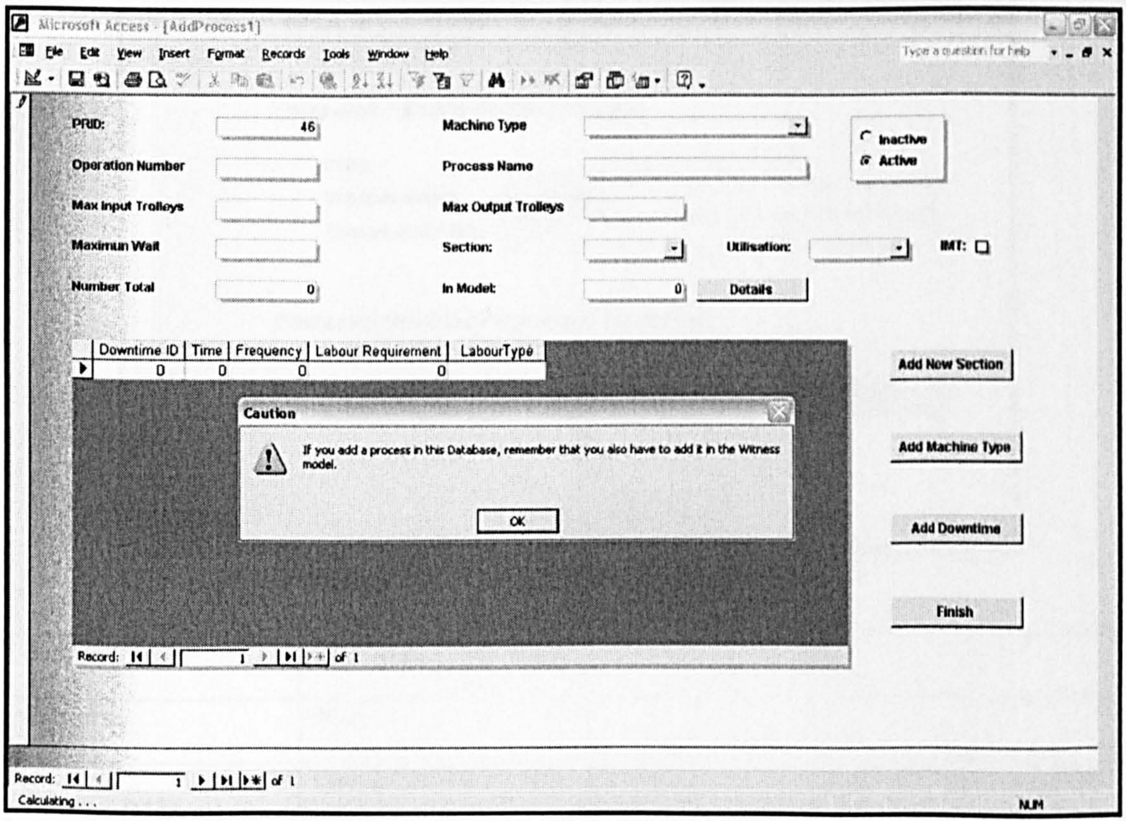
At the start of the form shown in Figure 7.2, the Product ID (PRID) of the new product is automatically generated by VBA code (refer to Appendix H: 8.4.2 for codes); PRID numbers have to follow a set sequence. A message box appears to remind the user to create the corresponding new process in the simulation model. The action of generating new process in the simulation model from the database is not incorporable at this stage but possibly through generating XML code that Witness Engine can interprets.

The user needs to define the number of machines in the model, with the "details" button. This button runs a macro, which in turns runs a VBA code and opens the "add operations" form (refer to Appendix H: 8.4.3 for codes). Machines are created and the user detailed the properties. If the user wants to modify something about the machine after they are created then the "edit" form is used instead. This specific code is explained in Appendix H: 8.4.4.

This form includes a Sub-form ("FT downtime/process to create all the downtimes associated with the new process.

Finally, four others buttons are available on the right part of the form:

- **Add New Section**: open a form to add an item to the section combo box. The manufacturing system is divided into sections of gear green, gear hard, shaft green, shaft hard and assembly. New sections can be added if the manufacturing system expands into other area.
- **Add Machine Type**: opens a form to add an item to the machine type combo box. Machine types in this manufacturing system are explained in Chapter 6.
- **Add Downtimes**: opens a form to add an item to the downtime combo box. Downtime types of the manufacturing system are also illustrated in Chapter 6.
- **Finish**: save the new process and open the switchboard form.



PRID: 46
Operation Number
Max Input Trolleys
Maximun Wait
Number Total 0
Machine Type
Process Name
Max Output Trolleys
Section:
Utilisation:
IMT: ☐
In Model: 0
○ Inactive
● Active

Downtime ID	Time	Frequency	Labour Requirement	LabourType
0	0	0	0	

Caution

If you add a process in this Database, remember that you also have to add it in the Witness model.

OK

Figure 7.2 Add a New Process Form

The details of the add new process 1 form, are as follow:

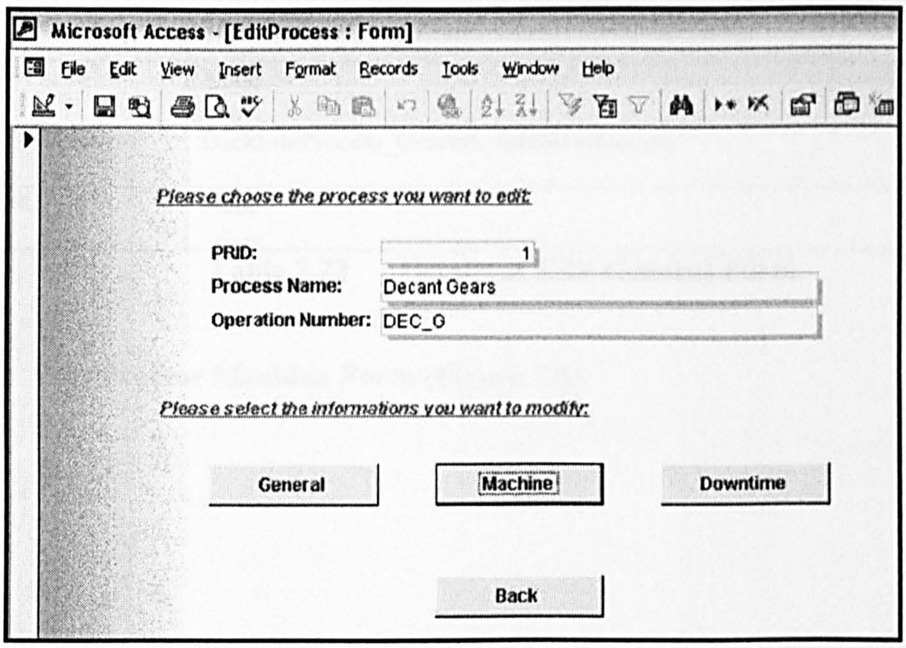
Source	FTproduct1

Subform	FTdowntime/process subform
Buttons (Macros)	BeforeAddOperations, OpenOperations, OpenAddMachineType, OpenAddDowntime, AddNewSection, FinishAddProcess.
Code VBA	Form_Load (Search PRID) SaveAddProceesBeforeAddOperations() (From macro "BeforeAddOperations")

Table 7.21 Details of Add Process1 form

7.3.1.2 Edit an existing process.

This section allows the user to modify its properties of an existing process. First, the user chooses the process to be edit, using the record selector. After that, the properties are divided into general, machine or downtimes. The button of the corresponding area is selected for edit, shown in Figure 7.3. The details of the edit process form are shown in Table 7.22.



Please choose the process you want to edit:

PRID: 1

Process Name: Decant Gears

Operation Number: DEC_G

Please select the informations you want to modify:

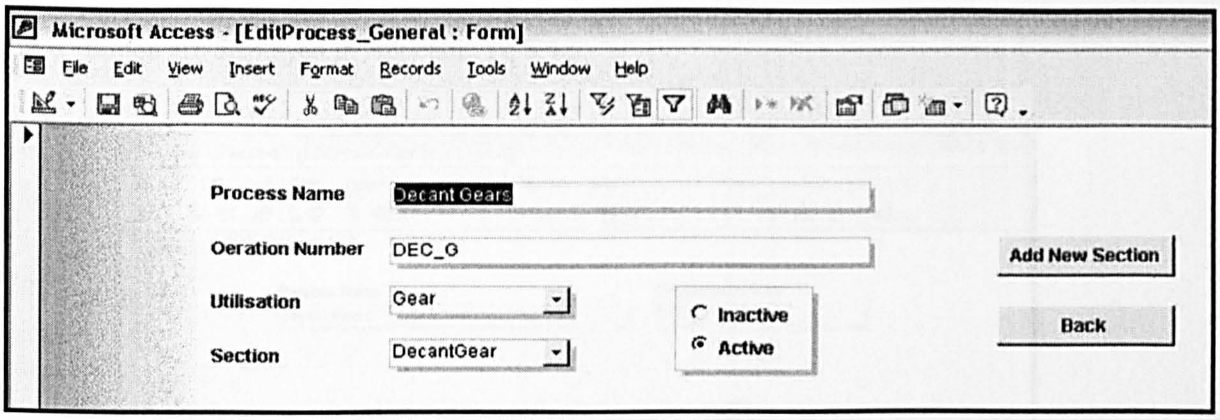
Figure 7.3 Edit Process Main Form

Source	FTproduct1 (read only)
Subform	None
Buttons (Macros)	OpenEditProcess_Name_OPnum, OpenEditProcess_Machine, OpenEditProcess_DownTime, BackAddProcess_EditProcess.
Code VBA	None

Table 7.22 Details of Edit Process Form

7.3.1.2.a Edit Process General Form (Figure 7.4)

Figure 7.4 shows the edit general form and another sub-form of adding new section which can be called with the button.



Microsoft Access - [EditProcess_General : Form]

Process Name: Decant Gears

Oeration Number: DEC_G

Utilisation: Gear

Section: DecantGear

○ Inactive

● Active

Figure 7.4 Edit General Form

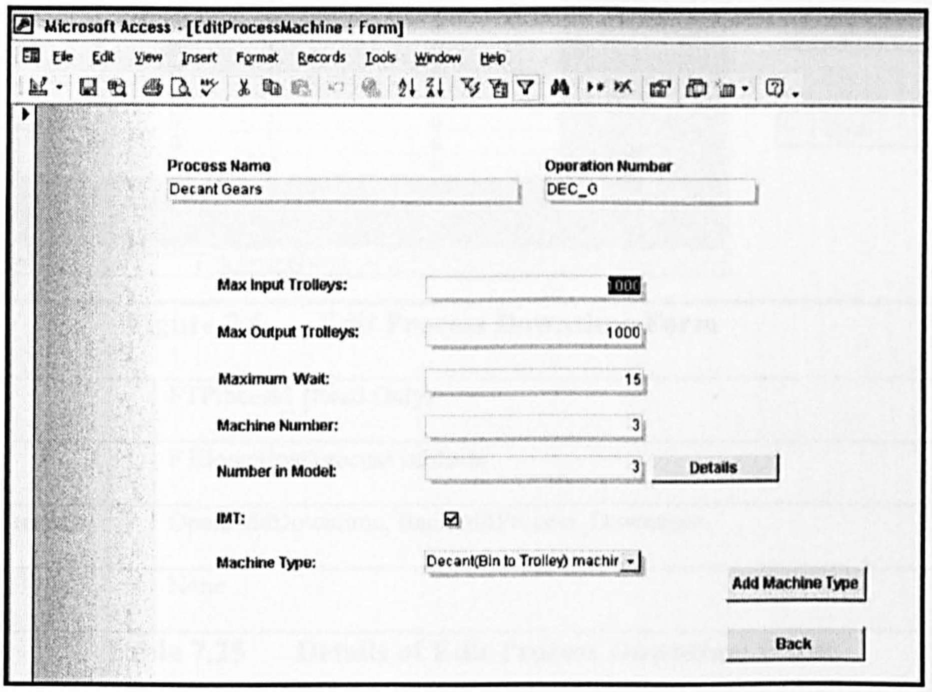
This form can be used to change the status of an obsolete process from active to inactive or vice versa. Details of this form are shown in Table 7.23.

Source	FTproduct1
Subform	None
Buttons (Macros)	BackEditProcess_General, AddNewSection.
Code VBA	None

Table 7.23 Details of Edit General Form

7.3.1.2.b Edit Process Machine Form (Figure 7.5)

With this form, the user can modify other properties of the "FTproduct1" table used to hold product information. The number of machines in the model can be added with the 'Details' button and the user also has the option to add a new machine type in the form shown in Figure 7.5. Details of the form are shown in Table 7.24. The codes for "edit operations" form and "details" button are displayed in Appendix H: 8.4.5.



