THE UNIVERSITY OF HULL

Optimisation of manufacturing systems for plastic moulded products in the automotive industry

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Abstract

This thesis presents a study of process planning instabilities and inefficiencies within a plastic component manufacturing company. The company was increasingly pressurised by high customer expectations and competition from the global market. A series of tools were used to highlight some of the prominent issues within the organisation. To improve on production efficiencies several lean manufacturing tools such as Value Stream Maps, Production Flow Analysis and Systems Thinking were applied. This thesis proposes a methodology for processing product lines within a supplier in the off-highway and niche vehicle industry and focuses upon categorising product lines depending upon their ranking of volume and value. The methodology presents a logical procedure for categorising parts into five "broad categories" analogous to the classical ABC stock control theory. On completion of the categorisation process, product lines are processed by a set of practical rules within the context of an "expert system". These rules have been devised by using multi-criteria ABC analysis and further applied to process the product lines throughout the manufacturing system. These rules are based on product line activity and they are defined in order to maintain minimum inventory levels as well as ensure the stable implementation of the factory production plan (smoothed over the production period), to also achieve a low throughput time and increase delivery performance, all with the goal of 100% on-time delivery to the customer. The analysis of sales data and high volume-to-value product lines has shown that there are five classes of product lines (A1, A2, A3, B1 & B2) which vary in their requirements for planning and operations as outlined in this paper. Evidence is presented which shows that an empirical relationship results a new "merit" parameter that can be determined by fitting a response surface to volume and value quantities and this relationship holds for a wide range of organisations. Indeed the technique can indicate which product lines are behaving in the market as expected and which are asynchronous with the market demand. The methodology was further simulated using Arena® software. The simulation study compared the models (before and after methodology implementation) and the results were analysed to assess the impact of the methodology on the production system.

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Chapter One ***Introduction***

This thesis results from work undertaken as a part of a Knowledge Transfer Partnership (KTP) project conducted with the University of Hull and Thompson Plastics (Hessle) Ltd. KTPs are one of the United Kingdom's (UK) leading programmes committed towards helping businesses excel in productivity and competitiveness through the expertise and knowledge that reside within the UK universities as well as a wide range of other associated knowledge bases. KTP's enable businesses to work with universities, colleges or research organisations that have expertise relevant to the corporation and can potentially help increase profitability. In a KTP project recent graduates (associates) with appropriate understanding in their field of expertise are employed to transfer the knowledge the company is seeking to introduce into the business. The work an associate does in the company is seen to be crucial to improve the competitiveness of the business. As described by the KTP organisation, through their website[1], the three partners (associate, knowledge base and the business) in a KTP project mutually benefit from each other as described below.

- ***Benefits to the associate****:* *KTP projects can enhance the associate's career prospects by providing them with the opportunity to manage a challenging project whilst attaining top class training in business management. Over 50% of associates register for higher degree courses and 70% are offered employment by there host company on completion of the project.*
- ***Benefits to knowledge base****: Through KTP schemes, academics are able to;*
  - *publish high quality research papers,*
  - *develop business relevant teaching materials,*
  - *contribute to the improvement in rating of their department, and*
  - *identify new research themes and new undergraduate and postgraduate projects.*
- ***Benefits for the company partner****: Project performance outcome varies from case to case. In a wide range of projects, on average;*
  - *the business can increase to over £220,000 in annual profit before tax,*
  - *further increase in the skills of existing staff, and*
  - *creation of three genuine new jobs.*

[1] www.ktponline.org.uk (date accessed 24th June 2005)

1.1. Thompson Plastics (Hessle) Ltd.

The Thompson Plastics (TP) Group is a privately owned business established in 1974, it has over 600 employees and a reputation for being an innovative organisation at the cutting edge of manufacturing. The Thompson Plastics Group is the UK's leading manufacturer of thermoformed plastic components for touring caravans, bathrooms, forklifts, agriculture vehicles and other heavy vehicles. The combined annual turnover of the group for the financial year 2003-2004 was £24 million (Thompson Plastics Group annual report). Brophy (1996) described the mission of the company as;

> *"The Thompson Plastic Groups aims are to be a world class designer and manufacturer of engineered plastic products for global speciality markets."*

The company likes to be perceived as having the ability for growth and has a keen commitment towards reinvesting profits in order to build a strong hold on the market. Recent growth has significantly excelled the group in the plastics industry to become a core 'Thermoforming' processor. Thompson Plastics group has a multi-national, multi-market operational setup and offer expertise to vehicle, touring caravan and holiday home industries where plastic engineering can revolutionise the evolution of products in these and many other market sectors. With headquarters in Hessle, Humberside, the group is divided into two main sectors;

1. Leisure Products Division
    a. Thompson Plastics (Hull) Ltd.
    b. Thompson Plastics (Manchester) Ltd.

2. Vehicle Products Division
    a. Thompson Plastics (Hessle) Ltd.
    b. Thompson Plastics (Bridgend) Ltd.
    c. Thompson Plastics (Newcastle) Ltd.

The Leisure Products Division manufactures components for holiday homes, touring caravans and bathrooms while the Vehicle Products Division, as its name suggests, manufactures components for the vehicle industry. TP (Hessle) Ltd. manufactures products for the off-highway and niche vehicle industry. The automobile industry is often perceived to be characterised by uncertainty, continuous change and innovation in technology and work practices. The company's desire is to discover innovative strategies for inventory and production management thereby improving customer service and profitability. The main processes in manufacturing at TP are Moulding (by the process of thermoforming), Trimming (using CNC machines) and Assembly. The general layout of the factory is represented in Figure 1.1. The factory has a classical functional layout with moulding machines and trimming machines grouped together in separate and specified areas. The layout of the factory along with the machines and equipment is presented in Figure 1.2.

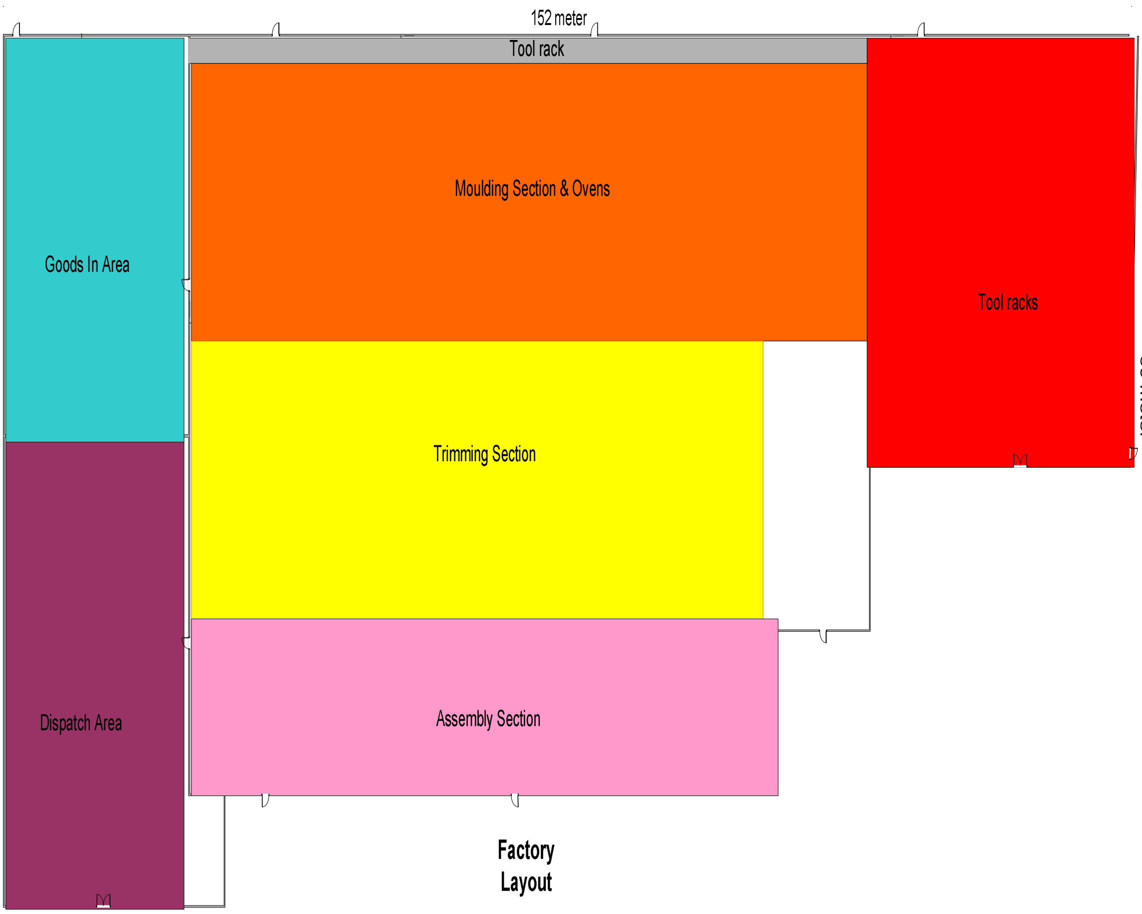


Figure 1.1 Thompson Plastics (Hessle) Ltd. - Functional layout of the factory.

LEGEND

	Tool Racks	**CNC-'X'**	Computer Numerical Control Machines	**DP'X'**	Drill Press
S	Service Table	**G'X'**	Vaccume Formed Moulding Machine	**S-H'X'**	Band Saw Horizontal
	Tool Rack	**LFPUR**	Long Fibre Polyurethane Resin Moulding Machine	**O'X'**	Drying Oven
		PU	Polyurethane	**BS-V'X'**	Band Saw Vertical

Figure 1.2 Thompson Plastics (Hessle) Ltd. - Detailed factory layout.

1.2. The Project

The project focused upon improving the efficiency of the manufacturing company by implementing the principles of lean manufacture. Although the company, Thompson Plastics (Hessle) Ltd., has modern manufacturing processes and methods, it recognised that it did not meet world-class manufacturing standards. Thompson Plastics (Hessle) Ltd. is a growing company whereby its manufacturing activities are becoming more complex and the current "system" may no longer reflect the needs of the organisation nor promote improvement thereby tolerating confusion and waste. There was, therefore, a need to work with the University to bring in new manufacturing methodologies to improve the competitiveness of the business at the start of the project.

The title of the project was: "Optimisation of manufacturing systems for plastic moulded products in the automotive industry". The aim of the project was described as the need "to optimise manufacturing/process control and improve planning systems and manufacturing efficiency in the plant." In essence, the goal of this project was to help promote leaner and system orientated manufacturing whilst continuously improve the service provided to customers. The main objectives of the project was to improve customer delivery performance whilst reducing production efficiencies

This study focuses on reviewing the manufacturing systems unique to a plastic thermoforming company, *i.e.* TP (Hessle) Ltd. The thesis is structured in seven chapters and details an approach to improving the delivery of products as well as increasing customer service by the implementation of proven techniques.

In chapter Two, it reviews the various manufacturing strategies, principles and concepts from a wide range of industries for improving performance. Chapter Three presents the characterisation of the current state of the company. It highlights the issues and concerns in the manufacturing processes and production system as to define the problem situation. Chapter Four presents and discusses multi-criteria ABC analysis which is then compared with Production Flow Analysis (PFA). These two techniques are applied to the problem situation in order to provide a solution for lean manufacturing. Chapter Five demonstrate the feasibility of the methodology on the production system using simulation tools. The methodology derived in Chapter Four is simulated and the results are analysed to understand the influence of the methodology.

Chapter Six presents the application of the methodology on various sections of the manufacturing system (planning, production, dispatch *etc.*). In particular, this chapter reveals the effect of implementing the methodology on the current production system at TP Ltd. The impact on various manufacturing sections are analysed and results are drawn from the analysis. Chapter Seven summarises and draws overall conclusions from the investigative work and also proposes areas for further study. The appendices included in the final section of the thesis contain simulation files and results in detail.

Chapter Two A Review of Lean Manufacturing Strategy

This chapter reviews the work of several researchers in the field of *Manufacturing Systems* whist describing the tools and techniques that have been successfully implemented to improve manufacturing efficiency. The chapter begins with a brief introduction of production systems, including production control philosophies, and progresses on to describe '*Manufacturing Strategy'* in addition to the importance of utilising contemporary styles as well as principles of managing production activities to succeed in the world of manufacturing. Accompanying, this is a brief discussion on the importance of Operations Management in terms of 'Old' and 'New' economies. In particular, this chapter discusses inventory in relation to stock control, stock value and stock management. The concept of seamless integration of the supply chain is also presented and discussed in some detail.