Process Name: Decant Gears

Operation Number: DEC_G

Max Input Trolleys: 1000

Max Output Trolleys: 1000

Maximum Wait: 15

Machine Number: 3

Number in Model: 3

IMT: ☑

Machine Type: Decant(Bin to Trolley) machir

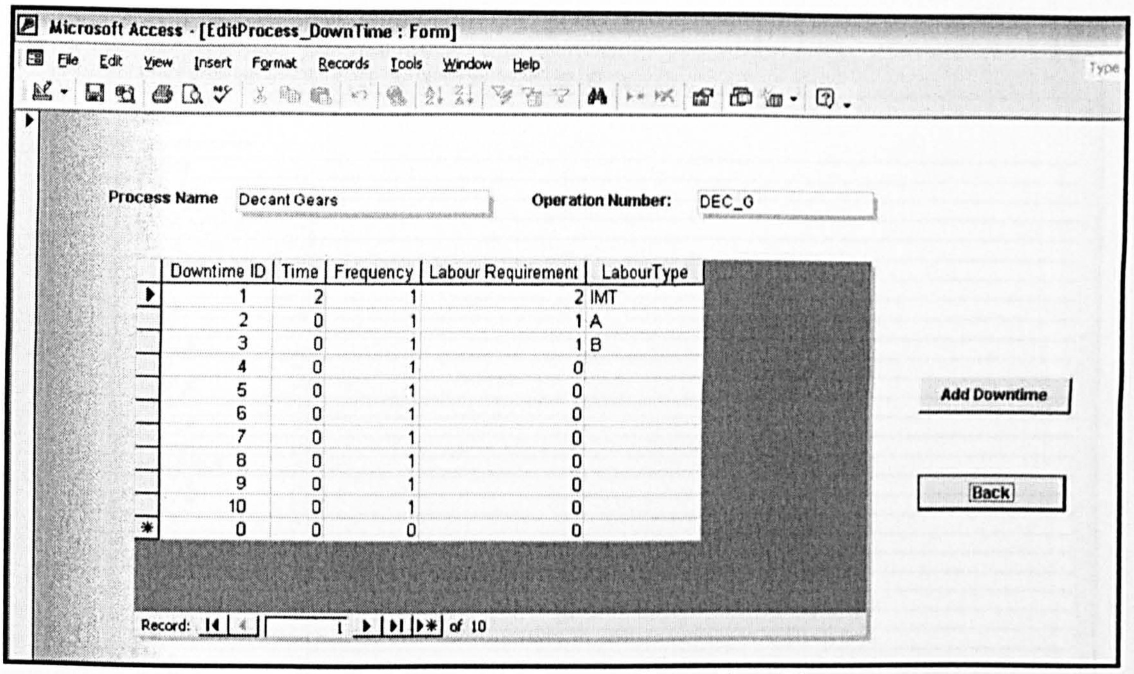
Figure 7.5 Edit Machine Form

Source	FTproduct1
Subform	None
Buttons (Macros)	OpenEditOperations, OpenAddMachineType, BackEditProcess_Machine.
Code VBA	None

Table 7.24 Details of Edit Machine Form

7.3.1.2.c Edit Process Downtime Form (Figure 7.6)

The downtime details of each process shown in the table, and can be as edited shown in Figure 7.6. The user has the option to add new downtimes if the downtime activities are not already on the list. A pull down menu showing what each downtime ID means is displayed when the mouse is moved to the downtime ID column. The details of the Downtime Form are displayed in Table 7.25.



Process Name: Decant Gears

Operation Number: DEC_G

Downtime ID	Time	Frequency	Labour Requirement	LabourType
1	2	1	2	IMT
2	0	1	1	A
3	0	1	1	B
4	0	1	0	
5	0	1	0	
6	0	1	0	
7	0	1	0	
8	0	1	0	
9	0	1	0	
10	0	1	0	
0	0	0	0	

Record: 1 of 10

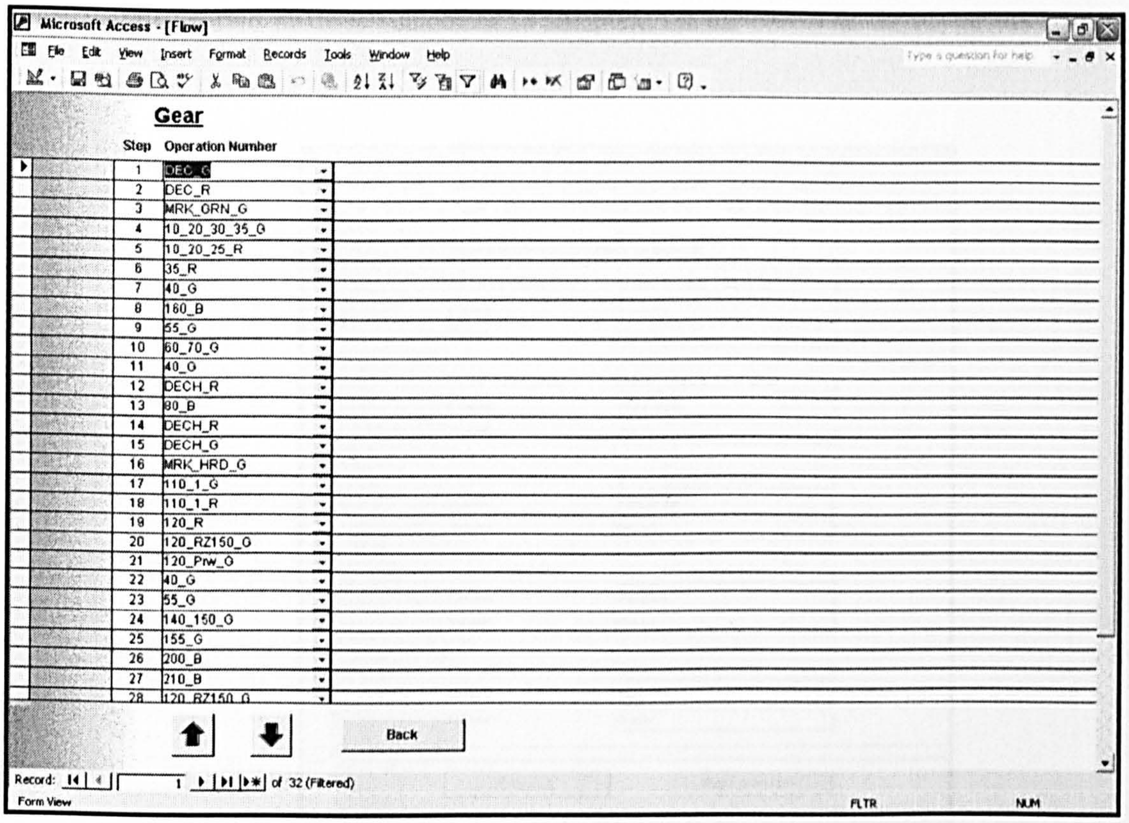
Figure 7.6 Edit Process Downtime Form

Source	FTProcess1 (Read Only)
Subform	FTdowntime/process subform
Buttons (Macros)	OpenAddDowntime, BackEditProcess_Downtime
Code VBA	None

Table 7.25 Details of Edit Process Downtime Form

7.3.1.3 Edit the flow (Error! Reference source not found.)

From the switchboard, users can define the flow of the component by selecting the appropriate button of “Gear Flow” or “Shaft Flow”. Both buttons access the same form (“Flow”), but the filter to display the data is different (Type= Gear or Shaft). The user edits the list of the processes each component goes through, adding, deleting or editing processes in the order shown in **Error! Reference source not found.**. The rearranging of processes is coded with VBA code (refer Appendix H: 8.4.6 for codes). The details of the form are displayed in Table 7.26.



Gear

Step	Operation Number
1	DEC_G
2	DEC_R
3	MRK_ORN_G
4	10_20_30_35_G
5	10_20_25_R
6	35_R
7	40_G
8	160_B
9	55_G
10	60_70_G
11	40_G
12	DECH_R
13	80_B
14	DECH_R
15	DECH_G
16	MRK_HRD_G
17	110_1_G
18	110_1_R
19	120_R
20	120_RZ150_G
21	120_Prw_G
22	40_G
23	55_G
24	140_150_G
25	155_G
26	200_B
27	210_B
28	120_RZ150_G

Figure 7.7 Edit Flow Form

Source	FTFlow
Subform	None
Buttons (Macros)	BackFlow
Code VBA	Command 9 and Command 10 (Arrows UP and DOWN)

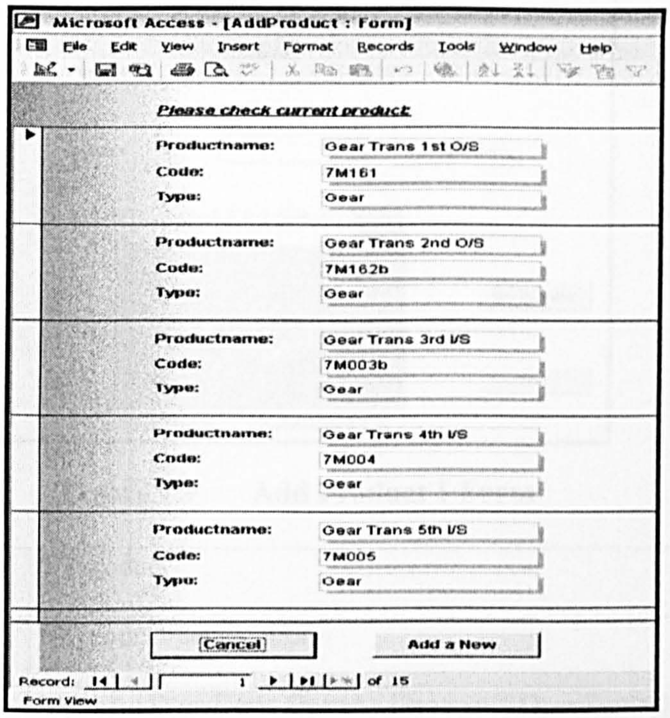
Table 7.26 Details of Flow Form

7.3.2 Product

Adding and editing a product is similar to adding and editing a process. The design and structure of the forms follow the same format.

7.3.1.1 Add a new product

Before adding a new product, the user checks the existing products in the database in order not to duplicate product. The "Add Product" form (Figure 7.8) displays a list of existing products. The subsequent form, the "Add Product1" form (Figure 7.9) is where the new product details are filled. Adding a product is more complicated than adding a process. A product has more properties and sub categories and therefore more forms are generated. Users are required to fill in three sub-forms to complete the actions. The details of the form are illustrated in Table 7.27.



Please check current product:

Productname: Gear Trans 1st O/S
Code: 7M161
Type: Gear

Productname: Gear Trans 2nd O/S
Code: 7M162b
Type: Gear

Productname: Gear Trans 3rd I/S
Code: 7M003b
Type: Gear

Productname: Gear Trans 4th I/S
Code: 7M004
Type: Gear

Productname: Gear Trans 5th I/S
Code: 7M005
Type: Gear

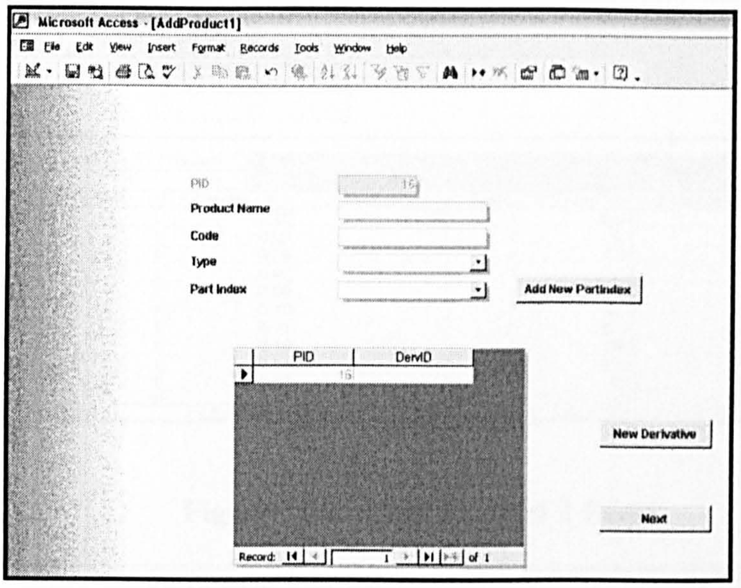
Figure 7.8 Check Current Products Form

Source	FTprocess (read only)
Subform	None
Buttons (Macros)	BackProductSwitchboard_AddProduct, OpenAddProduct1
Code VBA	None

Table 7.27 Details of Add Product Form

7.3.1.1.a Add Product 1 Form (Figure 7.9)

The user defines the product information: name, code, type, part index and derivatives as shown in Figure 7.9. New part index and its derivatives are entered in the Add New Part Index sub-form. Like the Process ID (PRID), the Product ID (PID) is generated automatically. The associated VBA code is detailed in Appendix H: 8.4.7. Details of the form are displayed in Table 7.28.



PID 16

PID 16

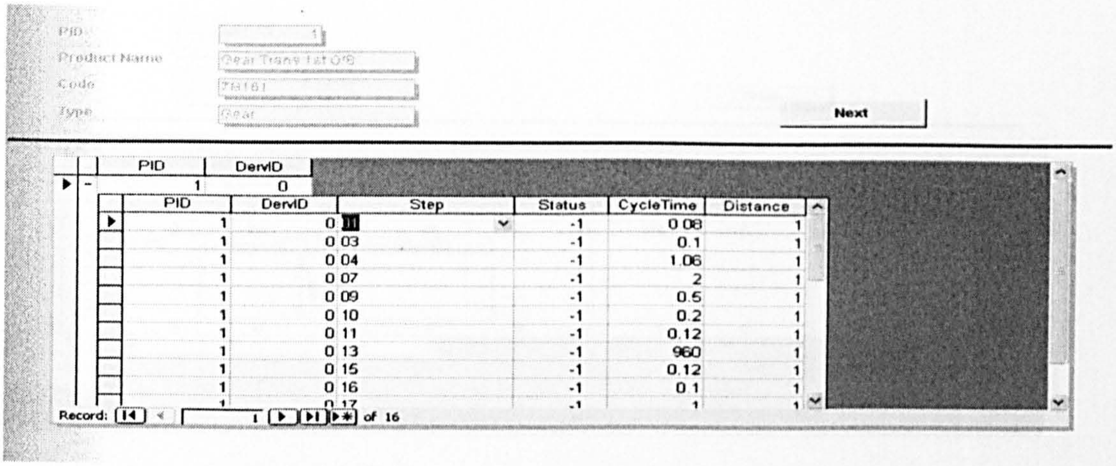
Figure 7.9 Add Product 1 Form

Source	FTproduct
Subform	FTproduct/derv subform
Buttons (Macros)	OpenAddNewDerv, OpenAddProduct2, OpenPartIndex
Code VBA	Form_Load (Search PID)

Table 7.28 Details of Add Product 1 Form

7.3.1.1.b Add Product 2 Form (Figure 7.10)

This form is divided into two parts. The upper one displays the previous product data entered for reference. In the lower part, the sub-form brings the user to define the flow with existing processes and properties by clicking to the + sign on the left hand corner of the table. Steps and status are defined. A status of -1 refers to that the product can visit any of the processes. A position number indicates that the product visits a specific machine in the list of machines in the process. Steps are generated through VBA (refer to Appendix H: 8.4.8). Details of the form are illustrated in Table 7.29.



PID 1

Product Name Gear Trans 1st O/S

Code 7H161

Type Gear

PID	DervID
1	0

PID	DervID	Step	Status	CycleTime	Distance
1	0	01	-1	0.08	1
1	0	03	-1	0.1	1
1	0	04	-1	1.06	1
1	0	07	-1	2	1
1	0	09	-1	0.5	1
1	0	10	-1	0.2	1
1	0	11	-1	0.12	1
1	0	13	-1	960	1
1	0	15	-1	0.12	1
1	0	16	-1	0.1	1
1	0	17	-1	1	1

Record: 1 of 16

Figure 7.10 Add Product 2 Form

Source	FTproduct (read only)
Subform	FTproduct/derv subform2, and inside FTroute subform
Buttons (Macros)	OpenAddProduct3
Code VBA	Status (On Got Focus).

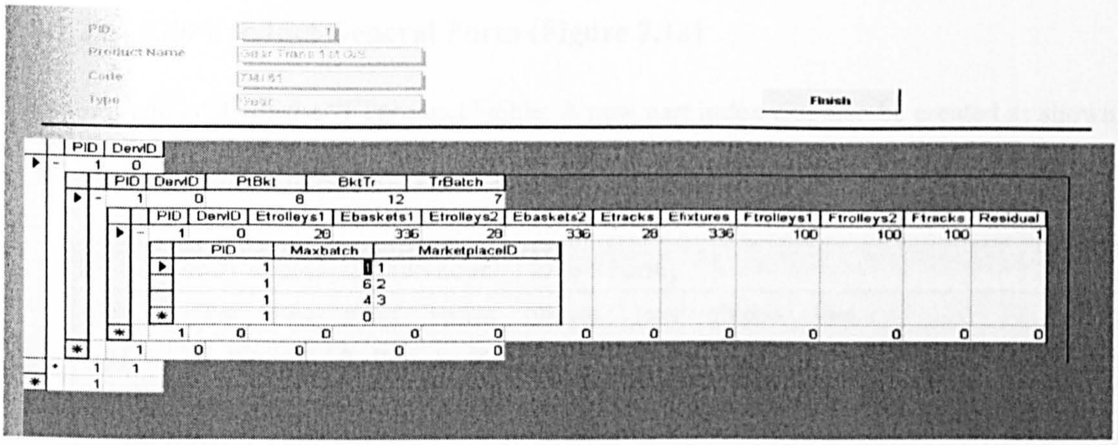
Table 7.29 Details of Add Product 2 Form

7.3.1.1.c Add Product 3 form (Figure 7.11)

The construction of this form is very similar to the previous one. The upper part is for display and reference, the user access to the sub-form in the lower part to enter details of handling, empties and marketplace information as shown in Figure 7.11. The tables of each section will pop up with clicking the + sign on the left hand corner of the table to fill the subsequent data. Details of the forms are displayed in Table 7.30.

Source	FTproduct (read only)
Subform	FTproduct/derv subform3, and inside FThandling subform, and inside FTempties subform, and inside FTmarketplace/product subform.
Buttons (Macros)	FinishAddProduct
Code VBA	None.

Table 7.30 Details of Add Product 3 Form


PID: 1
Product Name: Gear Trans 1st O/S
Code: 7M161
Type: Gear

PID	DervID
1	0
1	1
1	

PID	DervID	PtBkt	BktTr	TrBatch
1	0	6	12	7
1	0	0	0	0

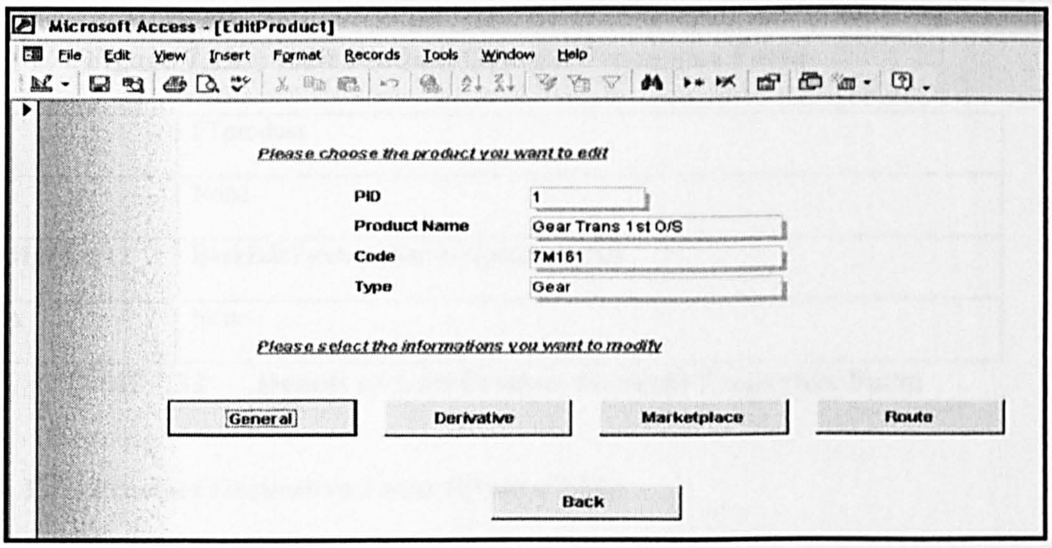
PID	DervID	Etrolleys1	Ebaskets1	Etrolleys2	Ebaskets2	Etracks	Efixtures	Ftrolleys1	Ftrolleys2	Ftracks	Residual
1	0	28	336	28	336	28	336	100	100	100	1
1	0	0	0	0	0	0	0	0	0	0	0

PID	Maxbatch	MarketplaceID
1	1	1
1	6	2
1	4	3
1	0	

Figure 7.11 Add Product 3 Form

7.3.1.2 Edit an Existing Product

The user chooses which product needs modifying with the record selector. After that, the type of information for examples: general, derivative, marketplace and route are selected to be edited as shown in Figure 7.12. Details of the form are displayed in Table 7.31.



Please choose the product you want to edit

PID: 1
Product Name: Gear Trans 1st O/S
Code: 7M161
Type: Gear

Please select the informations you want to modify

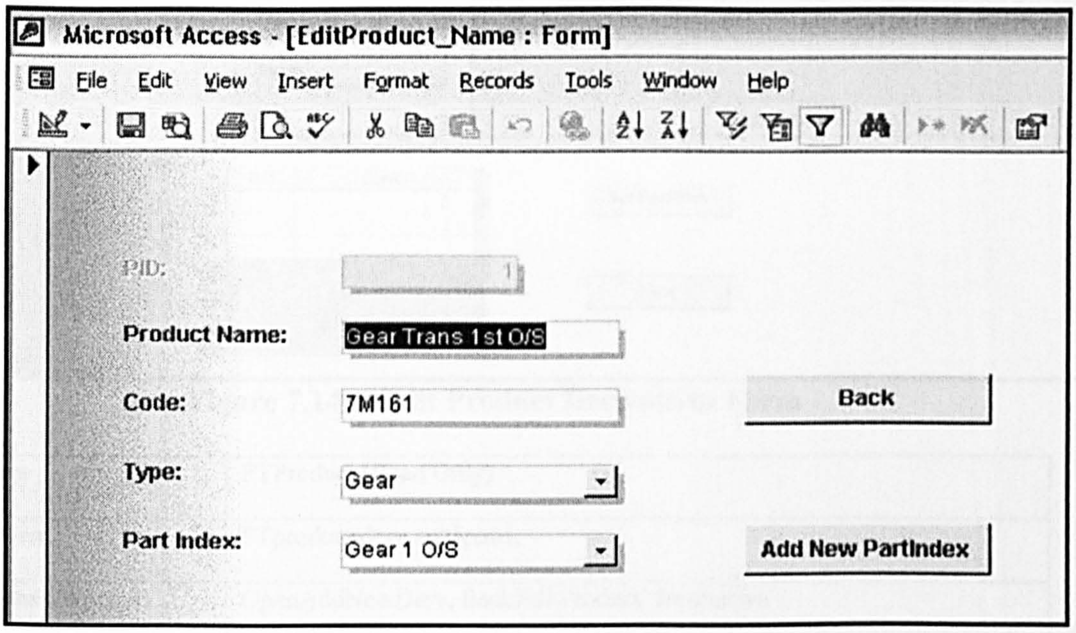
Figure 7.12 Edit Product Form

Source	FTproduct (read only)
Subform	None
Buttons (Macros)	OpenEditProduct_Name, OpenEditProduct_Derivative, OpenEditProduct_Marketplace, OpenEditProduct_Route, BackProductSwitchboard_EditProduct
Code VBA	None.

Table 7.31 Details of Edit Product Form

7.3.1.2.a Edit Product General Form (Figure 7.13)

This form edits data of the "FTproduct" table. A new part index can also be created as shown in Figure 7.13. Details of the form are displayed in Table 7.32.



PID: 1

Product Name: Gear Trans 1st O/S

Code: 7M161

Type: Gear

Part Index: Gear 1 O/S

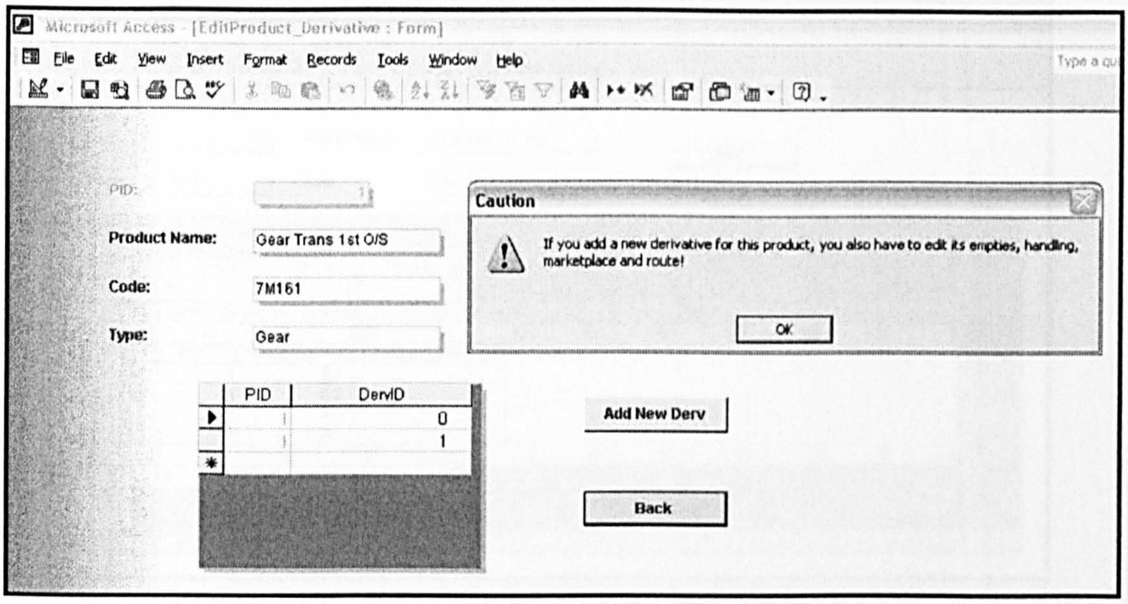
Figure 7.13 Edit Product General Properties Form

Source	FTproduct
Subform	None
Buttons (Macros)	BackEditProduct_Name, OpenPartIndex.
Code VBA	None.

Table 7.32 Details of Edit Product General Properties Form

7.3.1.2.b Edit Product Derivative Form (Figure 7.14)

Figure 7.14 shows the form to edit the derivatives of a product. If a new derivative is added, the user must also create the new derivative variable in the simulation model. Details of the form are displayed in Table 7.33.



PID: 1

Product Name: Gear Trans 1st O/S

Code: 7M161

Type: Gear

PID	DervID
1	0
1	1

Caution

If you add a new derivative for this product, you also have to edit its empties, handling, marketplace and route!

Figure 7.14 Edit Product Derivatives Form

Source	FTProduct (Read Only)
Subform	FTproduct/derv subform1.
Buttons (Macros)	OpenAddNewDerv, BackEditProduct_Derivative
Code VBA	None.