This chapter also places a strong emphasis on ABC categorisation. The concept of ABC categorisation is taken a step further when discussing the more complex Multi-Criteria ABC analysis. A case study highlighting the potential benefits associated with each analysis is presented and reviewed in detail in subsequent chapters. The principles of *Lean Manufacturing* are discussed in this chapter with special emphasis to *Group Technology (GT).* The history and evolution of GT is discussed along with the views of various researchers working in this field. The chapter further discusses the importance of customer and production schedules and ways to minimise 'schedule nervousness'. The concept of Soft System Methodology (SSM) is also introduced and the chapter finally concludes with a summary of literature presented in the field of Manufacturing.

2.1. Production Systems

Early efforts in production were exceedingly crude, the processes were laborious and the technology was basic. As production capabilities increased after harnessing mechanical power (post industrial revolution), the new relationship of man and machine highlighted the need for improved technology and management techniques. As production systems became more complex, both qualitative and quantitative modelling techniques were developed to deal with the new and more intricate relationships. Models may take the form of physical images, schematic charts or templates, or may be mathematical representations of particular situations. For example at the turn of 20th

century, scientific management *e.g.* Taylorism, focussed on man being machines with time and motion studies. However as the time progressed human relations became fundamentally more important, *e.g.* Hawthorne studies suggested that productivity increases when people spending a large amount of their time at work have a sense of belonging or feeling of being part of team.

Production is the intentional act of producing something useful *i.e.* by adding value to a tangible product. Ron (1998) defines the purpose of production, at least idealistically, as to enrich society through the production of functionally desirable, aesthetically pleasing, environmentally safe, economically affordable, highly reliable, high quality products. According to Riggs (1976), any system is a collection of interacting components with each component, in itself, possibly being a system in a descending order of simplicity.

The *Production System* can be seen as the structured process of the transformation of raw material to useful products. Essentially, the *Process* is the conversion of inputs into desired outputs by following procedural steps, as shown in Figure 2.1. In an industrial process, the inputs account for majority of the variable cost of production (Figure 2.1 b). Conversion facilities are associated with fixed cost, and the output produces the revenue. In a production system the process could be controlled potentially by inputs and outputs. Production control is managed through the interaction of feedback as illustrated in elementary form, by the diagram in Figure 2.1.

According to Riggs (1976) elementary system control consists of four main parts which can be defined as:

1. The system – this is an assembly of objects or functions united by some form of regular interaction or interdependence.
2. An Input – this consists mainly of "parameters", or those variables which can be varied at will by a controller.
3. An Output – these are other variables which can only be altered indirectly by varying the input, and are measured at convenient "measuring points" and time intervals.

4. Feedback – this is regular communication between the measuring points and the controller, giving information about deviations between actual outputs and planned output.

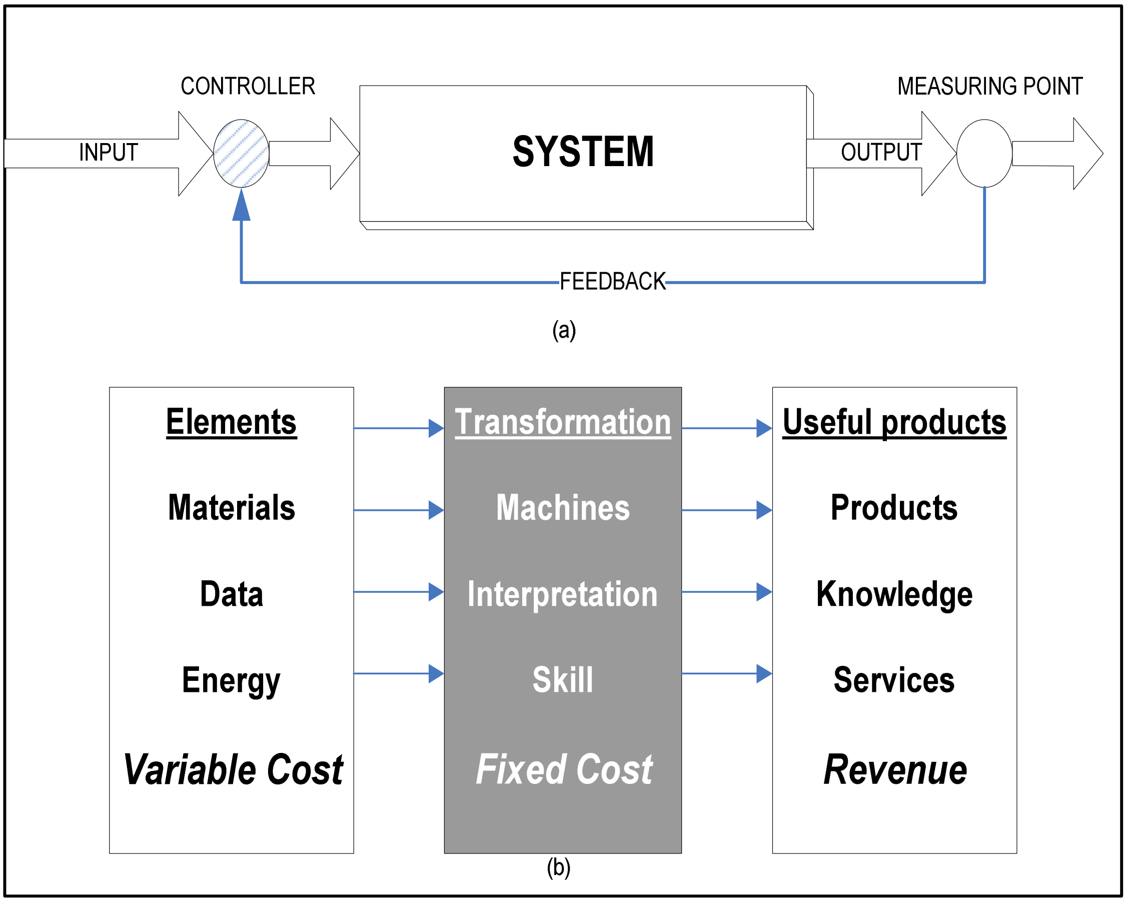


Figure 2.1 An illustration of a production system (Riggs, 1976) showing (a) a simple generic system; and (b) the inputs, transformation and outputs associated with the system.

2.2. Manufacturing Strategy

It is generally acknowledged that manufacturing strategy is essentially the build-up of a company's competitive advantage competing in today's turbulent commercial environment. According to Swamidass and Newell (1989), manufacturing strategy has been defined as the "effective use of manufacturing strengths as a competitive weapon for the achievement of business and corporate goals". Many researchers (Mohanty, 1999; Lau, 1999; Swink *et. al*. 1995) have suggested that manufacturing managers in a wide variety of industries have the same opinion that achieving low cost integrated with high quality is no longer enough to guarantee success. They only form the basic elements of survival in the business world and may not be the thriving factors. That is, in the contemporary situation of the bounded instability in the business world, it is imperative that an organisation must have an innovative manufacturing strategy. Mohanty (1999) comments on characteristics in a manufacturing strategy that are seen to be essential:

- The manufacturing strategy must support the business strategy by uniquely focusing on value-added work flows oriented towards a small set of objectives dictated by customers, competition and change;
- It should describe the allocation of resources within the manufacturing domain in a way that allows the achievement of these objectives;
- It should reflect on the patterns of actual decisions made by the company in terms of process technology, facility, system and human resources.

Miller and Hayslip (1989) have described manufacturing strategy as *"a projected pattern of manufacturing choices formulated to improve fundamental manufacturing capabilities and to support business and corporate strategy"*. However, according to Clark (1996), the creation of competitive advantage demands that strategic choices in manufacturing are integrated with the superior capacity derived from the new 'rationales'. Similarly, Voss (1995) has grouped various approaches to manufacturing strategy into three categories: competing through manufacturing, strategic choices in manufacturing strategy and best practices. He argues that none of the three strategies by itself is sufficient for effective development of a manufacturing strategy, but instead there is a logical cycle connecting all three.

Process planning is defined by the Society of Manufacturing Engineers (Alting and Zhang**,** 1989) as *"the systematic determination of the methods by which a product is to be manufactured economically and competitively"*. They propose that success for a manufacturing organisation operating under the increasing pressures of today's business climate lies in consistently meeting delivery promises to win and keep satisfied customers and in holding down capital tied up in inventory to improve the cash flow performance and reduce costs. Thus, the ability of a manufacturer to assign accurate and reliable order due dates is paramount.

Hill (1986) observed a change in the interest shown by businessmen and academics towards the subject of Operation Management (OM), he suggests companies must now be driven by the new principles of manufacturing strategy. Hill goes on to comment how general management must encourage the progression of new innovative programmes within academic circles whose goal is to further the understanding of OM techniques.

Hayes (2002) discusses the importance of OM teachings and suggests that the short term goal (over the next 5 years, for instance) should be to reallocate OM teaching and research to something like the following: 50% to traditional topics (*e.g.* process analysis and improvement, capacity measurement and management, and work planning/inventory control), with increased emphasis on service operations; 25% to project management, including new product development, designing products/systems that are easy to improve; and 25% to managing cross-company operations, including supply chains, subcontracting relationship and network collaborations.

2.3. Inventory

Successful operation of a manufacturing firm depends to a large extent on an adequate inventory balance of raw materials and components. Excessive inventory means a high amount of tied-up capital: a low inventory can result in interruptions to the production flow. Appropriate inventory levels are difficult to achieve where long lead times add to the uncertainty of demand between replenishments. It is generally accepted that in a batch manufacturing environment, the value of the batch will gradually increase as it goes into production. This increase in value is expenditure for materials and wages and this value will reach a maximum when the parts in the batch are complete. After this point, the value of the stock will decrease over a period as it is consumed, as illustrated in Figure 2.2, which gives a stock chart for a single batch, giving the values of the stock at different levels of time. This suggest if the production batch sizes are bigger than required it would affect the stock turns and maintain high values of Work In Progress (WIP).

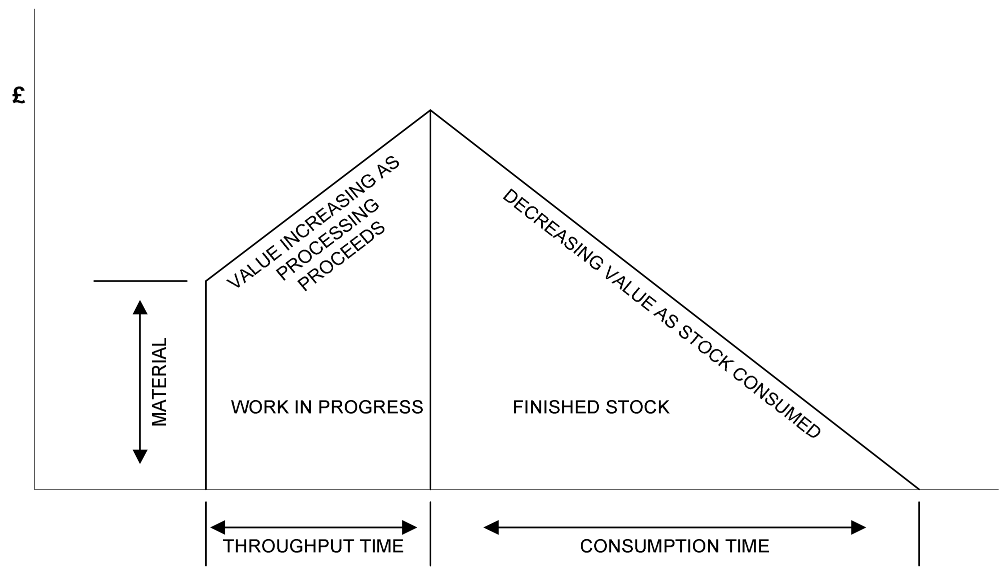
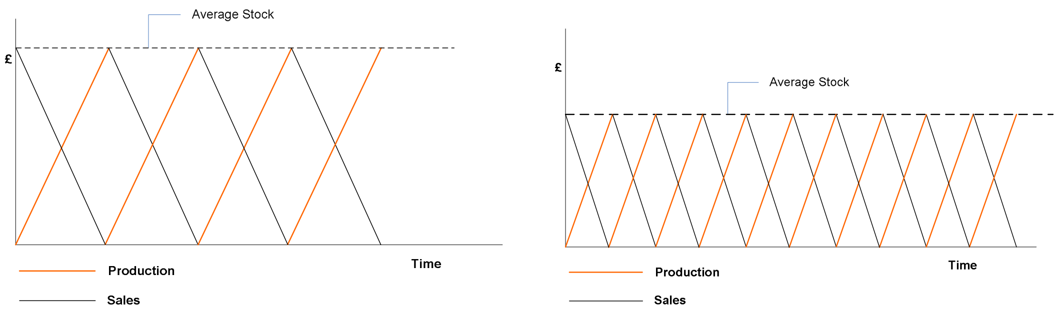


Figure 2.2 A stock chart (Burbidge, 1962).

The total stock at any instant will be sum of all the stocks of the component batches. According to Burbidge (1962) there are six main factors which control the value of the component stock:

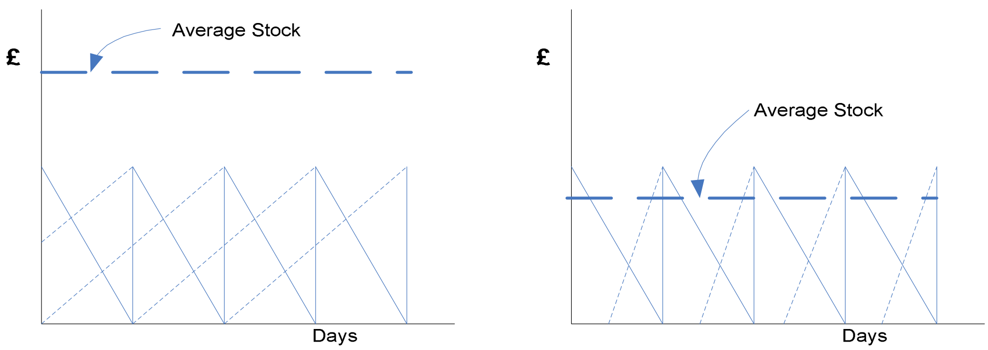
2. Continuity of consumption – for a single batch of components or for widely spaced intermittent batches, the average, or average total stock is just over half the maximum. If consumption is continuous the average stock will rise.
3. Scheduling efficiency and delays – ideally consumption should start the moment the components are completed. A delay between completion and consumption will increase the average stock. Delays during processing also tend to increase the average stock level, because they tend to increase the ratio of processing to consumption time.
4. Batch quantity – stock can be considerably reduced by reducing batch quantities and at the same time increasing the batch frequency, or number of batches produced in a given period of time (Figure 2.3).



(a) (b)

Figure 2.3 Illustrations of batch quantity and the stock investment (Burbidge, 1962) (a) high batch quantity and (b) low batch quantity.

4. The ratio of throughput to consumption time – the effect of this ratio is illustrated in Figure 2.4. This illustration shows in particular one of the reasons why minimisation of the throughput time is important in production



(a) (b)

Figure 2.4 An illustration of throughput time ratio and stock investment (Burbidge, 1962) (a) long throughput time (b) short throughput time.

5. Minimum stock – perfect scheduling is ideal, but it is sometimes necessary to make special provision against possible unavoidable variations in the production plan. This is generally done by minimum stock or *buffer stock,* to tide over emergencies. The provision has the disadvantage of inflating stock.
6. Changes in flow – seasonal demand causes lack of balance between processing and consumption. In order to keep stock level to a minimum, it is desirable to process at an even rate. In certain markets sales are seasonal and products cannot be sold out of season.

2.4. Supply Chain

It is believed that demand-based flow manufacturing is the high velocity supply chain concept that many manufacturers are successfully using to drastically cut cycle time and increase their competitive edge. In a demand-based flow manufacturing environment, inventory is "pulled" through each production work-centre only when needed to satisfy a customer requirement. This means the entire supply chain must be configured for maximum flexibility and quick response - so the irregular, or custom, orders can be filled as quickly as a standard item.

Tan and Kannan (1999) suggest that improving product and process quality have been well established as ways by which organizations can respond effectively to increased global competition. Now, however, the challenges facing organizations go beyond improving quality. Organizations are increasingly faced with the reality that they cannot exist in isolation, but are actually one piece of a very complex chain of business activity. The results of the study by Tan and Kannan (1999) support this notion and confirm that all three major components of a supply chain, *i.e.* suppliers, manufacturers and customers, must be effectively integrated in order to achieve financial and growth objectives. Moreover, the results indicate well defined linkages between specific practices and performance. Successful management of the supply chain is the key to the long-term success of an organization. This cannot occur however if organizations implement business practices in an arbitrary, uncoordinated manner, along the supply chain or if they direct scarce financial resources to initiatives without merit that are unlikely to yield positive outcomes. The results of the study by Tan and Kannan (1999) also highlight the fact that supply chain management initiatives alone cannot improve profitability or market share. With product life cycles shrinking, firms must unceasingly pursue new markets and technologies, and improve cost and delivery performance. Supply chain management provides a framework within which to implement a well conceived market strategy, but it cannot undo the effects of a poorly conceived one. Tan and Kannan (1999) further summarise that it is therefore imperative for managers to ensure their quality and procurement implementation strategies, tactics, and measurements are correctly aligned with strategies in the areas of finance, operations, marketing, new product development and sales.

The demand-based "pull" of material through production is in sharp contrast to the traditional "push" production process which is driven by a schedule that often just pushes inventory into stock that may not reflect what customers want. Worse, "push" production typically cannot quickly adjust for sudden shifts in what customers want, resulting in longer cycle times and ultimately surplus inventory.

According to Boer (1994), *"many industrial markets have turned into virtually world-wide battlefields in which customers are demanding ever wider ranges of relatively low cost reliable and high quality products and ever shorter and reliable delivery times"*. In response many authors have stressed the need for "new wave manufacturing strategies" (*e.g.* Harrison and Storey, 1996) to ensure manufacturing flexibility.

In the particular case of the automotive industry, the sector is often perceived as having uncertainty, continuous change and innovation in technology, work practices and markets. Managing change effectively by encouraging innovation, learning and continuous improvement is thus essential. West and Burnes (2000) suggest that many companies are seeking to promote organisational learning in a systematic and organisational-wide manner. They reviewed four issues which are of prime importance when seeking to build organisational learning:

1. **To relax organisational barriers:** In practice this involves building closer links with customers and suppliers, becoming more aware of the intentions of the competitors, tracking developments in technology and work practices, and monitoring political, economic and social trends.
2. **To involve people for organisational responses:** This emphasise that the responsibility of implementation of internal organisation responses cannot be confined to leaders but has to be seen as the responsibility of the wider

organisation. In this situation, the importance of employees is increased so that individuals and the team act as a buffer for, and champions of, change strategies.

3. **Develop organisational culture:** This is required to develop and encourage ways of thinking to be challenged by individuals and teams. Teams and individuals to be given increased opportunities to question and debate work organisation, and to contribute suggestions for improvement.
4. **Development of individuals:** This will help contribute effectively to the performance of the organisation. Research suggests that people within the organisation are generally enthusiastic to learn, and recognise that by increasing their skill levels and involvement, they would contribute more effectively to the organisation and increase their own employability.

West and Burnes (2000) further comment that organisational learning can bring many benefits to a company: innovation, flexibility, staff commitment etc. However, West and Burnes (2000) also suggested that by itself it cannot guarantee success citing Rover and Volvo as two examples where resources and expertise were in ample supply but were unable to guarantee the success of the business.

2.5. ABC Categorisation

Neighbour (2004) summarises that *Pareto* analysis is a simple tool that helps to separate the important from the trivial. Vilfredo Pareto, a 19th century Italian economist interested in his country's distribution of wealth, noticed that about 80% of the wealth was held by about 20% of the population. It is believed that in the late 1940's, Dr Joseph M Juran recognised Pareto's distribution applied to a much wider range of situations than just wealth. In particular, he found it applied to the defects present in products held in stock and by concentrating upon the defects in the 20%; he solved 80% of the problems. It was through Juran's work that the 80/20 distribution became known as the 'Pareto Principle' (Printing world, 2005).

According to Cohen *et al.* (1988), ABC classification is the most frequently used method for item aggregation; a principle which has been around a long time, at least since Pareto's 80/20 rule. As in the case of for the Pareto distribution, this approach is based on the fact that a small fraction of items account for a high percentage of total value use. It is useful to note here that this is an approach based on a single criterion.

The most common use of ABC analysis in operation is in inventory management. Roper (1994) suggests that in many companies 20% of product lines account for 80% of business activity. Concentrating on these 20% product lines could provide the following benefits;

- Improve high level of customer service as measured by delivery, lead time and reliability.
- Minimise inventory investment and inventory risk related to obsolescence, overstock and damage.
- Minimise operating cost necessary to provide the service.
- Maintain high level of operational flexibility to accommodate demand changes.

An early industrial application of the concept was used to control inventory at General Electric (Flores *et. al*. 1987). Being simple to implement, the ABC method and its associated control policies may not necessarily provide acceptable cost and service performance since they do not take into account other critical variables (related to production, distribution, customer service *etc*.). Many other researchers (Ramani, 1985; Flores, *et. al.* 1987; and Fariborz, 1993) have agreed that typical ABC classification takes into account the 'annual monetary investment' and it ignores, what they call, "the item criticality". In the production system, several measures, in addition to that of dollar usage, suggest important criteria for management. The certainty of supply, the rate of obsolescence, and the impact of stockout of the item are all examples of such considerations. Some of these may be more crucial than dollar-usage to the management of the item. Cohen *et al.* (1988) has termed these operationally 'critical' considerations as *Operation-Related Groups* (ORG).

Flores *et al.* (1987) further argues that although schemes of classifying items as A, B or C can be devised using any of the criteria listed above, a single measure may not sufficiently describe the management needs. It may be desirable to take more than one of the criteria into account and combine those criteria to form a *joint criteria matrix*. Flores and Whybark have proposed a bi-criteria approach using a standard ABC analysis on each of the two criteria independently then combining the two through the use of a matrix. So for each criterion, 20% should account for 'A'. The concept of joint criteria is illustrated in Figure 2.5, the matrix shows that ultimately this creates nine part groups. From Figure 2.5 the total number of parts in *Part Group* 1, 2 and 3 will account for the first 20% of parts with criticality 1 and category ‘A’. Similarly, total number of parts in *Part Group* 4, 5 and 6 will account for next 30% of parts with criticality 1 and category ‘B’. It therefore follows that *Part Group* 7, 8 and 9 will account for remaining 50% of parts with criticality 1 and category ‘C’.

Part Group.	Criticality - 1	Criticality - 2
1	A	A
2	A	B
3	A	C
4	B	A
5	B	B
6	B	C
7	C	A
8	C	B
9	C	C

Criticality - 1 \ Criticality - 2	A	B	C
A	1	2	3
B	4	5	6
C	7	8	9

Figure 2.5 A Joint Criteria Matrix showing the formation of the nine classes of parts.

From a dynamic perspective, researchers have developed complex mathematical models to inform decision making such as the Wagner-Whitin algorithm (2004). Indeed, more complex multiple criteria ABC analysis, based upon analytic hierarchy process (AHP), has been undertaken by others to generate a “criticality index” which includes consideration of a range of different factors, *e.g.* lead time, unit price, durability, order size requirement, *etc.* In terms of applicability to the analysis this list could further include part size, stillages available, capacity of a stillage, *etc.* The literature regarding multiple criteria ABC analysis is scarce, particularly in relation to managing product lines. Multi-criteria ABC technique has been applied in a manufacturing company in Mexico (Flores, *et. al.* 1986). The company faced the problem of an increase in the number of uncompleted assemblies due to component shortages. The company applied multi-criteria ABC analysis based on dollar usage and lead time to capture critical parts required for assembly. It was useful to note that some assembly parts which were falling under ‘C’ category of typical ABC analysis were now appearing in ‘A’ or ‘B’ categories of multi-criteria ABC analysis thus highlighting the important parts based on criticality. For multi-criteria ABC analysis, there is scarce information in the open literature. For example, it is unclear what the maximum number of criteria that should or could be taken into account for any multi-criteria matrix. The number of criteria or alternatives should be reasonably small to allow consistent pair-wise comparisons. Satty (1980) suggests a maximum number of seven in order to keep the complexity level low.

Roper (1994) provided three examples where the concept of adopting ABC analysis and concentrating on activity helped three companies (**X, Y** and **Z**) to improve their efficiencies. Company **X** manufactures fluid power components (valves and fittings) with around 7400 product lines. An ABC classification of parts by sales value had been used to identify stock products. But poor shop floor discipline resulted in poor delivery performance to stock and hence poor customer service. To improve service, product line activity was analysed on the basis of *total annual orders.* The analysis revealed that 350 parts (5%) accounted for 50% of total product lines ordered, these core products were company's high activity based items. These parts were placed on a repetitive manufacturing schedule and production capacity specifically planned on a monthly basis. Less than two months after implementation, core products achieved a 95% fill rate. Core products inventory was reduced and total machine hours were reduced by 15%. This created more capacity for producing other products with less predictable demand.

Company **Y** manufactures engineered products for commercial refrigeration market. As a premier supplier with a broad product line, they were losing sales to smaller, more focused competitors who could supply certain parts to customers more quickly and at lower price. The company had a standard eight weeks lead time, to ensure all products are produced and delivered on time. This long lead time was a concern to customers. The emphasis was to improve service and simplify the business. Analysis indicated that although there were no predictability of end-item (final part) level, there was a certain predictability at the major component level. Of 330 available compressors, 30 accounted for 90% of total usage. By stocking the most used components, they effectively removed purchase lead time from end product lead time for those products using only standard components. Company **Y** attained similar benefits as company **X** by applying principles of ABC classification.