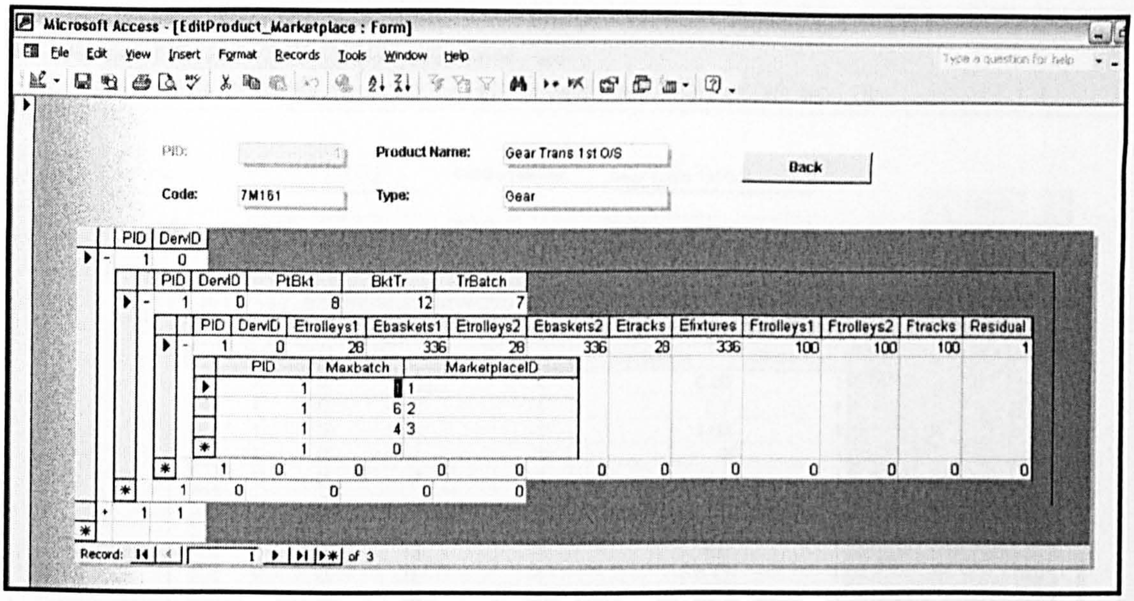
Table 7.33 Details of Edit Product Derivatives Form

7.3.1.2.c Edit Product Marketplace Form (Figure 7.15)

The marketplace of the product is edited in the edit product marketplace form shown in Figure 7.15. The details of the form are displayed in Table 7.34.

Source	FTProduct (Read Only)
Subform	FTproduct/derv subform3, and inside FThandling subform, and inside FTempties subform, and inside FTmarketplace/product subform.
Buttons (Macros)	BackEditProduct_Marketplace.
Code VBA	None.

Table 7.34 Details of Edit Product Marketplace Form



PID: 1

Product Name: Gear Trans 1st O/S

Code: 7M161

Type: Gear

PID	DervID
1	0
1	1

PID	DervID	PtBkt	BktTr	TrBatch
1	0	8	12	7
1	0	0	0	0

PID	DervID	Etrolleys1	Ebaskets1	Etrolleys2	Ebaskets2	Etracks	Efixtures	Ftrolleys1	Ftrolleys2	Ftracks	Residual
1	0	28	336	28	336	28	336	100	100	100	1
1	0	0	0	0	0	0	0	0	0	0	0

PID	Maxbatch	MarketplaceID
1	1	1
1	6	2
1	4	3
1	0	

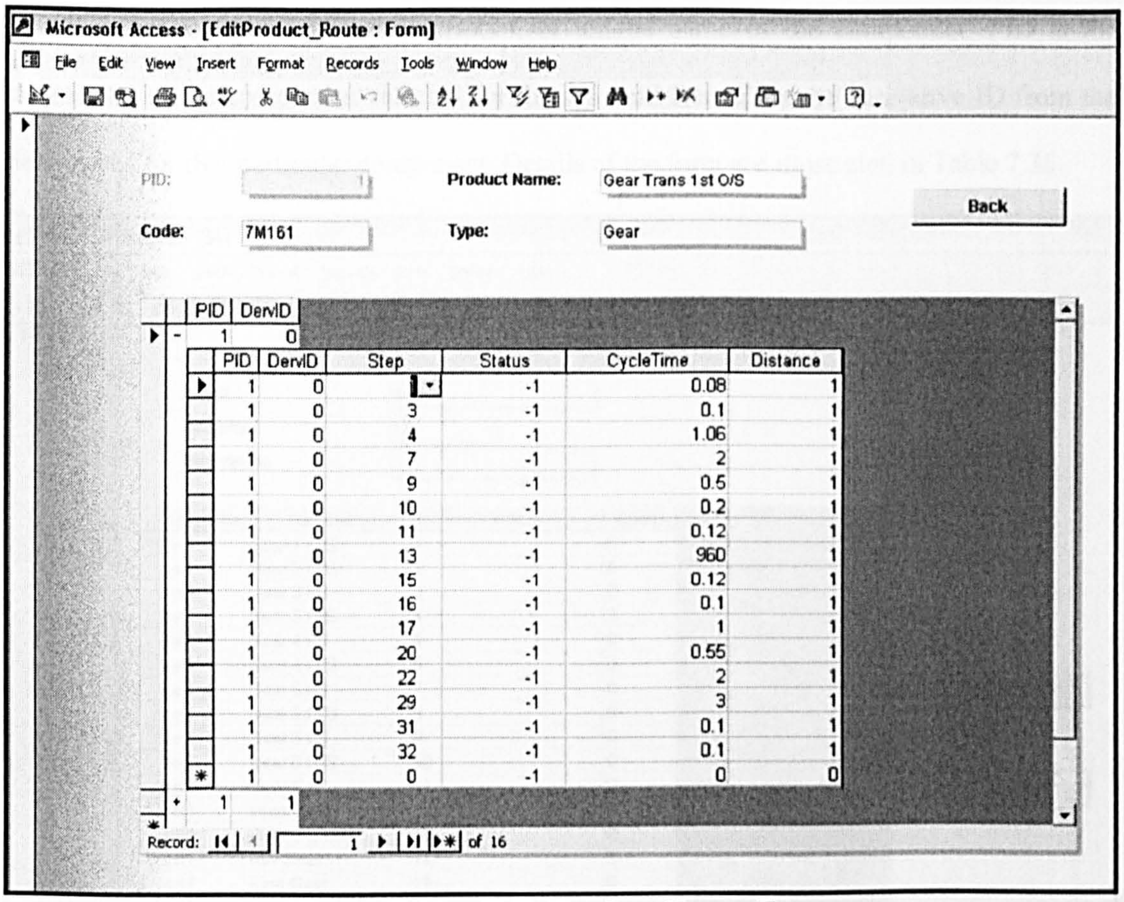
Figure 7.15 Edit Product Marketplace Form

7.3.1.2.d Edit Product Route Form (Figure 7.16):

The last form of the edit product section is the edit product route form shown in Figure 7.16. Details of the form are displayed in Table 7.35.

Source	FTProduct (Read Only)
Subform	FTproduct/derv subform4, and inside FTroute subform2
Buttons (Macros)	BackEditProduct_Route
Code VBA	Status (On Got Focus).

Table 7.35 Details of Edit Product Route Form



PID: 1

Product Name: Gear Trans 1st O/S

Code: 7M161

Type: Gear

PID	DervID
1	0
1	1

PID	DervID	Step	Status	CycleTime	Distance
1	0	1	-1	0.08	1
1	0	3	-1	0.1	1
1	0	4	-1	1.06	1
1	0	7	-1	2	1
1	0	9	-1	0.5	1
1	0	10	-1	0.2	1
1	0	11	-1	0.12	1
1	0	13	-1	960	1
1	0	15	-1	0.12	1
1	0	16	-1	0.1	1
1	0	17	-1	1	1
1	0	20	-1	0.55	1
1	0	22	-1	2	1
1	0	29	-1	3	1
1	0	31	-1	0.1	1
1	0	32	-1	0.1	1
1	0	0	-1	0	0

Figure 7.16 Edit Product Route Form

7.3.1.3 Edit Demands and Sets.

The section contains two forms for "sets" and "demand". A set represent those product derivatives that make up a set assembly. The demand represents the quantity and profile of the customer demand. They consists the orders for the manufacturing system and the making of the set details.

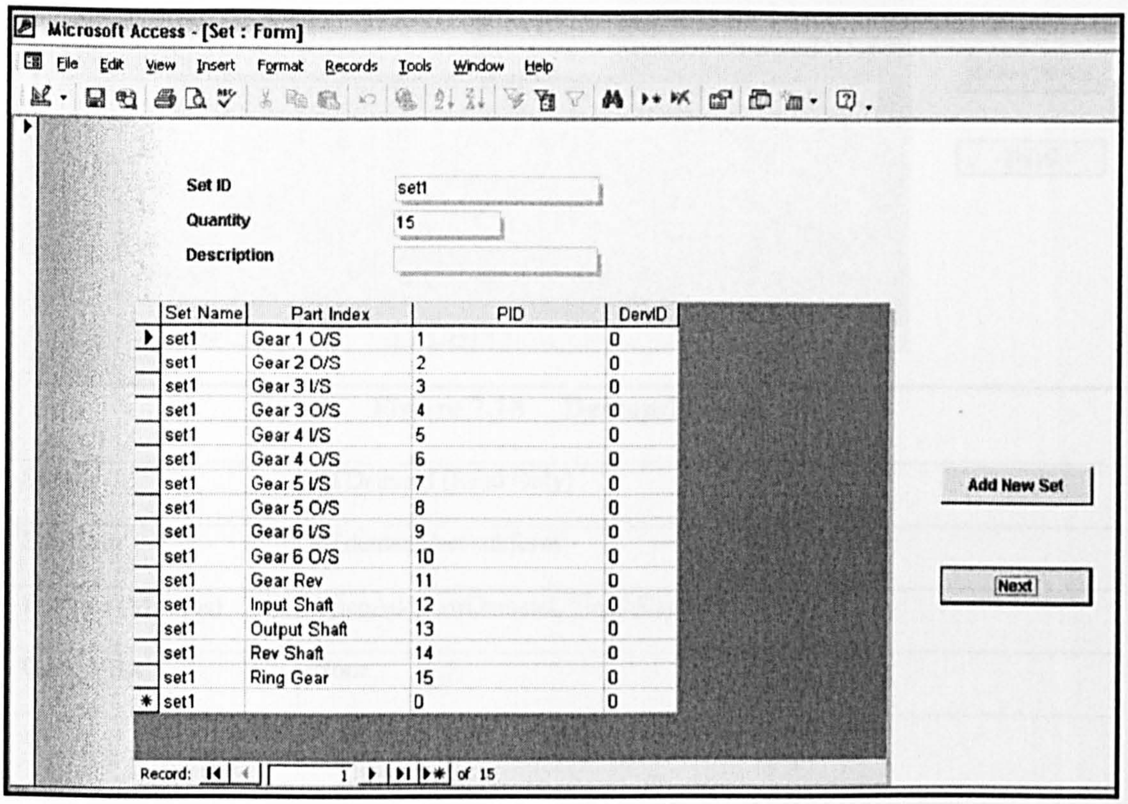
7.3.1.3.a Set (Figure 7.17):

This form is designed to add and edit a set. To add a set, the user needs to open the "AddNewSet" form, with the corresponding button.

The content of a set is critical and not easy to construct. In the forms, for a same set:

- Partindex can't de duplicated,
- PIDs are sub categories of partindex
- DervIDs are sub categories of PIDs.

The Part Index represents the description or unique name of the component. PID is the product ID of the component selected for the set. And DervID is the derivative ID from the derivatives for that particular component. Details of the form are illustrated in Table 7.36.



Set ID set1
Quantity 15
Description

	Set Name	Part Index	PID	DervID
▶	set1	Gear 1 O/S	1	0
	set1	Gear 2 O/S	2	0
	set1	Gear 3 I/S	3	0
	set1	Gear 3 O/S	4	0
	set1	Gear 4 I/S	5	0
	set1	Gear 4 O/S	6	0
	set1	Gear 5 I/S	7	0
	set1	Gear 5 O/S	8	0
	set1	Gear 6 I/S	9	0
	set1	Gear 6 O/S	10	0
	set1	Gear Rev	11	0
	set1	Input Shaft	12	0
	set1	Output Shaft	13	0
	set1	Rev Shaft	14	0
	set1	Ring Gear	15	0
*	set1		0	0

Record: 1 of 15

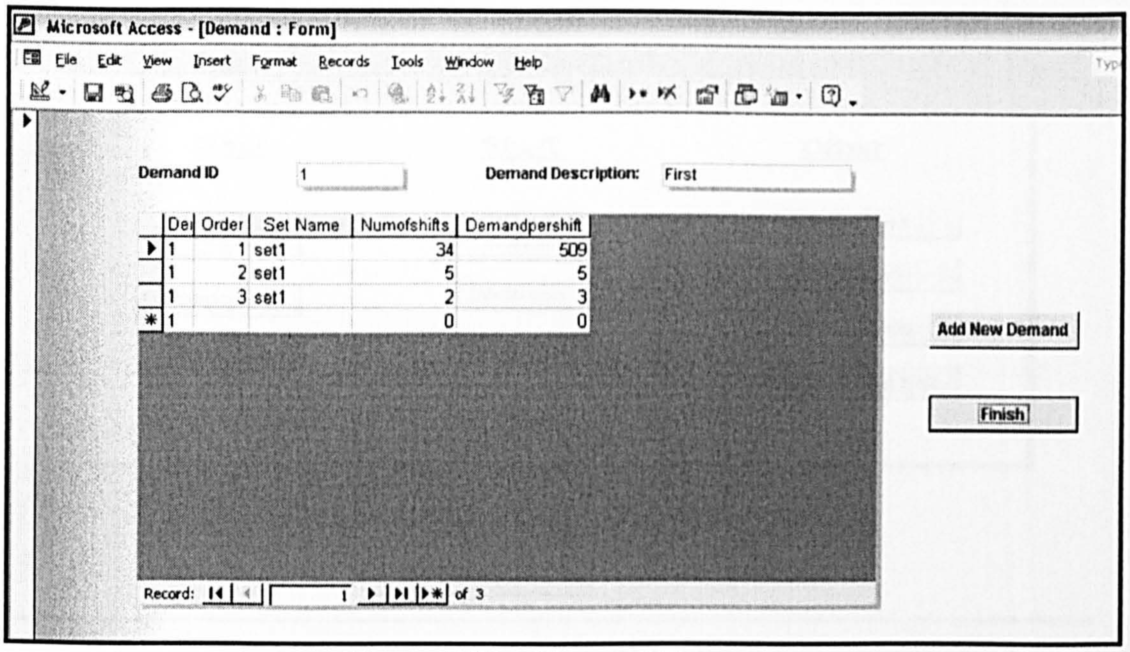
Figure 7.17 Set Form

Source	FTSet (Read Only)
Subform	FTset/product subform and inside FTset/product subform1
Buttons (Macros)	OpenAddNewSet, OpenDemand
Code VBA	Partindex, PID and DervID (On Focus).

Table 7.36 Details of Set Form

7.3.1.3.b Demand (Figure 7.18):

Different set configurations defined previously are selected to build a list of demand in the demand form shown in Figure 7.18. The sequence of the sets in the demand is processed accordingly. Details of the demand form are displayed in Table 7.37.



Demand ID: 1

Demand Description: First

Dei	Order	Set Name	Numofshifts	Demandpershift
1	1	set1	34	509
1	2	set1	5	5
1	3	set1	2	3
1			0	0

Record: 1 of 3

Figure 7.18 Demand Form

Source	FTDemand (Read Only)
Subform	FTdemand/set subform
Buttons (Macros)	OpenAddNewDemand, FinishDemand/Set
Code VBA	None

Table 7.37 Details of Demand Form

7.3.3 Export Data to Excel Spreadsheets

The final option is exporting the data from the database to the relevant excel worksheets in one workbook. The information needed to build the right spreadsheets have to be exported with queries. The users are able to select individual worksheets to export for example Route, distance, operations, etc. shown in Figure 7.19. Details of the form are displayed in Table 7.38. Codes and programs to export these spreadsheets are displayed.

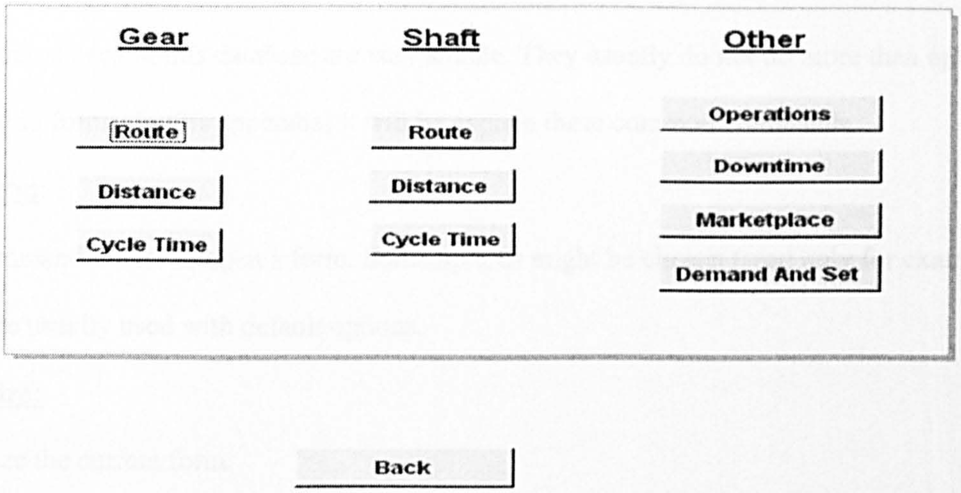
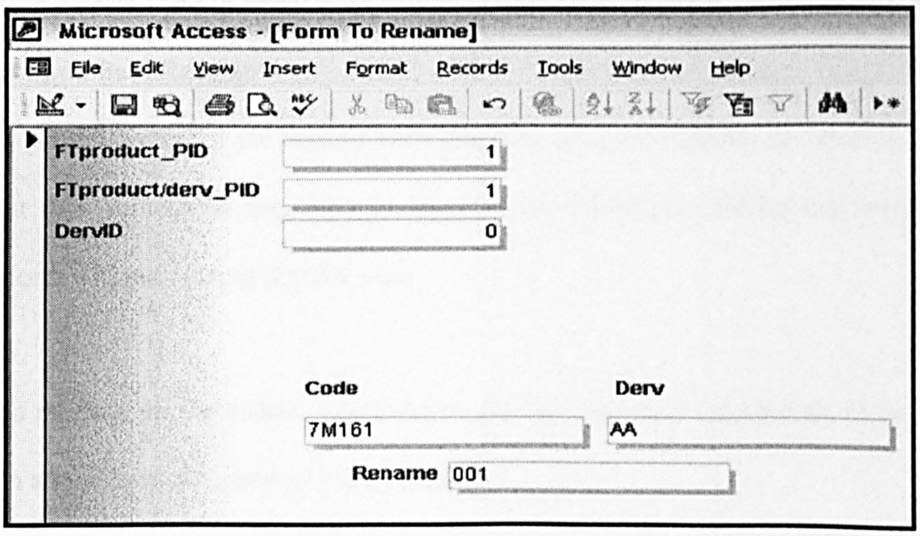


Figure 7.19 Exporting Form

Source	None
Subform	None
Buttons (Macros)	ExportOperation, ExportMarketplace, ExportDowntine, ExportDemand, ExportGearRoute, ExportGearDistance, ExportGearCT, ExportShaftRoute, ExportShaftDistance, ExportShaftCT.
Code VBA	None

Table 7.38 Details of Exporting Form

Although this form looks simple, the exporting action is complicated. All data needs to be defined and exported in a pre-programmed structure. The order of products is important to keep consistency between spreadsheets, structure and the "Form To Rename" form had been designed (Figure 7.20) to address the problem.



FTproduct_PID 1

FTproduct/derv_PID 1

DervID 0

Code 7M161

Derv AA

Rename 001

Figure 7.20 Form To Rename

Appendix 7.4.1: General code using in macros

Most macros used in this database are very simple. They usually do not do more than opening and closing forms. In this appendix, it will be explain these common commands.

Openform:

This command orders to open a form. Some options might be chosen (read only for example). It is there usually used with default options.

Maximize:

Maximize the current form.

Close:

Close a form or a table.

Runcommand Refresh:

Refresh the current form. This command is used to reload more or less the form and take it into account the recent modification created by VBA code or macros.

Setvalue:

Fill in a field in a form, by example. It is sometimes necessary to store a value in an unbound field to use it after. The value is written with this command.

Runcommand DesignView:

Display the current form in Design View. This command is use to reload a form, it is followed by next command: Runcommand FormView.

Runcommand FormView:

Display the current form in Form View (View usually used by users).

Runcommand SaveRecord:

Save the current record of the current form. Records are automatically saved when closing a form, but it is sometimes necessary to save the record before closing the form (to open another form without closing the first one).

MsgBox:

Display a message in the screen. It permits to give an important information to users and to draw him attention to the content of the message.

RunCode:

Run VBA code from a macro. With this command, a code written in a module can be run from a macro.

OpenTable:

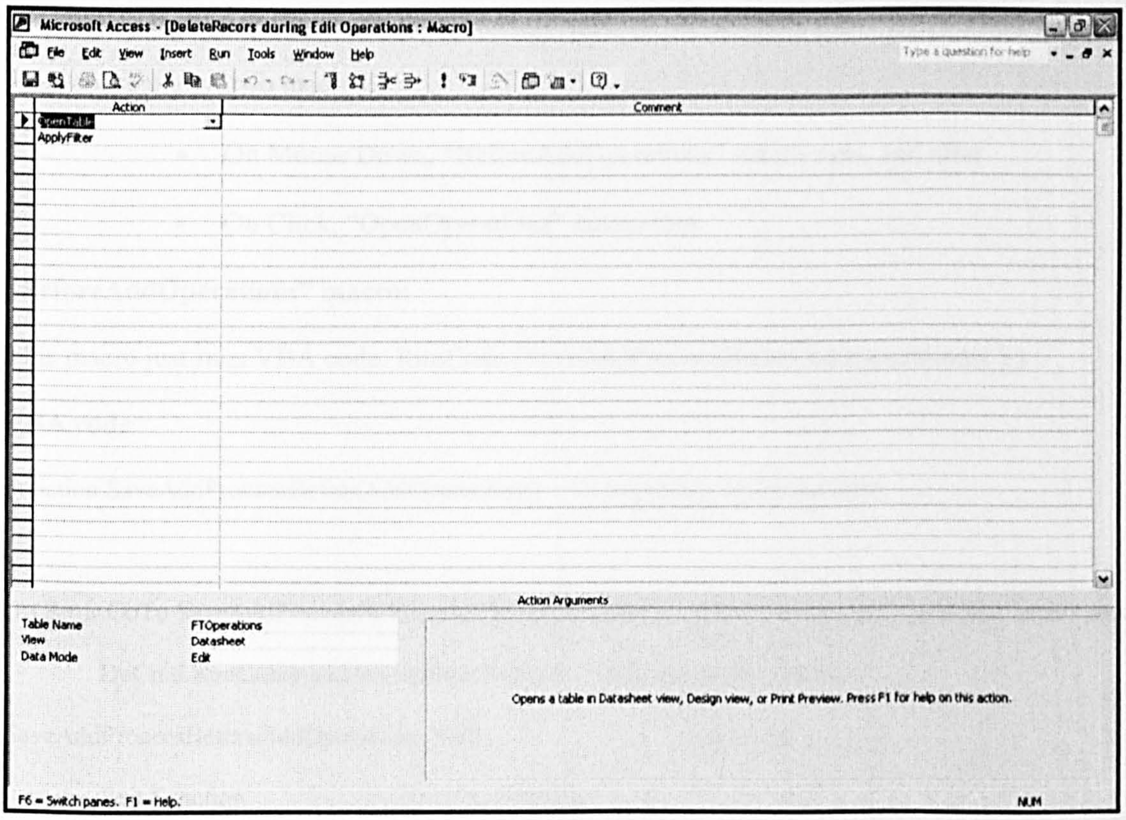
Open a table.

ApplyFilter:

By opening a form or a table, it is sometimes useful to apply a filter to only keep the interesting information. In that case, this command is used.

GoToRecord:

Go to a specific record according the option chosen: first, last, next, previous, and new. This command is used to move to a record or between records of a form.



Action	Comment
OpenTable	
ApplyFilter	

Table Name FTOperations
View Datasheet
Data Mode Edit

Opens a table in Datasheet view, Design view, or Print Preview. Press F1 for help on this action.

Figure 7.21 Macro Window

Appendix 7.4.2: PRID VBA code

PRID number is a critical number for the well working of the database. So, it is more reliable if this field is automatically generated. The following VBA code set this number.

Explanations of the code:

```
Dim a As Integer            // Definition of “a” as an integer

Private Sub Form_Load()  // On loading the “AddProcess1” form, run the following code

   DoCmd.OpenTable ("FTprocess1")              // Open the “FTprocess1” table

   a = DMax("[PRID]", "FTprocess1")            // set “a” as the maximum of existing PRID

   DoCmd.Close acTable, "FTprocess1"      // Close the “FTprocess1” table

   [PRID] = a + 1 // In the new record (the current one), PRID=a+1 (the maximum already existing + 1)

End Sub // End of code
```

Appendix 7.4.3: “Details” button

This button is used to define the number of machine of this process will work in the model. It runs, sequentially, two macros:

- On Mouse Down, “BeforeAddOperations” macro runs, and after
- On Click, “OpenOperations” macro runs.