Company **Z** is a value-added distributor of plastic sheet to the graphic industry. The company had to improve their customer service in order to sustain profits. An analysis of order activity indicated that 5% of product lines accounted for half of the order processed. These core products were set on repetitive schedule. The benefits of the change appeared within three months:

- Service level (next day fill rate) improved from high 80% to 98%.
- Inventory of core products declined by 200,000 or about 25%.
- Premium charges associated with shipping were reduced.
- Planning and processing of core products was more efficient.
- Material planners and schedulers spend less time managing core products, due to new planning tools and concepts. This leaves relatively more time for the less predictable products.

Roper further summarises that the application of activity-based management highlighted some common benefits of this approach:

- Focusing on high activity products within the business can provide the strategic focus needed to improve customer service and performance.
- Simplifying major area of business activity can free resources to better serve the unpredictable portion of the business, which typically requires more attention.
- An activity-based strategy can help rationalise operations and focus activity in supporting functional areas of the system.

As stated earlier organisations need to adapt to changes in processes and or resources in order to remain competitive. The implementation and use of best practices should be paramount in order to thrive in the global market. It is sometimes easy to simply adopt and implement some of the proven techniques in best practices but in many instances this might not be the case. For example, in the case of multi-criteria ABC analysis, the technique has often proved to be a positive one and has provided excellent results in several organisations over a period of time. This is not to say that it may be valid for every organisation. Generally, there are issues with any change in process or practise and these issues are complicated to analyse and their impact on the business is difficult to assess. The issue of 'unknown' could be tackled with the help of model simulation. Modelling and simulation are techniques to support companies providing a better understanding of their manufacturing systems, behaviours and processes and therefore helping them in decision making.

2.6. Model Simulation

Modelling of systems, such as those in manufacturing, can be achieved using a number of tools and techniques one of which is simulation. According to Kelto *et al.* (2004), simulation refers to a broad collection of methods and applications to mimic the behaviour of real systems, usually on a computer with appropriate software. Kelto *et al.* (2004) further describes the computer simulation as the method for studying a wide variety of models of real world systems by numerical evaluation using software designed to imitate system's operations or characteristics, often over time. Simulation deals with the models of a system. A system could be a bottling plant with machines and people or a call centre replying to customer queries. The simulation approach of analysing a model differs to the analytical approach, where the method of analysing the system is purely theoretical. As this approach is more reliable, the simulation approach gives more flexibility and convenience. The activities of the model consist of events, which are activated at certain points in time and in this way effect the overall state of the system. Events occur autonomously and are discrete so between the executions of two events nothing physically happens. Simulation modelling is applied to real world problems and hence it becomes essential that the analyst captures the real world situation as best as possible. Milona (2003), suggests that there has been a great deal of research related to the modelling and simulation of business processes in order to optimise and integrate enterprises, however, these have been isolated approaches and it is still difficult to measure the total impact of decisions.

In process modelling and simulation, the literature review generally agrees that a formal procedure is desirable. The steps involved in establishing a formal procedure varies from four to twelve. Banks (1999) proposed a 12 step procedure and emphasised on the verification and validation stages of the procedure. The primary aim of this step is to have a model that is accurate when used to predict the performance of the real world system it represents, or to predict the difference in performance between two scenarios or two model configurations. A similar 12 step procedure was proposed by Shannon (1998). Combining the fundamental steps from Banks (1999) and Shannon (1998) forms a new 13 step procedure which could be summarised as follows:

1. *Problem definition* – clearly defining the goals of the study so that the purpose is known, *i.e.* why the study is being undertaken and what questions need to be answered.
2. *Project planning* – this stage defines the appropriate personnel, management support and computer hardware and software resource availability.
3. *System definition* – determining and establishing the boundaries and restrictions to be used in defining the system (or process) and investigating how the system works.
4. *Conceptual model formulation* – this relates to developing a preliminary model either graphically (*e.g.* block diagram or process flow chart) or in pseudo-code to define the components, descriptive variables, and interactions (logic) that constitute the system.
5. *Preliminary experimental design* – selecting the factors to be varied, and the level of those factors to be investigated, *i.e.* what data needs to be gathered from the model, in what form, and to what extent. Agreeing the required outputs of the experiment.
6. *Input data preparation* – identifying and collecting the input data needed by the model. Defining the data sources and standardising the formatting.
7. *Model Translation* – formulating the model in an appropriate simulation language and coding the data.
8. *Verification* – concerns the simulation model as a reflection of the conceptual model *i.e.* does the simulation correctly represent the data inputs and outputs as designed?
9. *Validation* – provides assurance that the conceptual model is an accurate representation of the real system *i.e.* can the model be substituted for the real system for the purpose of experimentation?
10. *Final experimentation design* – designing an experiment that will yield the desired information and determining how each of the tests will run as specified in the experimental design is to be executed.
11. *Experimentation* – executing the simulation to generate the desired data and to perform sensitivity analyses.
12. *Analysis and interpretation* – drawing conclusions from the data generated by the simulation runs.
13. *Implementation and documentation* – reporting the results, putting the results to use, recording the findings, and documenting the model and its uses.

In this procedure the emphasis was on elements such as experimental design and interpretation of data. Greasley (2003) suggested that the cost of building sophisticated models and the risk associated with it could be high and if the modelling is not effectively defined and controlled. He also cites the importance of visual animated display as a communication tool to facilitate discussion and development of new ideas. Shannon (1998) suggests that simulation model may be more credible because its behaviour has been compared to that of the real system or because it requires fewer simplifying assumptions and hence capture more of the true characteristics of the system under study. Shannon (1998) further summarises the advantages of model simulation as:

- It helps to design layout, etc without committing resources to their implementation;
- It can be used to explore new staffing policies, operating procedures, decision rules, organisational structures, information flows, etc;
- Simulation allows to identify bottlenecks in information, material and product flows and explore opportunities for increasing the flow rates;
- It allows to test hypothesis about how or why certain phenomena occur in the system;
- Simulation allows to control time and the system could be virtually operated for months or years in a matter of seconds;
- It allows to gain insight into how a modelled system actually works and understand as to which variables are most important to performance;
- Simulation has great strength in its ability to let the analyst experiment with the new and unfamiliar situations and to answer "what if" questions.

There are some disadvantages of simulation which can be summarised as below:

- Simulation modelling requires specialised training and knowledge gained from continuous use, thus the skill levels of its practitioners may vary widely. The utilisation of the study largely depends upon the quality of the model and the competency of the analyst.
- Gathering highly reliable input data can be time consuming and the resulting data is sometimes highly questionable. Simulation cannot be compensating for inadequate data or poor management decisions.

- Simulation models are input-output models, *i.e.* they yield the probable output models of a system for a given input. They are therefore “run” rather than solved. They do not yield an optimal solution, rather they serve as a tool for analysis of the behaviour of a system under condition specified by the analyser.

2.7. Lean Manufacturing

The lean production model relates manufacturing performance advantage to the adherence to three key principles (Womack and Jones, 1996):

1. Improving the flow of material and information across a range of business functions;
2. An emphasis on customer pull rather than organisation push (enabled on shop floor with Kanban) and;
3. A commitment to continuous improvement by the development of people.

Christopher (2005) suggests that with demand-based flow manufacturing and today's systems technology, product complexity and variability do not pose the barrier they once did to creating an order fulfilment process having great flexibility - to build any model, having any options in much less cycle time than yesterday's batch and mass production systems could achieve. Today's marketplace requires high velocity supply chain performance. Customers can, and will, change suppliers when they are unable to get the goods they want in the response time they need them.

According to Hackwell (2005), Dr John Parnaby at Lucas Engineering Systems introduced the concept of runners, repeaters and strangers analysis. This analysis took a simplistic view of IT in manufacturing. Hackwell (2005) argues that Kanban works well if there is a stable demand on runners, but it has never been satisfactory if there is variability in demand as per repeaters and strangers. Even when the runners exhibit variability, computerised scheduling plays a very significant role. Hackwell insists that it is impossible to optimise a complex production environment without using computers.

According to Hackwell, most of the influences on modern manufacturing are now moving towards ‘agile’. With ‘lean’, from having Economic Batch Quantities (EBQ) which were significantly large, down to making one kanban for an EBQ. It is believed that EBQ has been in use since 1904 to compute the batch quantity or the number of parts to be manufactured or material ordered at one time. The formula used to calculate EBQ takes into account the item's usage rate, its unit cost and the cost to setup and process a manufacturing lot, Equation 2.1.

$$EBQ = \sqrt{\frac{2 * RC * D}{HC}} \quad \text{Equation [2.1]}$$

RC (Reorder cost) is the cost of placing a repeat order and might include allowances for drawing up an order (with checking, getting authorisation, clearance, distribution and filing). The reorder cost for the items made within the company is a batch setup cost which includes overheads on the work-centres and setter time. HC (Holding Cost) is the cost of holding an item in stock for a period of time. The usual period for the calculation purpose is a year. D (Demand) in this case is the total demand forecasted by the customer or the total anticipated customer requirement for an item over a period (year). With an EBQ close to one and lots of small orders with potentially significant variance, good work sequence through the process becomes important, and scheduling becomes critical.

In general, *Batch* manufacturing is estimated to be the most common form of production, constituting more than 50% of total manufacturing activity in United States (Wemmerlöv and Hyer, 1989). Companies aim to make batch manufacturing more efficient and productive with achieving higher integration between design and manufacturing stages of a product. An approach directed to achieving this goal is a production technique, known as **Group Technology** (GT). GT has been described by various researchers in different words but the paradigm is essentially the same.

> *"Group Technology is a manufacturing philosophy in which similar parts are identified and grouped together to take the advantage of their similarities in design and production."* (Groover, 2001)

> *"Group Technology is a production methodology for classifying parts and processes… … widely used in the identification of cells for the purpose of manufacture" (Burbidge, 1996)*

In GT similar parts are arranged into **part families**. Part families are deemed to be groups of parts with similar design and/or manufacturing characteristics. **Machine groups** are responsible for the manufacture of these part families. A machine group can be considered to be a set of workers and a set of machines and/or other facilities laid out in one reserved area, which is designed to complete the specified part family.

In 1925, R. Flanders presented a paper in the United States before the American Society of Mechanical Engineers in which he described a way of organising manufacturing at Jones and Lamson Machine Company that would be called GT. Further developments in this area were contributed by A. Sokolovskiy of the Soviet Union and A. Korling of Sweden (Groover 2001).

A researcher from Soviet Union, **S. Mitrofanov**, in 1959 published a book entitled **Scientific Principles of Group Technology.** By the end of 1965 there were about 800 plants in the Soviet Union using GT as a direct result of the success of the manufacturing technique described by the book (Groover 2001).

GT is a clustering methodology adopted in many industries, including the design of job-shops and flexible manufacturing systems. GT has helped reversed the direction of declining US productivity since 1970's (Greene and Sadowski 1984, Hyer 1984, Ham *et al.* 1985). A major prerequisite in implementing GT is the identification of part families (Wemmerlöv and Hyer 1987, Kaparathi and Suresh 1991. GT is also very important when designing cellular manufacturing systems (Malakooti, Behman; Malakooti, Nima and Yang, 2004) and once the part families have been formed it is ideal to process these part families by **group of machines**. Grouping the production equipment into machine cells, where each cell specializes in the production of part family, is called cellular manufacturing (CM). Irani (1999) described CM as;

> *"a manufacturing cell is an independent group of functionally dissimilar machines, located together on the shop floor, dedicated to the manufacture of a family of parts."*

2.8. Cellular Manufacturing

For many years Cellular Manufacturing (CM) has been advocated as the preferred way to arrange the shop floor resources of an organisation (Burbidge, 1979; and Parnaby 1986). Although specific interpretations vary, for *e.g.* Kumar (1992) defined cellular manufacturing as the manufacturing of products requiring similar processes or similar manufacturing routes in an area on the factory floor containing dissimilar machines, arranged in physical proximity, an agreed definition as per Kumar (1992) is that "a manufacturing cell is the organisation of the shop floor whereby a single team of operators have the resources to manufacture or assemble a group or family of similar products and/or components." This is in contrast with the traditional or functional layout whereby products are routed through required but separate functional areas.

According to Irani (1999), in 1990 a report published by Ingersoll Engineers Ltd. suggested that just over half of UK's engineering companies were using CM in some areas of their organisation. However, a survey by Boughton and Arokiam (2000) on barriers to the use of CM is listed in Table 2.2. These issues listed are particularly significant since initial investigations of product characteristics of the small, medium sized enterprises (SME's) who had not implemented CM suggests that two-thirds of the organisations have products which fall into the runner-repeater category. Irani (1999) summarise the disadvantages of CM as;

1. Use of cells
    - Need for high investment in machine installation and re-layout.
    - Lack of flexibility in handling demand changes, product mix changes, infrequent ordering of parts, variable lot sizes, changes in part design and process plans, improvements in manufacturing technology.
    - Imbalance of utilization of machines and labour.
    - Potential for crippling delays due to machine breakdowns, worker absenteeism, etc.

2. Implementation problems associated with methods used for cell formation
    - Lack of a comprehensive cell formation method.
    - Data collection and analysis is time-consuming.

- Significant difficulty in incorporating the impact of dynamic operational factors into the cell design process.

Anticipated Difficulty	**Respondents (%)**
Lack of sufficient space	100
Disruption to production	96
Duplication of resources	91
Introduction of new products	91
Sharing of key resources	77
Difficulty of moving machines	68
Under-utilisation of resources	68
Demand variability	46

Table 2.1 Barriers to usage of Cellular Manufacturing (Boughton and Arokiam, 2002).

Irani (1999) further suggests that the benefits of CM are significantly high and summarises crucial advantages associated with the application of CM which are as follows;

1. Strategic advantage
    - On-time delivery
    - Improved response
    - Reduced inventory
    - Improved quality
    - Improved work flow
    - Increased operational flexibility
    - Improvements in company culture
    - Accountability
    - Better equipment utilization
    - Better use of skilled labour
    - Job satisfaction
    - Improved information flow

2. Shop floor advantage
    - Speed throughput in parts manufacturing and assembly.
    - Reduced work-in-progress and finished goods inventory level.
    - Reduced material handling and travel distances for parts.
    - Eliminating non-value added operations (storage, inspection, and handling).

3. Increased capacity by reducing set-up times and encouraging group scheduling of parts.
    - Performing accurate machine and manpower requirement analysis.
    - Improving quality by reducing scrap and process variations due to better monitoring of operations.
    - Creating sensible cost centres around each cell's activities and outputs.
    - Simplified production and assembly planning and control, scheduling, load balancing, and capacity requirements analysis.
    - Helping to introduce just-in-time manufacturing to minimize lateness in delivery schedules.
    - Providing manufacturing capacity and schedule information promptly to sales and marketing personnel.

CM also promotes the implementation of 5'S on the shop floor. 5'S is five step technique to stabilise, maintain and improve the safest, best working environment to support Quality, Cost & Delivery (QCD). In a conventional manufacturing set-up, all similar machine types are divided into organisational units each of which specialises in a particular manufacturing process, or sub-process. The main difference between the conventional type of manufacturing and CM is the way machinery is arranged on the shop floor. Ignoring fixed layout, it is widely accepted by researchers that there exists three basic ways to arrange machines in a factory; *Line/Product Layout, Function/Process Layout*, and *Group/Cell Layout.* Mikell and Groover (2001) further expand on the three layouts as;

2.8.1. Line/Product Layout

This layout is practiced where material flows through a sequence of machines. The machines and other work centres are arranged in the sequence in which they are used to manufacture the product. It is believed that this arrangement suits high-volume/low variety products. With line layout the machines or other work stations are laid out in a line in their sequence of usage. Usually it can, therefore, only be used efficiently when all components made on the line use the same work stations in the same sequence, and where there is an approximate balance between the work loads at each station, *e.g.* a car production line.

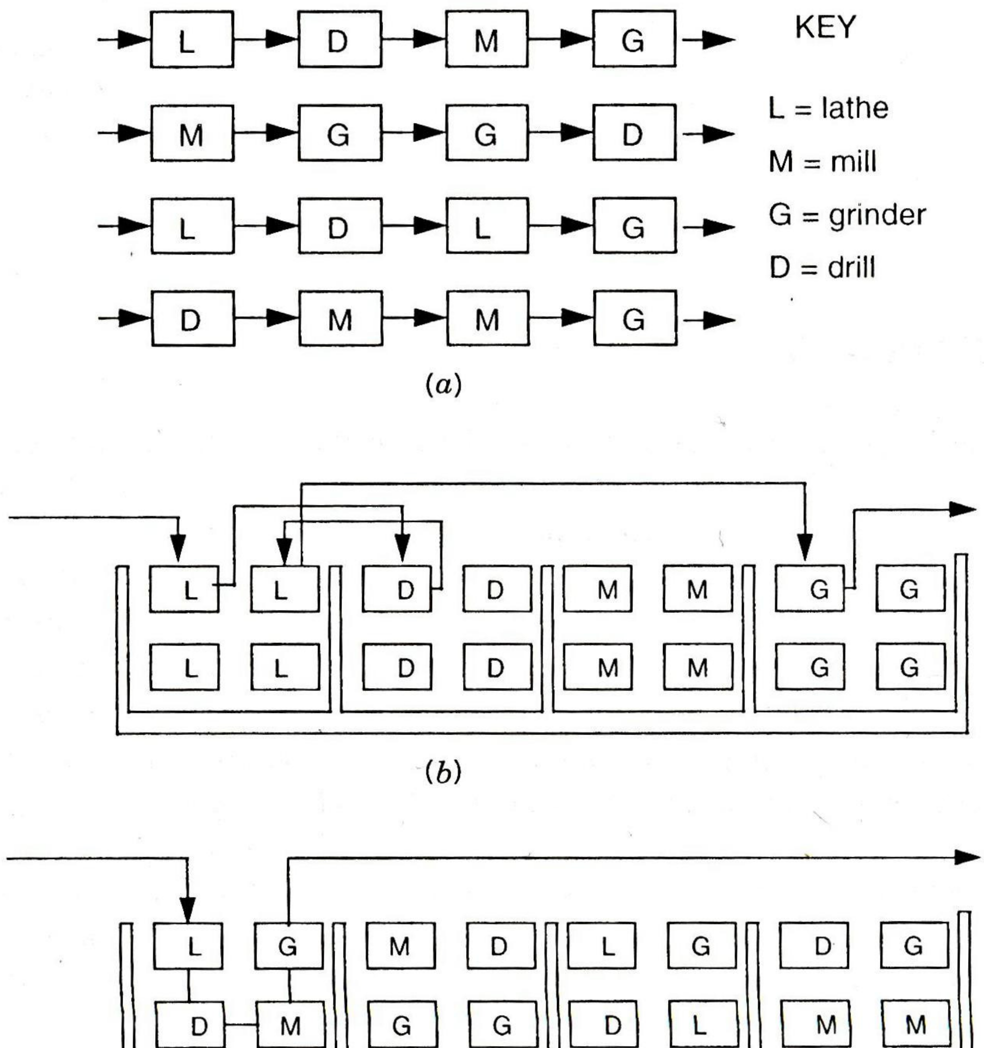


Figure 2.6 Types of Layout: (a) Line Layout; (b) Functional Layout; and (c) Cell Layout. (Source: Mikell P. Groover 2001)

For these reasons, line layout is used mainly in simple process industries, and in assembly, where because most operations are manual, it is fairly simple to divide up the work to achieve an even work load at all stations on the line *e.g.* food production. Figure 2.6 (a) shows the line layout where machines are lined up in a sequence in a machine shop. In component processing in the engineering industry, line layout can only be used for parts required in very large quantities, or for families of relatively simple and similar parts, all of which use the same machines in the same sequence. Line layout is therefore only used in component processing to make a very small proportion of the parts made in industry.

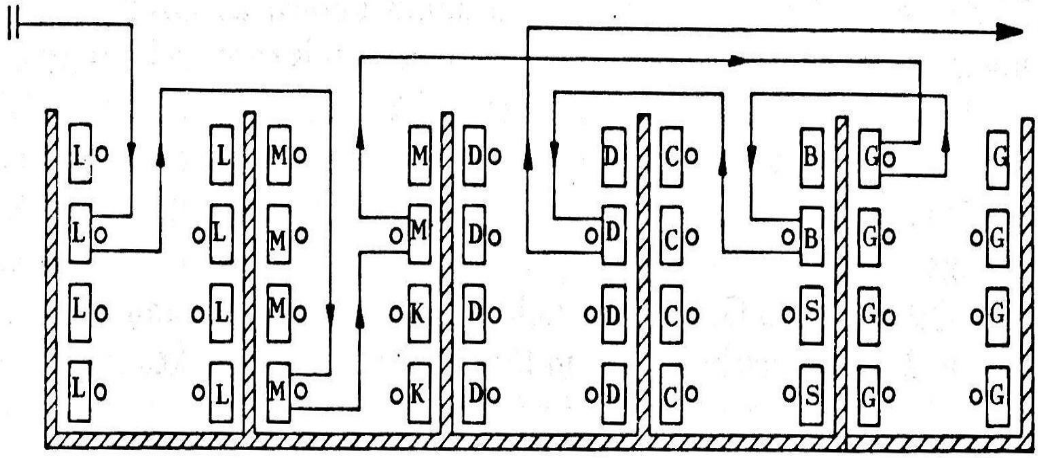
2.8.2. Functional/Process Layout

Figure 2.6 (b) represents a functional layout. In this type of layout, machines of specific types are grouped together. This is a type of layout that can result in large amounts of material handling, a large amount of Work-In-Progress (WIP) inventory, excessive set-up times and long manufacturing lead times. Where line layout cannot be used, the machines and other work centres are used to make many different parts in batches. The traditional approach to the organization of batch production is known as functional layout and is based on process specialisation. The workers in the factory are divided into organizational units each of which specialises in a particular process or part of a process. In this case the traditional approach to organisation is to form 'sections' which specialise in processes. For example in an engineering workshop the typical sections would be turning, milling, drilling, grinding and gear cutting.

2.8.3. Group/Cell Layout

Cell layout is a result of GT. Machines are arranged as cells. Each cell is capable of performing manufacturing operations on one or more families of parts. The families of parts can also determine the capacity and utilization of the cell. The new method of factory organisation known as GT is based on product specialisation. In this case each group of workers specialises in the production of a particular list or family of products and is equipped with all the machines and equipment necessary to complete these products as shown in Figure 2.6 (c). The physical nature of the change from traditional forms of organisation in batch production machine shops to GT is illustrated diagrammatically in Figure 2.7. The machine shop in this illustration still makes the same components in groups as it did with the traditional form of organisation. It still uses the same machines and the same method and tooling. The main change has been in the organisation of the workers and in the layout of the plant.

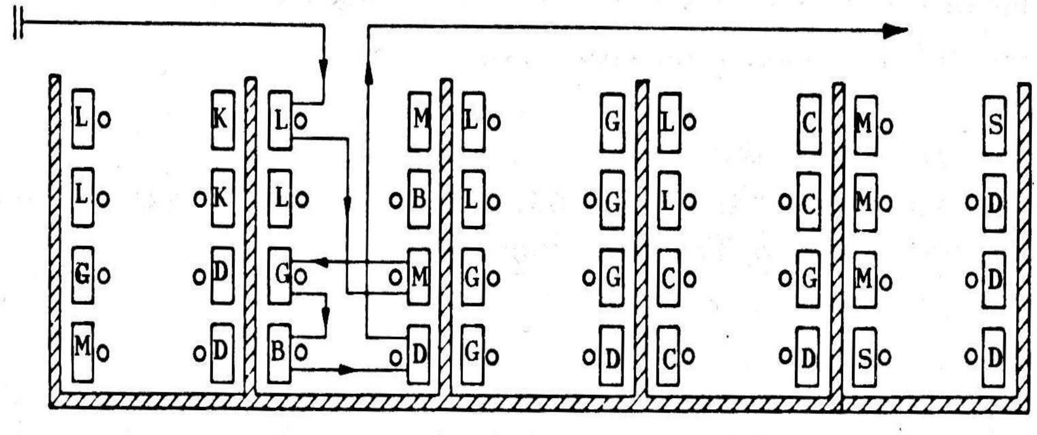
FROM : PROCESS-SPECIALISING SECTIONS



L=lathes; M=millers; D=drills; C=gear cutting; B=broach; S=shaper; G=grinder; K=keyseater.

Each part visits many sections.
Workers specialise in one process only.
Most sections contain only one type of machine.

TO : GROUPS COMPLETING "FAMILIES" OF COMPONENTS



Each part visits only one group.
There is the possibility of choice: some workers can specialise and some can work a variety of machines.
Most groups contain several types of machine.

Figure 2.7 The change to group in machine shop.

(This illustration is extract from a study into the effects of Group Production Methods, published by ILO's International Centre of Advanced Technical and Vocational Training)

2.9. Implementation Options for GT

The biggest single obstacle in changeover to GT from a conventional production layout is the problem of grouping the parts into families. There are three general methods that could solve this problem (Figure 2.8).