“BeforeAddOperations” macro:

This macro just runs VBA code: RunCode (SaveAddProceesBeforeAddOperations( ))

VBA code:

```
Function SaveAddProceesBeforeAddOperations()     // Beginning of the function


On Error GoTo SaveAddProceesBeforeAddOperations_Err     //If an error appears, go to the “error” code.

        DoCmd.RunCommand acCmdSaveRecord   //Save the current record.

SaveAddProceesBeforeAddOperations_Exit:                    //Exit code

        Exit Function               //Exit the function

SaveAddProceesBeforeAddOperations_Err:           //Error code

        MsgBox Error$//Display a message explaining corresponding to the appeared error

        Resume SaveAddProceesBeforeAddOperations_Exit            //Go to the exit code.


End Function            // End of code
```

“OpenOperations” macro:

1. Open the form “AddOperations”, with the condition:

   “AddOperations” **OpNum** = “AddProcess1” **OpNum**

2. Maximize “AddOperations” form.

Appendix 7.4.4: Add Operations form

This forms aims to create one or several machines of a same new process. Those machines could have been created manually but it is more safe if is automatic: mistakes might be avoided. On loading, the following code runs.

```
Dim Step As Integer              //Definition of “Step” as an integer
Dim ind As Integer               //Definition of “ind” as an integer
Private Sub Form_Load()  // Beginning of the code


  Step = 0             //Initial value for “Step”
  ind = 1              //Initial value for “ind”
  Step = Data.Value    //In the form, “Data” field stores the number of machines to create!
  Do    //Beginning of a loop
    DoCmd.GoToRecord , "", acNewRec   //Go to the new record.
    Forms![AddOperations]![Index] = ind  //In this record, set: “index”=“ind”, incremental.
    Step = Step – 1      //decrement the remaining steps.
    ind = ind + 1//Increment the index.
  Loop Until (Step = 0)  //Stop when “Step”=0, it means when all machines had been created.


  Form.AllowAdditions = False                         //Forbid to add machines now.
  Forms("AddProcess1").MaxWait.SetFocus               //Set focus in “MaxWait” field.
  Forms("AddProcess1").Details.Visible = False    //Hide the “Details button” to avoid to create machines
twice.
End Sub //End of code
```

Appendix 7.4.5: Edit Operations form

This form enables to modify the number of machines in the model and its properties. The value "NumberInModel" must corresponds to the number of machines (or records), that why the definition (creation or deletion of machines) is automatic.

```
Dim Step As Integer             //Definition of "Step" as an integer
Dim ind As Integer              //Definition of "ind" as an integer
Dim del As Integer              //Definition of "del" as an integer
Dim las As Integer              //Definition of "las" as an integer
Dim val As String               //Definition of "val" as an integer
Private Sub Form_Load() //On load, run this code.
   Step = 0                            //Initialize value of "Step"
  Step = Data.Value                    //Store in step the value of "Data" (=NumberInModel")
  DoCmd.GoToRecord , "", acLast//Go to last record
  las = [Index]                        //Store in "las" the value of the index of the last step
    If Step = [Index] Then             //If it doesn't need to add or delete machines
                                       //DO NOT DO ANYTHING!
  Else                                 //Else
    If Step > [Index] Then             //if it needs to add one or several machines
      ind = las + 1                    //calculate the value of the next index
      Step = Step – las        //decrement the number of records to add
      Do                               //for each machine to add
        DoCmd.GoToRecord , "", acNewRec              //Go to the new record
        Forms![EditOperations]![Index] = ind       //Write the index of the new record
        Step = Step – 1        //decrement the number record to create
        ind = ind + 1                  //increment the index
      Loop Until (Step = 0)            //stop when all record are created
    Else                               //Else (last case)
      If Step < [Index] Then           //if it needs to delete one or several machines
        del = las – Step       //calculate the number of record to delete
        DoCmd.RunMacro ("DeleteRecors during Edit Operations") //Run the macro "DeleteRecors
during EditOperations".
        Do             //Beginning of the loop
```

```
          DoCmd.GoToRecord , "", acLast          //Go to last record
          DoCmd.RunCommand acCmdDeleteRecord              //Delete this record
          del = del – 1                     //decrement the number of records to delete
        Loop Until (del = 0)                       //End when records are deleted
        DoCmd.Close acTable, "FTOperations", acSaveYes //save the table
      Else                  //this case must not appear but, in case of next message will be displayed
        MsgBox ("Error: case does't exist")
      End If
    End If
  End If
  [Dedicated].SetFocus              //set focus to "dedicated" field
  [Index].Enabled = False           //disable access to the "index" field
  Form.AllowAdditions = False                //Forbid to add machines
  Form.AllowDeletions = False                //Forbid to delete machines
End Sub                             //end of code
```

Appendix 7.4.6: Flow form, Up and Down buttons

These two buttons have to move up or down the process in the gear or shaft flow. VBA code has also been used to reassure the adding of processes in the flow and take care of the index number by deleting a process in the flow.

```
Dim temp1 As String                        //Definition of "temp1" as a string
Dim temp2 As String                        //Definition of "temp2" as a string
Private Sub Command10_Click()   //Beginning of moving DOWN code: swap OpNum between current and
next records
On Error GoTo Err_Command11_Click       //on error go to error code
  temp1 = Forms![Flow]![OpNum]//write the OpNum of the current record in temp1
  DoCmd.GoToRecord , "", acNext          //go to next record
  temp2 = Forms![Flow]![OpNum]// write the OpNum of the current record in temp2
  Forms![Flow]![OpNum] = temp1//write temp1 in the current record, in the OpNum
  DoCmd.GoToRecord , "", acPrevious      //go to previous record
  Forms![Flow]![OpNum] = temp2//write temp2 in the current record, in the OpNum
  DoCmd.GoToRecord , "", acNext          //go to next record
  DoCmd.RunCommand acCmdSelectRecord          //Select this record
```

```
Exit_Command11_Click: //exit code
  Exit Sub                    //exit the function
  Err_Command11_Click:                                //error code
  MsgBox ("This action is prohibited")    //Message to display if selected record is the first or the last one.
  Resume Exit_Command11_Click                  //go to exit code
  End Sub      //end of function
Private Sub Command9_Click()   //Beginning of moving UP code: swap OpNum between current and
previous records
On Error GoTo Err_Command11_Click     //on error go to error code
    temp1 = Forms![Flow]![OpNum]      //write the OpNum of the current record in temp1
  DoCmd.GoToRecord , "", acPrevious     //go to previous record
  temp2 = Forms![Flow]![OpNum]// write the OpNum of the current record in temp2
  Forms![Flow]![OpNum] = temp1//write temp1 in the current record, in the OpNum
  DoCmd.GoToRecord , "", acNext         //go to next record
  Forms![Flow]![OpNum] = temp2//write temp2 in the current record, in the OpNum
  DoCmd.GoToRecord , "", acPrevious     //go to next record
  DoCmd.RunCommand acCmdSelectRecord         //Select this record
Exit_Command11_Click: //exit code
  Exit Sub                    //exit the function
 Err_Command11_Click:                          //error code
  MsgBox ("This action is prohibited")    //Message to display if selected record is the first or the last one.
  Resume Exit_Command11_Click                  //go to exit code
  End Sub      //end of function
Private Sub Form_AfterDelConfirm(status As Integer)        //Beginning of the function, called by deleting
a record in the flow table.
Dim i As Integer          //Definition of "i" as an integer
Dim fin As Integer                  //Definition of "fin" as an integer
i = 1                               //initializes i
If status = 0 Then                  //if deletion is confirmed
  DoCmd.GoToRecord , "", acLast//Go to last record
  fin = Forms![Flow]![Step]             //Memorise in "fin" the value of the step
  DoCmd.GoToRecord , "", acFirst        //Go to first record
```

```
    Do                                  //Beginning of a loop
      Forms![Flow]![Step] = i           //increment the step, beginning by i=1
      i = i + 1                         //increment i
      If i <> fin Then                  //if next record is not the last one
        DoCmd.GoToRecord , "", acNext   //Go to next record
      End If                            //end of condition
    Loop Until (i = fin)                //end of loop if current record is the last one
    MsgBox ("Deleted")                  //display a message to confirm the deletion
  Else                                  //else (if deletion is not confirmed)
    MsgBox ("No deleted")        //display a message to confirm the no deletion
  End If                                // end of else
  End Sub                        //end of deletion code
```

When users add a process to the flow, it is better if the "step" is written automatically to avoid problems:

```
Private Sub Step_GotFocus()             //Beginning of the function, called when the "step" focus gets
the focus.
  On Error GoTo Err_Command11_Click            //on error go to error code
  DoCmd.RunCommand acCmdSelectRecord           //Select the current record
  DoCmd.GoToRecord , "", acPrevious            //Go to previous record
  temp1 = Forms![Flow]![Step]                  //memorise in temp1 the value of step.
  DoCmd.GoToRecord , "", acNext                //Go to next record
  Forms![Flow]![Step] = temp1 + 1              //Write the right value of step
Exit_Command11_Click:  //exit code
  Exit Sub                       //exit the function
Err_Command11_Click:                           //error code
    Resume Exit_Command11_Click                //go to exit code
End Sub //end of function
```

Appendix 7.4.7: PID VBA code

PID number is a critical number, as the PRID, for the well working of the database. So, it is more reliable if this field is automatically generated. The following VBA code set this number.

```
Dim a As Integer            // Definition of "a" as an integer
Private Sub Form_Load()  // On loading the "AddProduct1" form, run the following code
```

```
  DoCmd.OpenTable ("FTproduct")                // Open the "FTproduct" table
  a = DMax("[PID]", "FTproduct")          // set "a" as the maximum of existing PID
  DoCmd.Close acTable, "FTproduct"             // Close the "FTprocess1" table
  DoCmd.SelectObject acForm, "AddProduct1"     //Select the form
  DoCmd.GoToRecord , "", acNewRec              //Go to new record
  [PID] = a + 1                                //Set the right PID field
End Sub          // End of code
```

Appendix 7.4.8: AddProduct2 VBA code

By editing the route of a product, users can choose if the product, for a specific process, go through a specific or any machine of this process. "Status3 field gives this choice:

- Status = -1 : the product can go through any machine of the process
- Status = an integer N: the product go through the machine of this process which "index" = N.

But, for each step of the product, the "step" choice list is different, due to the particularities of each process (machines opened of dedicated). This choice list is based on a query source, and, for each step, this query must pick-up the value of "step". Using directly the value of "step" in the query, it didn't work because the query can't read in a specific record of Subform. So, when "status" field gets the focus, the value of "step" is stored is a hidden filed of the form ("val2") and the query read this value.

Corresponding VBA code:

```
Private Sub Status_GotFocus()            // When "status" gets focus, run this code
  Form.Refresh                           // Refresh the form
  Forms![AddProduct2]![val2] = Step              // Store the value of "step" in "val2"
End Sub                                  //End of code
```

Appendix 7.4.9: Set definition VBA code

To edit a set, users have to pick-up different products. But, a set can't contain two products with:

- the same partindex
- the same PID
- and for a given PID, the same DervID.

It needs to use VBA code to limit the choice lists at right choices. So, values of "PartIndex" and "PID" have to be stored in temporarys' fields (same methods as in previous appendix).

Corresponding VBA code:

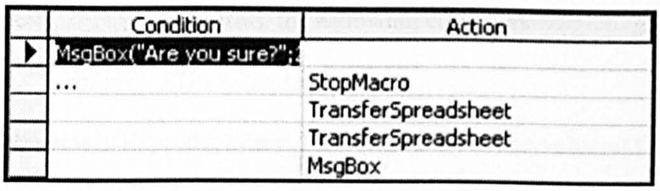
```
Private Sub PartIndex_LostFocus() // When "PartIndex" lost focus, run this code
        Forms![Set]![TempPartIndex] = PartIndex // Store the value of "PartIndex" in "TempPartIndex"
        DoCmd.RunCommand acCmdRefreshPage // Refresh the form
End Sub         //End of code
Private Sub PID_GotFocus()        // When "PID" gets focus, run this code
        DoCmd.RunCommand acCmdRefreshPage            // Refresh the form
End Sub         //End of code
Private Sub PID_LostFocus()                         // When "PID" lost focus, run this code
        Forms![Set]![TempPID] = PID                 //Store the value of "PID" in "TempPID"
        DoCmd.RunCommand acCmdRefreshPage            // Refresh the form
End Sub                                 //End of code
Private Sub DervID_GotFocus()     // When "DervID" gets focus, run this code
        DoCmd.RunCommand acCmdRefreshPage            // Refresh the form
End Sub                       //End of code
Private Sub DervID_LostFocus()    // When "DervID" lost focus, run this code
        DoCmd.RunCommand acCmdRefreshPage            // Refresh the form
End Sub         //End of code
```

"TempPartIndex" and "TempPID" are used in queries to display choice lists.

Appendix 7.4.10: Exportation code

Exporting data in Excel Spreadsheets requires a specific macro code. All used macros are built on the same frame:

1. A message asks the user to confirm the exportation (Yes or No)
2. If No, the macro stops
3. If yes, spreadsheets are exported to the specific path
4. A message confirms the transfer.



Condition	Action
MsgBox("Are you sure?";	
...	StopMacro
	TransferSpreadsheet
	TransferSpreadsheet
	MsgBox

Example of exporting macro

The following code line has to be explained:

MsgBox("Are you sure?";273;"Exporting Data")<>1

"Are you sure?": text displayed

273: this code means that "Ok" And "Cancel" buttons appear in the message box.

"Exporting Data": Caption of the message box

<>1: This is the condition, it means:

- If "Ok" is not pressed, stop the macro
- Else: execute the following code lines.

Appendix 7.4.11: "Form To Rename" VBA code

The following VBA code automatically generates the "rename" field of the table "FTproduct/derv", for each existing product. This code runs before exporting data, to be sure than the order of products will be right in spreadsheets.

This is the frame of the following code:

- Overwrite each "rename" field with big numbers to be sure not to create duplicated values.
- Set "rename" field of each record with automatically 3 numbers:
    - "1" becomes "001"
    - "13" becomes "013"

Comment: if more than 99 different products exist, this code will not work anymore. A condition will have to be modified.

```
Dim a As Integer          // Definition of "a" as an integer
Dim b As Integer          // Definition of "b" as an integer
Dim fin As Integer                    // Definition of "fin" as an integer
Dim id As String          // Definition of "id" as a string
```

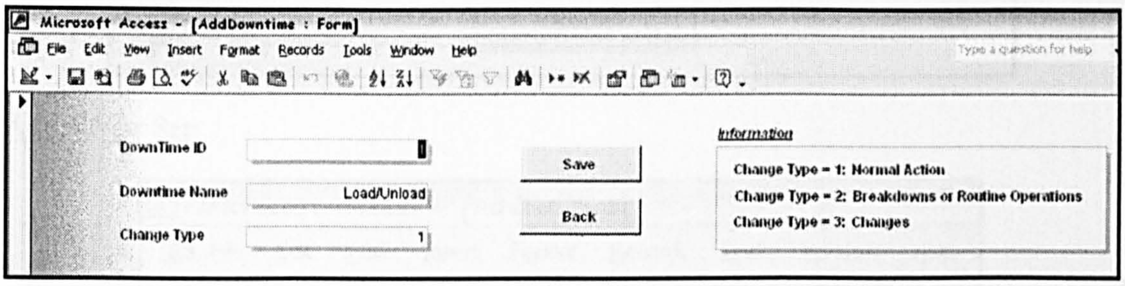
```
Private Sub Form_Load()          //On load, the following code runs

DoCmd.GoToRecord , "", acLast    //Go to the last record

a = Forms![Form To Rename]![FTproduct/derv_PID]//Store in "a" the value of the PID

b = Forms![Form To Rename]![DervID]              //Store in "b" the value of the DervID

DoCmd.GoToRecord , "", acFirst   //Go to the first record

id = 10000         //initialize "id" to 10000

fin = 0            //initialize "fin"

Do                 //beginning loop

  Forms![Form To Rename]![Rename] = id //Rename = 10000, to be sure not to create a duplicate
record

  id = id + 1      //increment "id"

If (Forms![Form To Rename]![FTproduct/derv_PID] = a And Forms![Form To Rename]![DervID] = b)

Then     //if all "rename" fields had been overwritten

  fin = 1                        //set "fin" to 1

Else                             //Else

    DoCmd.GoToRecord , "", acNext      //Go to the next record

End If                           //End of if

Loop Until (fin = 1)             //End of loop if "fin"=1

DoCmd.GoToRecord , "", acFirst   //Go to the first record

fin = 0            //reinitialize "fin"

id = 0             //reinitialize "id"

Do                 //beginning of the loop

  id = id + 1      //increment "id"

  If id < 10 Then //for the 9 first records

    Forms![Form To Rename]![Rename] = "00" + id          //Add two 0 before these number

  Else                 //Else

    Forms![Form To Rename]![Rename] = "0" + id  //Add one 0 before these number

  End If           //End of if

    If (Forms![Form To Rename]![FTproduct/derv_PID] = a And Forms![Form To Rename]![DervID]
= b) Then          //If the current record is the last one

    fin = 1                      //Set "fin" to 1

  Else                           //Else
```

```
        DoCmd.GoToRecord , "", acNext         // Go to the next record
      End If                  //End of if
  Loop Until (fin = 1)               //End of loop
  End Sub                 //End of code
```

Appendix 7.5: Secondary forms

This appendix resumes all the “secondary” forms used in the database.

<u>**Add a New Downtime**</u>:

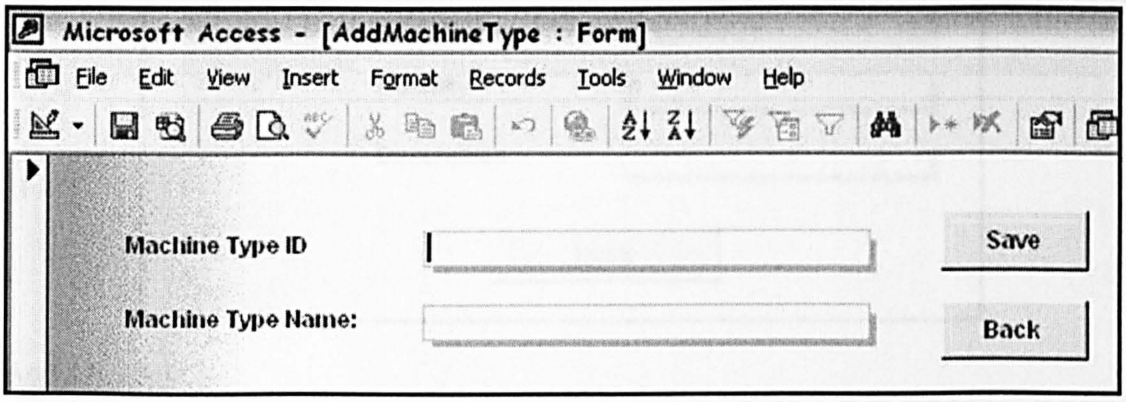


DownTime ID
Downtime Name: Load/Unload
Change Type: 1

Information

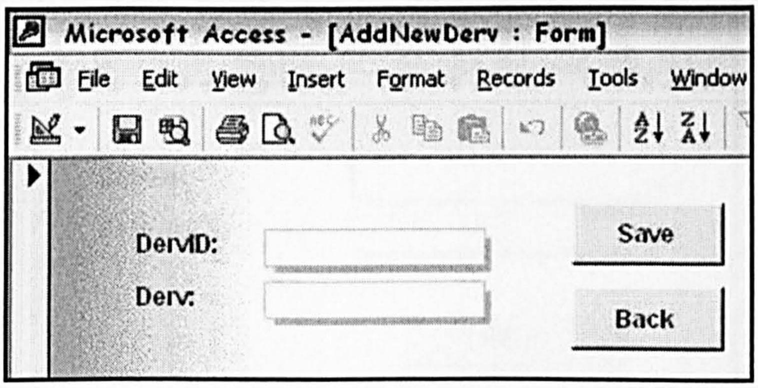
Change Type = 1: Normal Action
Change Type = 2: Breakdowns or Routine Operations
Change Type = 3: Changes

<u>**Add a New Machine Type**</u>:



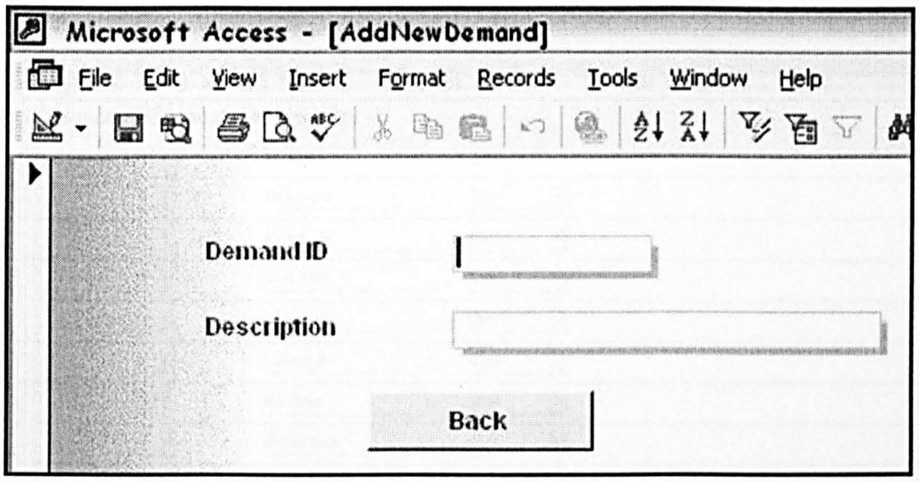
Machine Type ID
Machine Type Name:

<u>**Add a Derivative**</u>:

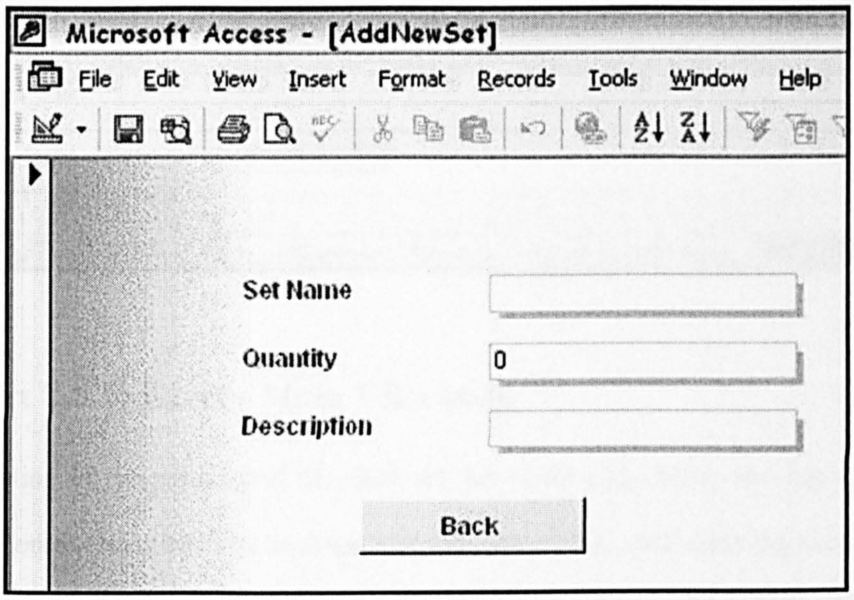


DervID:
Derv:

Add a New Demand:

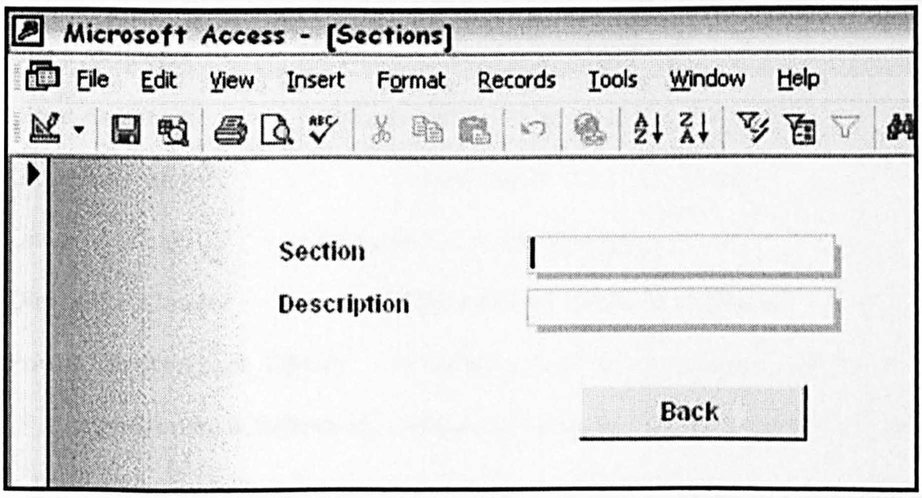


Add a New Set:

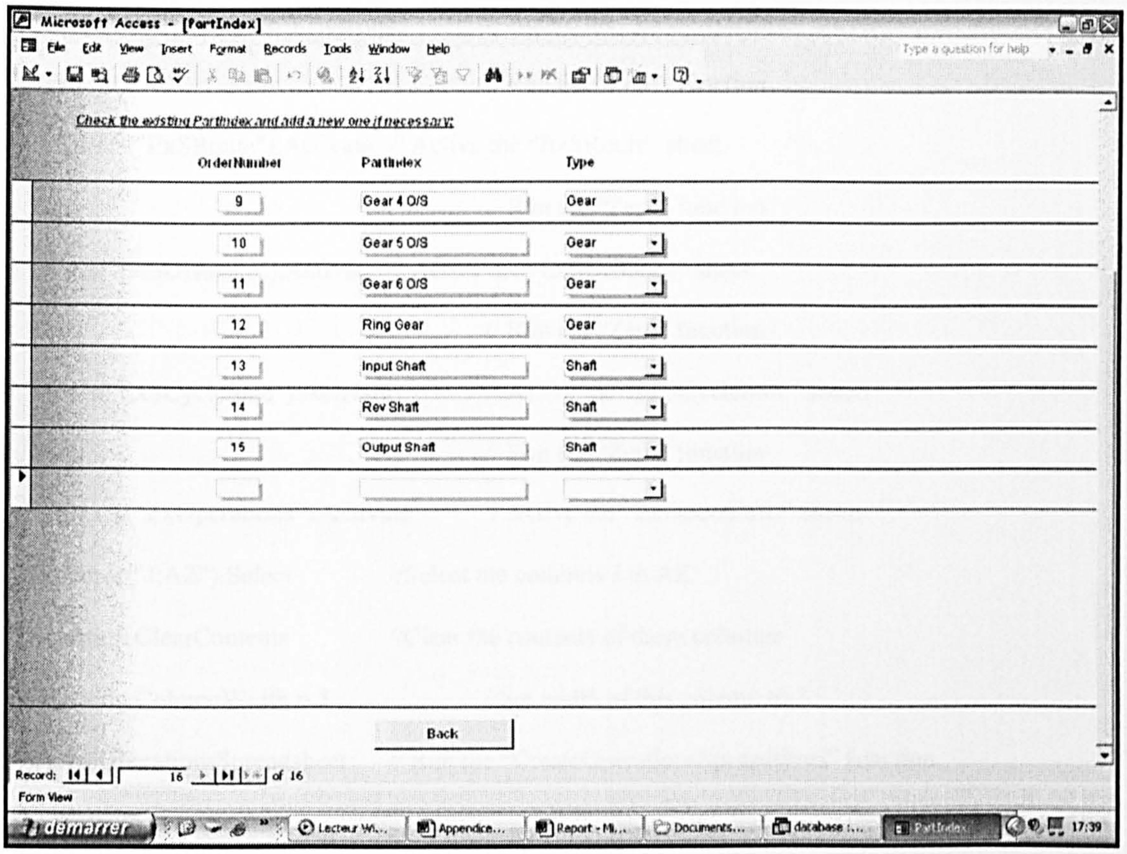


Quantity 0

Add a Section:



Add a PartIndex:



Check the existing PartIndex and add a new one if necessary:

OrderNumber	PartIndex	Type
9	Gear 4 O/S	Gear
10	Gear 5 O/S	Gear
11	Gear 6 O/S	Gear
12	Ring Gear	Gear
13	Input Shaft	Shaft
14	Rev Shaft	Shaft
15	Output Shaft	Shaft

Appendix 7.6.1: Excel - Main VBA code

At the opening of the main excel file, data are not in the right form, and can't be read by Witness. Modifications have to be done; the following VBA code does the necessary work when opening the file.