- Visual Inspection
- Parts Classification and Coding
- Production Flow Analysis

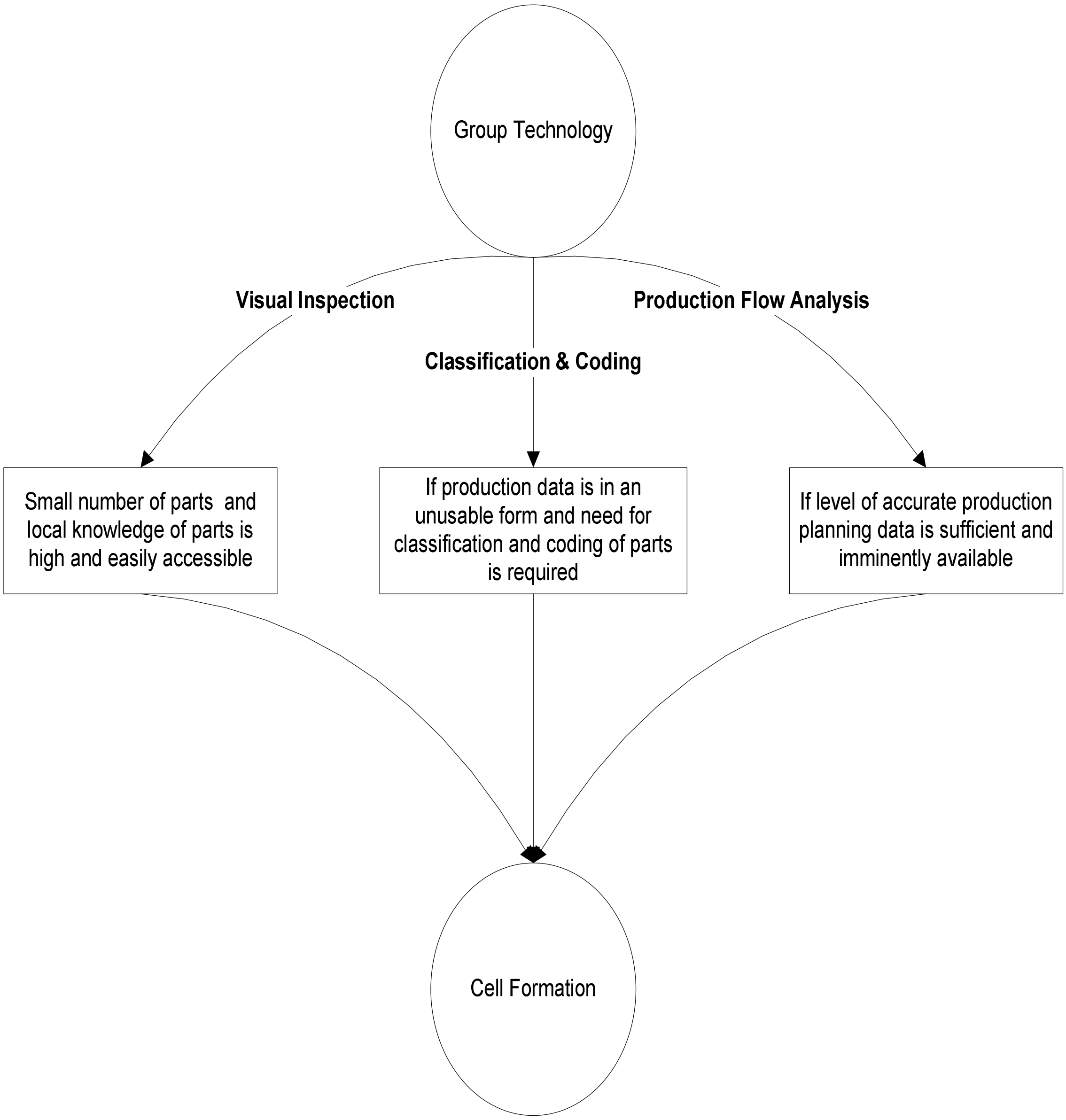


Figure 2.8 Methods for implementing GT.

2.9.1. Visual Inspection or Eyeballing

This is the least reliable method from the three methods of grouping parts into families. It is however the simplest and least expensive method. This involves the classification of parts into part families by looking at either the physical part or their photographs and arranging them into groups which posses similar features. This method is very limited in scope when dealing with a large number of parts. Where the total number of unique components involved is comparatively small and local knowledge of parts is high and easily accessible, the visual inspection method is the most suitable option. When the number of components involved is too high for a manual drawing analysis there is a choice between production flow analysis and classification and coding.

2.9.2. Parts Classification and Coding (C&C)

This is the most time consuming of the three methods. Similarities among parts are identified in C&C and these similarities are related in a coding system. The methods attempts to group parts with identical or similar design and manufacturing attributes into families. Attributes of a part such as dimensions, shape features, auxiliary holes, or gear teeth are captured in a code number. The code number for each part provides a compact and consistent description of the attributes of each part. This numerically processable information forms the basis for sorting and grouping the parts into families. The cell for each family is identified by matching the attributes of the parts in each family to machine capabilities and available capacity on those machines. Nearly all the early applications were planned using the technique of C&C**.** But it was observed by Burbidge (1979) that this technique of classification and coding does not yield very good results when applied to part family formation for developing cells in a plant layout. The major drawback of this system is that it does not consider the actual flow of material. The main reason that C&C is not the best suited option for finding groups and families are as follows:

- Finding a total division of all the parts in families never succeeds. There are always some parts which are not in the same family as others because that part is dissimilar in shape even though it is made on same set of machines.

- Parts, which have different tolerances, should be manufactured on different machines but it tends to bring together these parts because they have similar shape and/or function.
- It tends to bring together those parts into the same families which should be made on different machines because they vary enormously in requirement quantities (*e.g.* 10 units and 100000 units).
- Parts which are made of different materials are grouped into the same family because there shape is similar. Rather than in some cases where it could be made more efficiently on different machines.
- C&C finds families of similar parts. It provides no help in finding the sets of machines needed to make them.
- C&C requires special skills and is expensive to introduce and maintain.

2.9.3. Production Flow Analysis

This is an approach to part family identification and machine cell formation that was pioneered by J. Burbidge. Production flow analysis (PFA) is a method of identifying part families and associated machine grouping that uses the information contained on production route sheets rather than on part drawings. Parts with identical or similar routings are classified into part families. Theses part families can then be used to form logical machine cells in a GT layout. This method requires reliable and well-documented route sheets. The technique of PFA involves the systematic analysis of the route cards for all the parts made in an enterprise. It is based on the assumption that there is a family-group structure existing in all manufacturing enterprises, even if it is not at present used as the basis for plant layout. PFA seeks to find this existing natural association between particular families, or lists of parts, and particular groups, or lists of machines. The analysis inevitably finds a proportion of parts (known as exceptions) which do not fit into the simple general pattern. Special consideration must be given to these parts to see if it is possible, by re-routing or other means, to make them fit the general arrangement of families and groups.

According to Burbidge (1996), Production Flow Analysis uses a progressive form of analysis with FIVE different stages known as: *Company Flow Analysis, Factory Flow Analysis, Group Analysis, Line Analysis, and Tooling Analysis*, but in general, to apply the principles of CM three prominent stages are considered; (a) Factory Flow Analysis (b) Group Analysis and (c) Line Analysis.

- *Company Flow Analysis* – This is the first stage where the flow of material is simplified between the factories or divisions in a large company.
- *Factory Flow Analysis* – Factory Flow Analysis is an important step in PFA with the aim to change factories from process organisation to product organisation. In this stage, flows due to parts that repeatedly move to and fro between shops (machine shop, forge, foundry, welding, press, assembly, heat treatment) are eliminated by a major redeployment of equipment. The objectives of the conversion are:
  a. Reduced throughput time.
  b. Better decision making processes.
  c. Enhanced possibility for automation.
- This is aimed at getting an optimal solution at factory level by dividing them into departments based on product organisation and simplifying the material flow between them.
- *Group Analysis* – At this level the departments are further divided into groups and analysed. The basic idea of GA is to form an initial part-machine matrix, which can be converted into a final part-machine matrix. Any component manufacturing department can be illustrated by a matrix showing all the parts it makes and all the machines and other work-centres used to make them. In such a matrix the machines and parts are numbered in an appropriate individual sequence resulting in the association of parts and machines appearing to be random
- *Line Analysis* – In Line Analysis the flow of material between work centres is studied and simplified.
- *Tooling Analysis* – This identifies 'tooling families' to plan operation sequencing, and to find sets of parts suitable for automation.

Irani (1999) suggested that there is a possible drawback of PFA, that it assumes the accuracy of existing route sheets, with no consideration given to whether those process plans are up-to-date and optimal with respect to the existing mix of machines. Management and control of product families that are identified through PFA implementation can be further enhanced by using Value Stream Maps. Irani (1999) further argues that, despite innumerable attempts to find an alternative to batch manufacture, most companies still use the approach that was developed in the 1920s. They have a small number of dedicated machines groups that are used to produce the key 'A' value components that affect product delivery and a functional layout machine shop to produce the remaining components. Although this approach is based on practical experience, rather than the result of any scientific analysis, it has stood the test of time. This is unlike the case of GT where very few of the companies that introduce it in the 1960s are still using it.

2.10. Value Stream Maps

According to Rother (2003), a value stream is all the actions (both value added and non-value added) that are required to bring products through the main flows essential to every product. A value stream map (VSM) is a tool with set of pre-defined symbols that helps to see and understand the flow of material and information as a product makes its way through the value stream. Hines (1997) defines VSM as a visualisation tool oriented to the Toyota version of lean manufacturing. He further explains that VSM helps to understand and streamline work process using the tool and techniques of lean manufacturing. The goal of VSM as suggested by Hines is to identify, demonstrate and decrease waste in the manufacturing process. In a VSM, mapping out the activities in the manufacturing process with cycle times, down times, in-process inventory, material movement, information path flows, helps to visualise the current state of the process and highlights waste. Hines further suggested that the VSM process usually indicates that the physically mapping of the "current state" whilst also focusing on where to get to, or the "future state" map, can serve as the foundation for other lean improvement strategies.

2.11. Schedule changes

Schedule nervousness caused by uncertainty in demand or supply can be an obstacle to the effective execution of material requirement planning and processing. Many researchers and practitioners (Wemmerlov, 1976; Campbell, 1971; Steele, 1975) have cited excessive change in production schedules, often referred to as schedule nervousness, as an obstacle to realising the full effectiveness of material requirement planning and processing systems. Schedule nervousness leads to increased cost, reduced productivity, lower service level, and a general state of confusion on the shop floor. Schedule changes are often initiated in response to uncertainties in demand and/or in supply (Whybark and Williams, 1976). As actual demand deviates from the forecast, the production schedule may need to be adjusted accordingly, leading to changes in quantity or timing of orders. Likewise, uncertainty in supply due to scrap losses, production overruns, variations in vendor lead times, variations in route times, machine breakdowns and tooling problems may also necessitate schedule changes (Whybark and Williams, 1976).

Various strategies have been recommended to reduce schedule nervousness. For example, Blackburn (1986) provides a review of these strategies;

- Freezing the schedule within the planning horizon: Here each set of periods within the planning horizon is treated as an independent set of periods. Planned orders for set of periods classified as one will be implemented and then planned orders for the next set of periods will be implemented and so on. The approach will eliminate all nervous behaviour. The approach may incur increases in total setup time and holding costs since it does not use the best ordering policy for each stage.
- Lot-for-lot policy: This approach requires orders to be placed in the same period at all stages. As a result, nervousness due to horizon factors is limited only to a change in the size of the order at each level; there will be no new, previously unplanned orders. As with the strategy above, this approach may result in suboptimal cost performance.
- Safety Stocks: This approach carries safety stocks at the top stage to reduce nervousness caused by the rolling horizon. Sufficient safety stock at finished levels will eliminate changes at lower levels (components or assembly part level), but total inventory carrying costs are likely to rise due to holding costs of carrying the proposed buffers.
- Forecasts beyond the planning horizon: This approach uses a forecast of demand beyond the planning horizon to protect against an order being placed near to the end of the planning horizon which will most likely be revised upward as the schedule is rolled out. Single-stage studies which have employed this idea have shown it to have mixed results (Chand, 1982); it

should prove to be effective in multi-stage setting since there are greater benefits for avoiding changes in multi-stage systems.

2.12. Soft System Methodology (SSM)

In order to identify the root cause to a system problem several tools have to be considered, one of which is soft system analysis; formally defined as the use of system ideas to analyse (*i.e.* examine) soft situations to identify where problems could exist involving people (as supposed to hard system approach). Checkland (1985) claims that SSM was developed because the methodology of system engineering, based on defining goals or objectives, simply did not work when applied to messy, ill-structured, real world problems. He further suggests that the inability to define objectives or to decide which are the most important is usually part of the problem. The basic purpose of a soft system is to clarify the problems that are felt to exist in given situation. Checkland (1985 and 1988) continues to describe the most important characteristics to the soft system methodology:

I The initial stage of a soft system methodology is the progression from solely concentrating on the core of a problem to examine the problem's wider implications on the situation as a whole, utilising system thinking as described by Checkland (1988)

II Various human activity systems are carried out when investigating the initial situation and are carefully considered and sited as 'root definitions' (RD's). RD's explicitly name a number of features in the relevant system. This is further explained with the help of the CATWOE elements (see below).

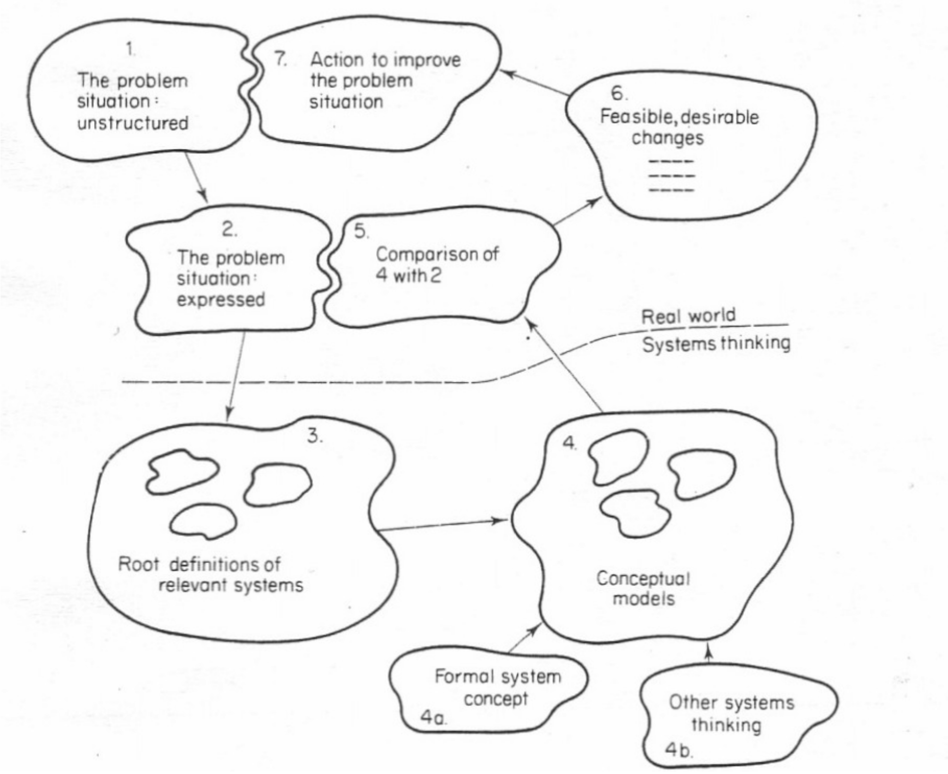


Figure 2.9 The SSM in summary (Checkland, 1985).

CATWOE

C ('customer')	Who would be victims or beneficiaries of this system where it to exist?
A ('actors')	Who would carry out the activities of this system?
T ('transformation process')	What input is transformed into what output by this system?
W ('Weltanschauung')	What image of the world makes this system meaningful?
O ('owner')	Who could abolish this system?
E ('environmental constraints')	What external constraints does this system take as given?

III Each RD makes plain its Weltanschauung, the point of view from which the (human activity) system is described – since one man's 'terrorism' is another's 'freedom fighting'.

IV Conceptual models of the system are built. They are models of purposeful activity considered relevant to debate and argument about the problem situation. They are not at this stage thought of as designs.

V The debate about the situation is structured by comparing models with perception of real world. The aim of the debate is to find some possible changes which meet two criteria: systemically desirable and culturally feasible in the particular situation in question.

VI Definition of desirable and feasible changes gives a new problem situation (how to implement), and the cyclic process can begin again.

VII SSM thus seeks accommodation among conflicting interests.

VIII SSM is doubly systemic. It is itself a cyclic learning process; and it uses systems models within that process.

Within SSM's two types of human activity exist according to Checkland (1988), categorised as type one 'real-world' and type two 'system-thinking activities (Figure 2.9). Type one activity should be implemented only by those within the problem situation and relate to stages 1, 2, 5, 6 and 7, whereas type two activities can involve those outside the problem situation as well as those in it and relate to the remaining stages 3, 4, 4a and 4b. Citing those who should be involved with what can be critical within certain industries in particular those with 'old-fashioned' methods of working and/or specific historical issues. Correct categorisation of human resources will assist the speed, accuracy and validity of the overall investigation but is however highly dependent on the parameters of each study and as such requires careful consideration.

Historically two types of system thinking are described in illustrative form, Figure 2.10 shows 'Hard' system thinking which involves focusing in on the 'how' when trying to achieve an idea or objective. A 'Soft' system could therefore be regarded as being concerned with the criteria significant to overall improvement, a more holistic/global outlook to a problem.

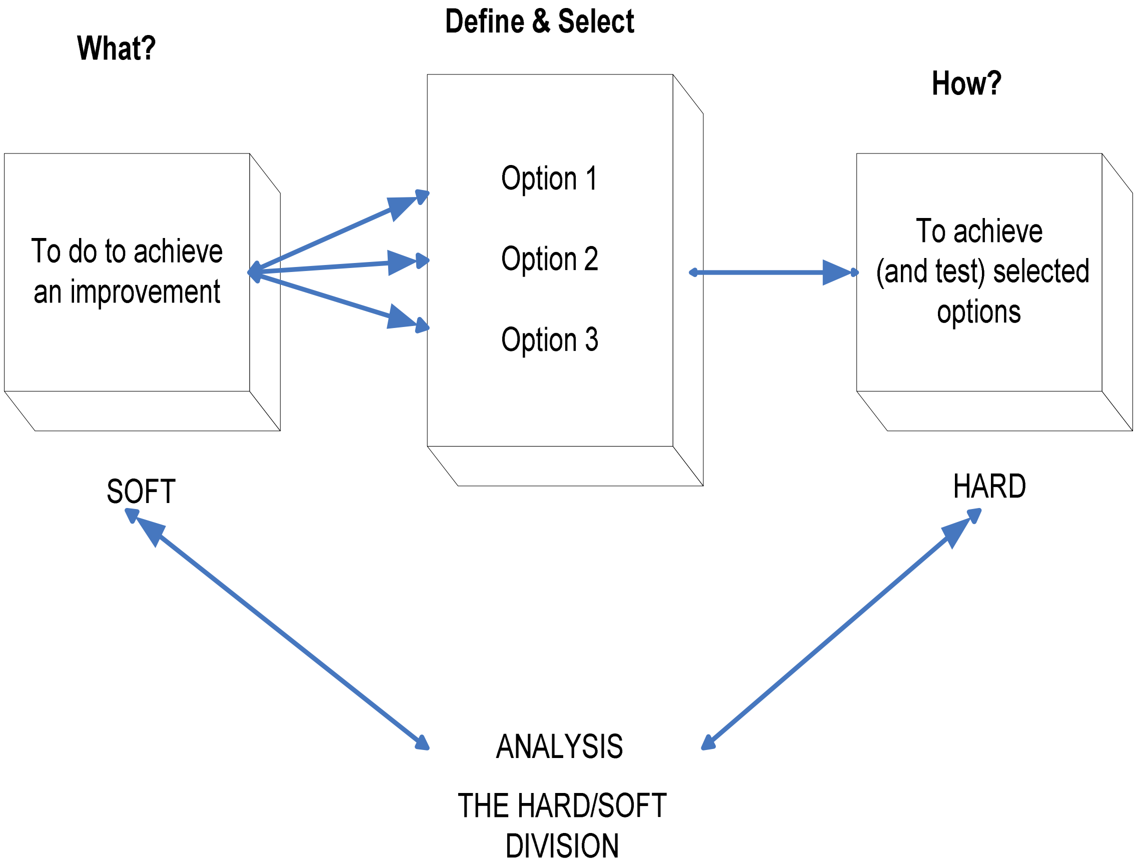


Figure 2.10 Hard/Soft systems division and the transition between the two.

To summarise hard system analysis addresses those parts of an enterprise that have a tangible form, *e.g.* the structure, the level of staff, the equipment they use etc. Soft system thinking, however, considers the systems that could be envisaged throughout, and in particular, those that involve human activity. Checkland (1985) summarises differences between 'Hard' and 'Soft' systems thinking in Table 2.3.

Soft systems analysis is used as a means of improving the understanding of a situation in the early stages of an investigation, and at subsequent stages to clarify where changes might be beneficial. Once the problems have been clarified, it will be necessary to utilise appropriate hard techniques to solve them.

The 'hard' systems thinking of the 1950s and 1960s	**The soft systems thinking of the 1980's and 1990s?**
Oriented to goal seeking	Oriented to learning
Assumes the world contains systems which can be 'engineered'	Assumes that the world is problematical but can be explored by using system models
Assumes system models to be models of the world (ontologies)	Assumes system models to be intellectual constructs (epistemologies)
Talks the language of 'problems' and solutions'	Talks the language of 'issues' and 'accommodations'
Advantages	**Advantages**
Allows to use of powerful techniques	Is available to both problem owners and professional practitioners; keeps in touch with the human content of problem situations
Disadvantages	**Disadvantages**
May need professional practitioners	Does not produce final answers
May lose touch with aspects beyond the logic of the problem situation	Accepts that inquiry is never ending

Table 2.2 The 'hard' and 'soft' traditions of system thinking compared (Checkland 1985).

2.13. Summary

Production is an art of converting raw material into a useful commodity; how efficient this conversion is, depends upon the control of variables that perform the transformation process. In this era of global competition it is paramount for organisations to excel in building strong relationships with customers whilst improving on quality, cost and the delivery of products. Management should strive to identify and implement innovative strategies to counteract the threat from competition and strengthen the stability of the organisation. In doing so, organisations need to be updated with contemporary and effective management styles and techniques to help remove inefficiencies and improve overall profitability. It is of utmost importance that whichever techniques are implemented fully coincide with the most prominent requirements of the business. For example lean manufacturing is a tool box and within that tool box there are several tools, each tool is specific to a particular job and will benefit the organisation most when used in the right place and for right purpose. In order to use the right tool it is necessary to understand the problem situation from a holistic view. SSM is an excellent technique to understand and analyse the key issues in the form of conceptual models. SSM moves away from the idea of an 'obvious' problem requiring a solution focusing on the idea of a 'situation' that people may regard as problematic. One of the lean manufacturing tools is cellular manufacturing. The fundamental philosophy of cellular manufacturing is to assign a 'Group' of machines for the manufacture of a 'Family' of parts. It is mainly implemented in the metal cutting industry. However the benefits such as on-time delivery, improved response, reduced inventory, improved quality and improved workflow, claimed by this approach can be achieved by other industrial sectors as well. The concept of *Pareto* provides the ability to focus on a small number of issues from a given set that have maximum influence. With the help ABC analysis product lines can be categorised and treated in a way that maximises the profitability of the organisation. The slightly complex yet effective way to control and manage the criticalities in the business has been intelligently defined by the multi-criteria ABC analysis.

Many researchers have strongly suggested the need to reduce production batch sizes to reduce overall inventory costs. The suggested EBQ model for batch size is based on limited variables and does not accommodate variables that are specific, and differ form organisation to organisation. This suggests that production batch sizes should be controlled in a way that provides smooth customer service whilst keeping minimum inventory costs. This is possible not only through internal controls but requires the entire supply chain to provide seamless flow of material to fulfil end-user demand. In today's world customers are expecting high quality products with continually low prices. In order to meet the high expectations of customers, supply-chains need to unite and provide transparency into each others organisations. It is believed that in years ahead it will be the fluent, well organised supply-chains that will prosper in the global market as opposed to organisations which despite being well organised act independently.

Thompson Plastics (Hessle) Ltd. has substantially increased production activities over the past few years resulting in increased product variety, shortened life cycles, highly variable demand patterns and an erratic production schedule; the company over this time was unable to sustain its "traditional" ways of managing and controlling its manufacturing activities, much of which were driven by the knowledge and expertise of people who had been working in the organisation for a long time. In fact, ironically, staff turnover and loyalty was not an issue. This chapter characterises the production environment of TP (Hessle) Ltd and investigates the underlying issues that are affecting the performance of the company.

3.1. Thompson Plastics (Hessle) Ltd

In identifying the problem situation, it is usual to comment first on the key global metrics which are as follows:

- There were 118 customer delivery sites[2];
- Workforce of 105 excluding 40 employees working for the group and based at Hessle site[3];
- TP Group turnover £36 Million (2003-4);
- TP Hessle turnover of £8 Million (2003-4).

3.2. Initial examination of the problem situation

TP (Hessle) Ltd. has a workforce striving to achieve a higher standard of service now expected by customers. Before an in-depth analysis of the manufacturing operations was undertaken, some initial analyses were carried out to establish any overlaying generic issues or any factors related to the operating environment of the company. The tools used to conduct these analyses were Stakeholder analysis, SWOT (Strength, Weakness, Opportunity and Threat) analysis and sales portfolio.