Function called form this code is explained in next appendices.

```
Dim s As Integer              // Definition of "s" as an integer
Dim a As Integer              // Definition of "a" as an integer
Dim val As Integer                   // Definition of "val" as an integer
Dim z As Integer              // Definition of "z" as an integer
Dim head As Integer                  // Definition of "head" as an integer
Private Sub Workbook_Open()          //Following code runs when opening the file.
    ActiveWorkbook.RefreshAll  // Data come from external files, they have to be refresh.
  Sheets("ExGRoute").Activate        // Active the "ExGRoute" sheet.
  Zero                                       // Run the "Zero" function
  Sheets("ExGDistance").Activate // Active the "ExGDistance" sheet.
```

```
Zero                                   // Run the “Zero” function
Sheets("ExGCycletime").Activate        // Active the “ExGCycletime” sheet.
Zero                                   // Run the “Zero” function
 Sheets("ExSRoute").Activate // Active the “ExSRoute” sheet.
Zero                                   // Run the “Zero” function
Sheets("ExSDistance").Activate // Active the “ExSDistance” sheet.
Zero                                   // Run the “Zero” function
Sheets("ExSCycletime").Activate        // Active the “ExSCycletime” sheet.
Zero                                   // Run the “Zero” function
 Sheets("ExOperations").Activate       // Active the “ExOperations” sheet.
Columns("J:AZ").Select            //Select the columns J to AZ
Selection.ClearContents           //Clear the contents of these columns
Selection.ColumnWidth = 3              //Set width of this column to 3
CreateOperationsSpreadsheet     // Run the “CreateOperationsSpreadsheet” function

Sheets("ExOperations2").Activate       // Active the “ExOperations2” sheet.
Columns("J:AZ").Select            //Select the columns J to AZ
Selection.ClearContents           //Clear the contents of these columns
Selection.ColumnWidth = 3              //Set width of this column to 3
IMT                                    // Run the “IMT” function
Createoperations2                      // Run the “CreateOperations2” function
 Sheets("ExDemand").Activate // Active the “ExDemand” sheet.
s = 2                                  //Initialize “s”
Columns("F:F").Select             //Select the column F
Selection.ClearContents           //Clear the contents of this column
Cells(1, 6).Value = "Total Demand"     //Write “Total Demand" in cell (1,6)
Do                                     //Loop
 Cells(s, 6).Value = Cells(s, 4).Value * Cells(s, 5).Value//In column 6, write the result of the
operation (column 4)*(column5)
 s = s + 1 //Increment the line
Loop Until (Cells(s, 1).Value = "")    //Do it till the table is finished
```

```
    Sheets("ExDowntime").Activate // Active the "ExDowntime" sheet.
    Cells.Select                                  //Select all cells
    Selection.ClearContents             //Delete all cells
    DT                                            // Run the "DT" function
    ZeroDowntime                                  // Run the "ZeroDowntime" function
       Sheets("ExGRoute").Activate // Active the "ExGRoute" sheet.
    Cells(1, 1).Select                            //Select the first cell.
End Sub                              //End of code
```

Appendix 7.6.2: Excel – "Zero" function

Imported files do contain all needed data, but cells without data are blanks, so it needs to fill in these cells by 0.

```
Dim r As Integer // Definition of "r" as an integer (row)
Dim c As Integer // Definition of "s" as an integer (column)
Sub Zero()                  //Zero function
r = 2                       //Initialize "r"
c = 3                       //Initialize "c"
Do                          //First loop: column by column
  Do                        //Second loop: row by row
    If Cells(r, c).Value = "" Then  //If the cell is empty
    Cells(r, c).Value = 0           //Fill it with a 0
    End If                                  //End of if
    r = r + 1                               //Go to next row
  Loop Until (Cells(r, 1).Value = "")       //End of second loop if next row is empty
  r = 2                                     //Come back to the beginning of the rows
  c = c + 1                                 //Go to next column
Loop Until (Cells(1, c).Value = "") //End of first loop if next column is empty
End Sub           //End of code
```

Appendix 7.6.3: Excel – "ZeroDowntime" function

The "Downtime" spreadsheet must also be filling in with zeros. But the design of this sheet is different, so it needs a specific code.

```
Sub ZeroDowntime()        //”ZeroDowntime” function
r = 5                     //Initialize “r”
c = 2                     //Initialize “c”
Do                        //First loop: column by column
  Do                      //Second loop: row by row
    If Cells(r, c).Value = "" Then  //If the cell is empty
      Cells(r, c).Value = 0            //Fill in it with a 0
    End If                             //End of if
    r = r + 1                          //Go to next row
  Loop Until (Cells(r, 1).Value = "")  //End of loop when next row is empty
  r = 5                                //Come back to the beginning
  c = c + 1                            //Go to next column
Loop Until (Cells(4, c).Value = "") //End of loop when next column is empty
End Sub                   //End of code
```

Appendix 7.6.4: Excel – Operations functions

The “ExOperations” and “ExOperations2” need to be built with excel VBA.

```
Dim a As Integer          // Definition of “a” as an integer
Dim b As Integer          // Definition of “b” as an integer
Dim find As Integer               // Definition of “find” as an integer
Dim dedi As Integer               // Definition of “dedi” as an integer
Dim writ As Integer               // Definition of “writ” as an integer
Dim op As String          // Definition of “op” as a string
Dim c As Integer          // Definition of “c” as an integer
Dim name As String                // Definition of “name” as a string
Sub CreateOperationsSpreadsheet()// This function builds the “ExOperations” spreadsheet.
a = 2                     // Initialize a
dedi = 10                 // Initialize dedi
writ = 1                  // Initialize writ
Do                        // Loop 1: sort all operations of “OperationsDetails”
   op = Sheets("OperationsDetails").Cells(a, 1).Value        //Store the opNum of the first operation.
  If Sheets("OperationsDetails").Cells(a, 3).Text = "FALSE" Then     //If the machine is not dedicated
```

```
    c = 0          //False = O
  Else             //Else
    c = 1          //True=1 (machine dedicated)
  End If//End of if
    find = 0       //Initialize "find"
  b = 2            //Initialize "b"
  Do               //Loop 2: search the corresponding OpNum in the "ExOperations" sheet.
      If Sheets("ExOperations").Cells(b, 7).Value = op Then //If the row "b" correpons to this
proccess
      find = 1               //The process had been found
      Sheets("ExOperations").Cells(1, dedi).Value = writ     //Write the heading of the column
      Sheets("ExOperations").Cells(b, dedi) = c     //Write if the machine is dedicated or not
    Else                     //Else
      b = b + 1  //Increment "b"
    End If                   //End of if
   Loop Until (find = 1 Or Sheets("ExOperations").Cells(b, 7).Value = "")     //Do it until the
corresponding process had been found or the list totally scanned.
  a = a + 1                  //Increment "a": go to next line in "OperationsDetails" sheet
  If op = Sheets("OperationsDetails").Cells(a, 1).Value Then  //If next operation is the same process
    dedi = dedi + 1          //Increment the column of dedicated machines
    writ = writ + 1          //Increment value of heading
  Else                       //Else
    dedi = 10                //Go to the first "dedicated" column
    writ = 1                 //Reinitialize the heading value
  End If         //End of if
  Loop Until (Sheets("OperationsDetails").Cells(a, 1).Value = "")     //Do it until the list of machines
in "OperationsDetails" had been scanned
Sheets("ExOperations").Activate    //Activate the "ExOperations" spreadsheet.
End Sub                          //End of this function
Sub Createoperations2()   // This function builds the "ExOperations2" spreadsheet.
a = 2            //Initialize "a"
dedi = 10        //Initialize "dedi"
```

```
writ = 1      //Initialize "writ"

Do            //Loop1: Scan the list of machines in "OperationsDetails" spreadsheet

  op = Sheets("OperationsDetails").Cells(a, 1).Value //Store the opNum of the first operation.

  name = Sheets("OperationsDetails").Cells(a, 4).Text        //Store the "Operator" of the first
operation.

  find = 0      //Initialize "find"

  b = 2         // Initialize "b"

  Do            //Loop 2: find the process in the "ExOperations2" sheet

    If Sheets("ExOperations2").Cells(b, 7).Value = op Then  //Scan the "ExOperations2" list to find
the corresponding process.

        find = 1              //Find = 1 when the process had been found

        Sheets("ExOperations2").Cells(1, dedi).Value = writ  //Write the heading

        Sheets("ExOperations2").Cells(b, dedi).Value = name  //Write the "Operator" in the
corresponding row

    Else                  //Else

        b = b + 1  //Increment the row number

    End If                //End of if

  Loop Until (find = 1 Or Sheets("ExOperations").Cells(b, 7).Value = "")        //Go out the loop
when all processes had been scanned or if the process had been found

  a = a + 1      //Increment the row in "OperationsDetails" sheet

  If op = Sheets("OperationsDetails").Cells(a, 1).Value Then  //If next process in the same than the
previous one.

    dedi = dedi + 1       //Increment "Operator" column in "ExOperations2"

    writ = writ + 1       //Increment the heading value

  Else                    //Else

    dedi = 10             //Come back to the first column of "Operator" in "ExOperations2"

    writ = 1              //Reinitialize the heading

  End If         //End of if

Loop Until (Sheets("OperationsDetails").Cells(a, 1).Value = "")               //Go out the list when
all process had been sorted

Sheets("ExOperations2").Activate  //Activate this sheet

End Sub          //End of code
```

Appendix 7.6.5: Excel – Build Downtime Spreadsheet

The “Downtime” spreadsheet cannot be exported directly from MS Access in the right design.

So, it needs to be built in Excel, with VBA code.

```
Dim findID As Integer                // Definition of “findID” as an integer

Dim current As Integer   // Definition of “current” as an integer

Dim ID As Integer                    // Definition of “ID” as an integer

Dim head As Integer                  // Definition of “head” as an integer

Dim col As Integer                   // Definition of “col” as an integer

Dim prid As Integer                  // Definition of “prid” as an integer

Sub DT()                             //DT: function sort the data of “DowntimeDatas” in “ExDowntime”

  ‘***** Design of the sheets                    //Build the table (headings)

  Sheets("ExDowntime").Activate //Activate the “ExDowntime” sheet

  Sheets("ExDowntime").Cells(4, 1) = "PRID"                    //Write “PRID” in cell 4,1

  Sheets("ExDowntime").Cells(2, 1) = "ID"             // Write “ID” in cell 2,1

  Sheets("ExDowntime").Cells(1, 1) = "Downtime"  // Write “Downtime” in cell 1,1

  findID = 1                                   //Initialize “findID”

  current = 2                                  //Initialize “current”

  ID = 1                                       //Initialize “ID”

  head = 2                                     //Initialize “head”

  Do     //Loop A: Scan all downtimes of “DowntimeDatas” sheet and write it in “ExDowntime” sheet.

  If Sheets("DowntimeDatas").Cells(current, 2).Value = ID Then        //Check the existing

DowntimeID to build the table

    ID = ID + 1  //Increment the ID value

    Sheets("ExDowntime").Cells(1, head) = Sheets("DowntimeDatas").Cells(current, 3).Value

//Report the downtime name in “ExDowntime”

    Sheets("ExDowntime").Cells(3, head) = Sheets("DowntimeDatas").Cells(current, 8).Value

//Report the change type in “ExDowntime”

    Sheets("ExDowntime").Cells(2, head) = Sheets("DowntimeDatas").Cells(current, 2).Value

//Report the ID in “ExDowntime”

    Sheets("ExDowntime").Cells(4, head) = "T"       //Create the heading “T”

    Sheets("ExDowntime").Cells(4, head + 1) = "F" //Create the heading “F”

    Sheets("ExDowntime").Cells(4, head + 2) = "LR"          //Create the heading “LR”
```

```
    Sheets("ExDowntime").Cells(4, head + 3) = "LT"          //Create the heading "LT"
    head = head + 4          //Increment the heading columns
  End If//End of if
  current = current + 1     //Increment the row in "DowntimeDatas")
  Loop While (Sheets("DowntimeDatas").Cells(current, 2).Value <> "")          //End of loop A.
   '***** Fill in the table  //The table is now built, it needs to fill it in.
current = 2        //Read another time the sheets to build the table
head = 5           //Place the focus to the first cell to fill in
  Do    //Loop 1: scan the whole "DowntimeDatas" sheet
    Sheets("ExDowntime").Cells(head, 1) = Sheets("DowntimeDatas").Cells(current, 1).Value
        //Write in "ExDowntime" the value of the first PRID
    col = 2        //Initialize "col"
    Do //Loop 2: fill in the downtimes for each PRID
      If Sheets("DowntimeDatas").Cells(current, 3) = Sheets("ExDowntime").Cells(1, col) Then //search the right place to copy the data
        Sheets("ExDowntime").Cells(head, col) = Sheets("DowntimeDatas").Cells(current, 4)
       //Copy the value of "time" in "ExDowntime"
        Sheets("ExDowntime").Cells(head, col + 1) = Sheets("DowntimeDatas").Cells(current, 5)
       //Copy the value of "freq" in "ExDowntime"
        Sheets("ExDowntime").Cells(head, col + 2) = Sheets("DowntimeDatas").Cells(current, 6)
       //Copy the value of "LabourRequirement" in "ExDowntime"
        Sheets("ExDowntime").Cells(head, col + 3) = Sheets("DowntimeDatas").Cells(current, 7)
       //Copy the value of "LabourType" in "ExDowntime"
        col = 0//col = 0 means that the current downtime had been copied in "ExDowntime" sheet.
      Else       //Else
        col = col + 4     //Go to the next Downtime in "ExDowntime"
      End If              //End of if
    Loop Until (col = 0)  //Go out when the current downtime had been copied (col=0)
    If Sheets("ExDowntime").Cells(head, 1) <> Sheets("DowntimeDatas").Cells(current + 1, 1)Then        //If the next PRID is the different than the current one
      head = head + 1              //Increment "head"
    End If                         //End of if
```

```
      current = current + 1  //Increment “current”
   Loop While (Sheets("DowntimeDatas").Cells(current, 2).Value <> "")                    //Go out when the whole
list had been scanned and sorted in “ExDowntime”
   End Sub          //End of code
```