[2] Source: Tetra ERP system, 18/02/04
[3] Source: TP Site Director report, 18/02/04

3.2.1. Stakeholder Analysis:

Stakeholder analysis is the identification of a project's key stakeholders, an assessment of their interests, and the ways in which these interests affect the organisation. The first step in stakeholder analysis is to identify the stakeholders in a project. Figure 3.1 shows the key stakeholders of the company. The next step is to work out their power, influence and interest, so as to identify the focal bodies. Hence following the initial identification of the stakeholders, an evaluation was undertaken to establish the importance to as well as their influence on TP. The stakeholder analysis is summarised in Table 3.1. The score in the 'Influence' and 'Importance' columns within the table is rated between a minimum of 1 and maximum 5. The final step is to develop a good understanding of the most important stakeholders thereby highlighting how they are likely to respond, and to plan a better strategy to validate the weighted score generated in Table 3.1.

Figure 3.1 Key stakeholders in the company - as perceived by the author.

Stakeholders	Expectations	Impact (Imp*Inf)	Importance	Influence
Plastic Industry	New technology and continuous services	**+ 6**	3	2
Government	Compliance to regulations	**+ 2**	2	1
Department of Trade & Industry	Growth and development of Plastic industry	**+ 6**	3	2
Top management	Growth and development of the group with higher profit and prosperous business	**+ 20**	4	5
Director	Overall business stabilisation, increase in profit and better customer relations	**+ 16**	4	4
Employee	Good salary and benefit	**+ 12**	3	4
Suppliers	Prompt payment	**+ 16**	4	4
Customers	High quality and low cost of finished products with ontime delivery	**+ 20**	5	4
Educational Institutes	Technology Development and enhancement in teaching and research.	**+ 1**	1	1

Table - 3.1 Stakeholder analysis - as perceived by the author.

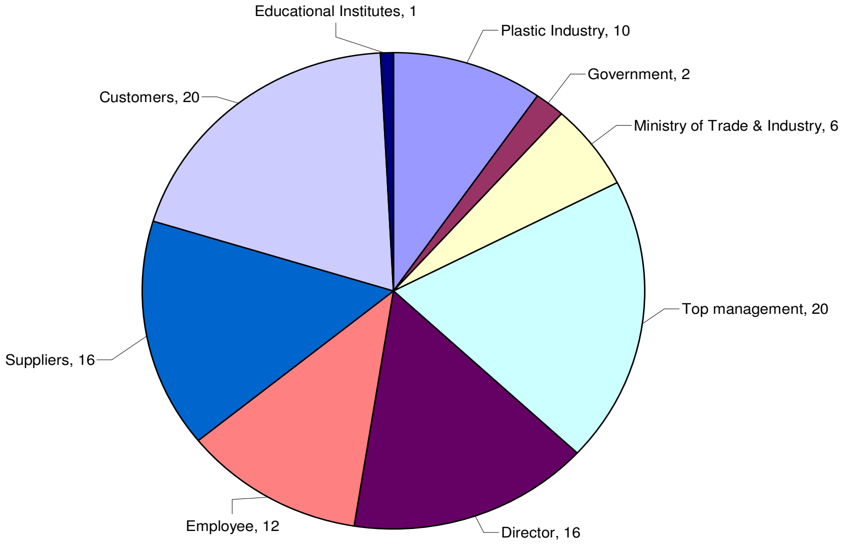


Figure 3.2 Stakeholder impact Pie Chart.

The weighted scores presented in Table 3.1 are reflected in Figure 3.2 in the form of a pie chart. It is perhaps not surprising that the customer is ranked first with a score of 20 along with the top management. It is also interesting to note that the stakeholder analysis reveals following facts:

- Customer, Suppliers and Directors were the most important factors of the organisation.
- The above three had a direct influence on the profitability of the organisation.
- The Government did not have a major stake in the organisation in terms of regulations and compliance.

As identified from stake holder analysis; customers, suppliers and directors were the major players in supporting and influencing the organisation. The project was geared to identify key issues from the perspective of key stakeholders and to find an optimal solution to overcome those issues, some of which may include improvement in delivery performance and shopfloor efficiency

3.2.2. SWOT Analysis:

A SWOT analysis examines the Strengths (S), Weaknesses (W), Opportunities (O) and Threats (T). It has always been important for a business to know and understand how it fits in and interacts with the surrounding environment on both an internal (office/factory/shop environment) and external basis (how a business operates within the outside world). A SWOT analysis is used primarily to evaluate the current position of a business from an internal perspective and to determine a management strategy for the future. Figure 3.3 shows an elementary diagrammatic form of the SWOT analysis for Thompson Plastics. A more detailed commentary is provided below.

Strengths	Weaknesses
• Specialized machines • Strong organisational culture • Dedicated workforce aiming to reach higher • Specialized engineered products manufacturer	• Complex management structure • Computer system difficult to cope with production requirement • Complicated production planning • Shop floor space utilization
Opportunities	**Threats**
• Exploit specialised machines • Takeover of rival companies in weak position with lack of experience • Government policies	• Customers moving to other places (developing countries for cheaper production cost • New rival entrants • Governments policies (regulations)

Figure 3.3 SWOT analysis.

Strengths:

The strength of the company lies in its hi-tech machines, workforce, and organisation. The specialised process Long Fibre Polyurethane Reinforcement (LFPuR®) produces hi-definition composite products. LFPuR® technology when coupled with other materials such as Acrylic Capped ABS, provide products which are tough, have excellent aesthetic appearance (colour and gloss), and possess good UV protection essential for external (outdoor) products. The dedicated workforce is a key strength and is necessary for the improvement and growth of the business.

Weaknesses:

The main weakness in the company is seen as the complex management system. Additionally the group's resources are divided between numerous sites with little top-management control. This potentially results in a complexity and confusion of managing and controlling resources. The computer system is another weakness which affects the entire company. The computer fails to deliver the specialised requirements necessary for planning and production thereby highlighting other weaknesses, such as poor level of user knowledge. Other weaknesses include improper utilisation of floor space and inadequate production planning.

Opportunities:

The LFPuR® is seen as a futuristic process. This can attract customers with specialised requirements. Many organisations in the plastic industry are keen on strong yet light weight plastic components. This process may interest those organisations and which may, in turn, strengthen the position of the company.

Threats:

The real threat comes from rival companies entering the market and being able to sell products at a cheaper price and at a faster pace with comparable quality. The relocation of customers to other countries for cheaper production can be a direct threat to the business, as is government policy, and new environmental legislations.

The SWOT analysis has shown that the organisation is supported by a well-trained workforce with good team working skills. The analysis also shows that the organisation specialises in the manufacture of hi-tech products, however there appears to be some internal issues in managing and controlling resources. There appears to be requirement for a robust yet flexible production processing system that could influence the primary requirement of the business. The analysis also suggests that there is a need to further understand the complexity within the business using more analytical tools and techniques.

3.3. Sales/Product Portfolio

Sections 3.1 and 3.2 provided an overview of the situation and suggested a need for a more directive strategy towards customer service. In order to understand the underlying complexity, a more detailed analysis was further required. An analytical approach to product lines and their sales value was therefore undertaken and is described in Figures 3.4 and 3.5, showing the sales value and quantity sold to each customer in the financial year 2002/03 and 2003/04, respectively. The analysis showed that:

- Thermoking was the top sales value customer followed by AGCO Ltd. and then Wrightbus Ltd.
- Plastics Manchester (sister company) was the lowest value customer.
- In terms of value to volume ratio, the customer with the highest value was shown to be 'Wrightbus', *i.e.* products sold to Wrightbus tended to have a high monetary value.

In this analysis, although it is not at all obvious, it should be noted that each organisation listed in Figures 3.4 and 3.5 are not independent of each other. There are many companies that are actually subsidiaries of major groups or represent different delivery locations. In analysing Figures 3.4 and 3.5, various comments can also be made about the transition in the pattern of sales from one year to the next. Over the two years in question, the changes observed are:

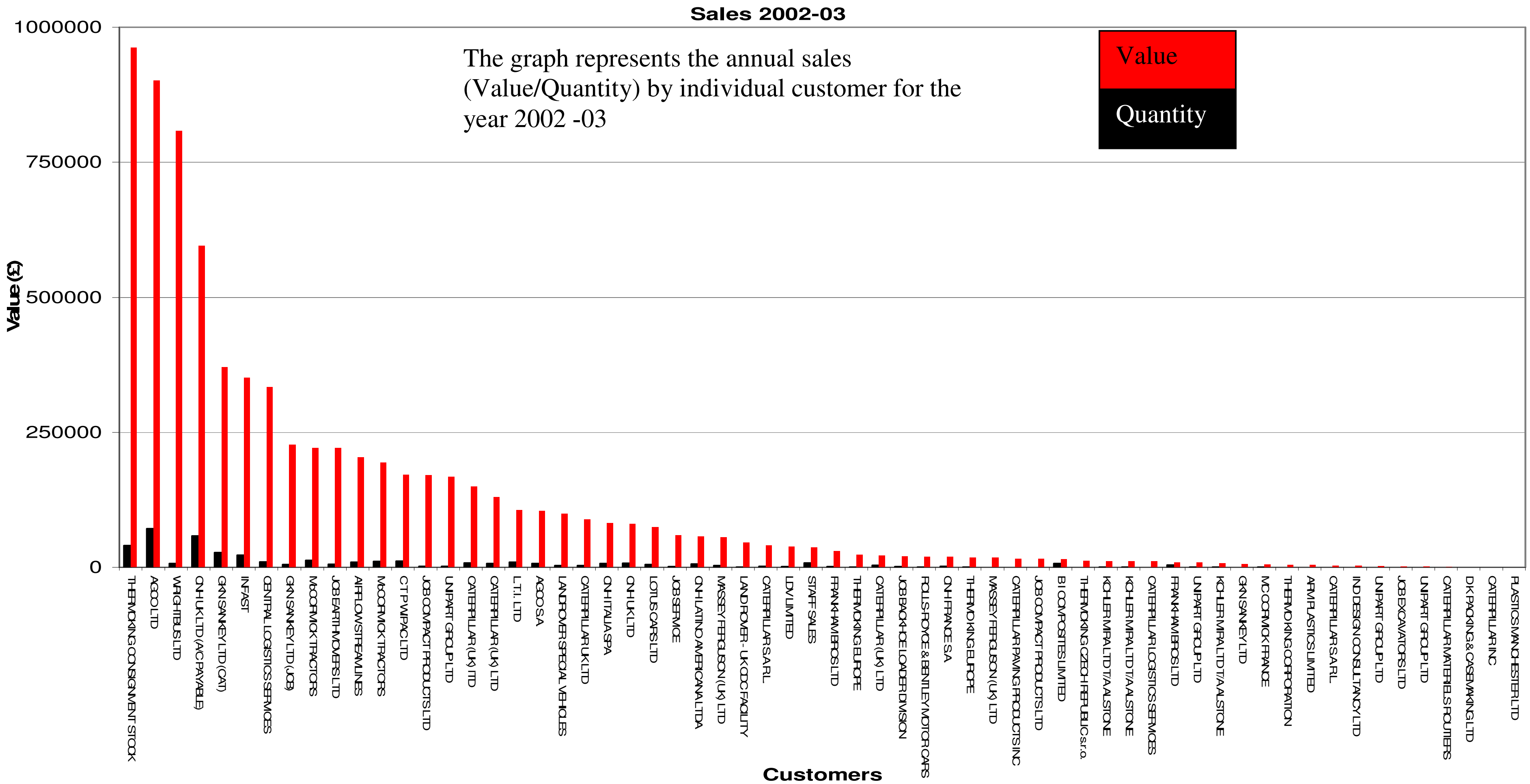


Figure 3.4 Sales chart (2002-03).

- Thermoking Consignment remains the top sales value customer followed by CNH UK Ltd. and Wrightbus whereas AGCO Ltd. loses its second place. Further investigation showed this was caused because the company moved overseas and much of the business was transferred to local suppliers. This is a practical example of "Threat" in SWOT analysis presented in Figure 3.3, where customers are moving overseas to reduce costs or due to any other reason.
- From Figure 3.5, JCB Earthmovers Ltd. is the lowest value customer. From Figure 3.6, JCB as a group though is not the lowest value customer. This suggests that the services required by the group need to be uniform and based on group regulations. The service level should be irrespective of how often or how much the subsidiary company orders.
- High value products were supplied to Wrightbus Ltd.
- The quantity of products sold to CNH UK Ltd. is much higher than that of the top sales value customer (Thermoking Ltd.). This demonstrates that it does not necessarily mean that the customer with highest monetary value will be the one with highest quantity demand.

It is apparent from Figure 3.4 and 3.5 that there is an erratic sales pattern from customer. Customers were continuously changing product varieties and order quantities. In order to 'delight' customers a methodology was required that not only promise improvement in customer service but also improve efficiency and promote lean production.

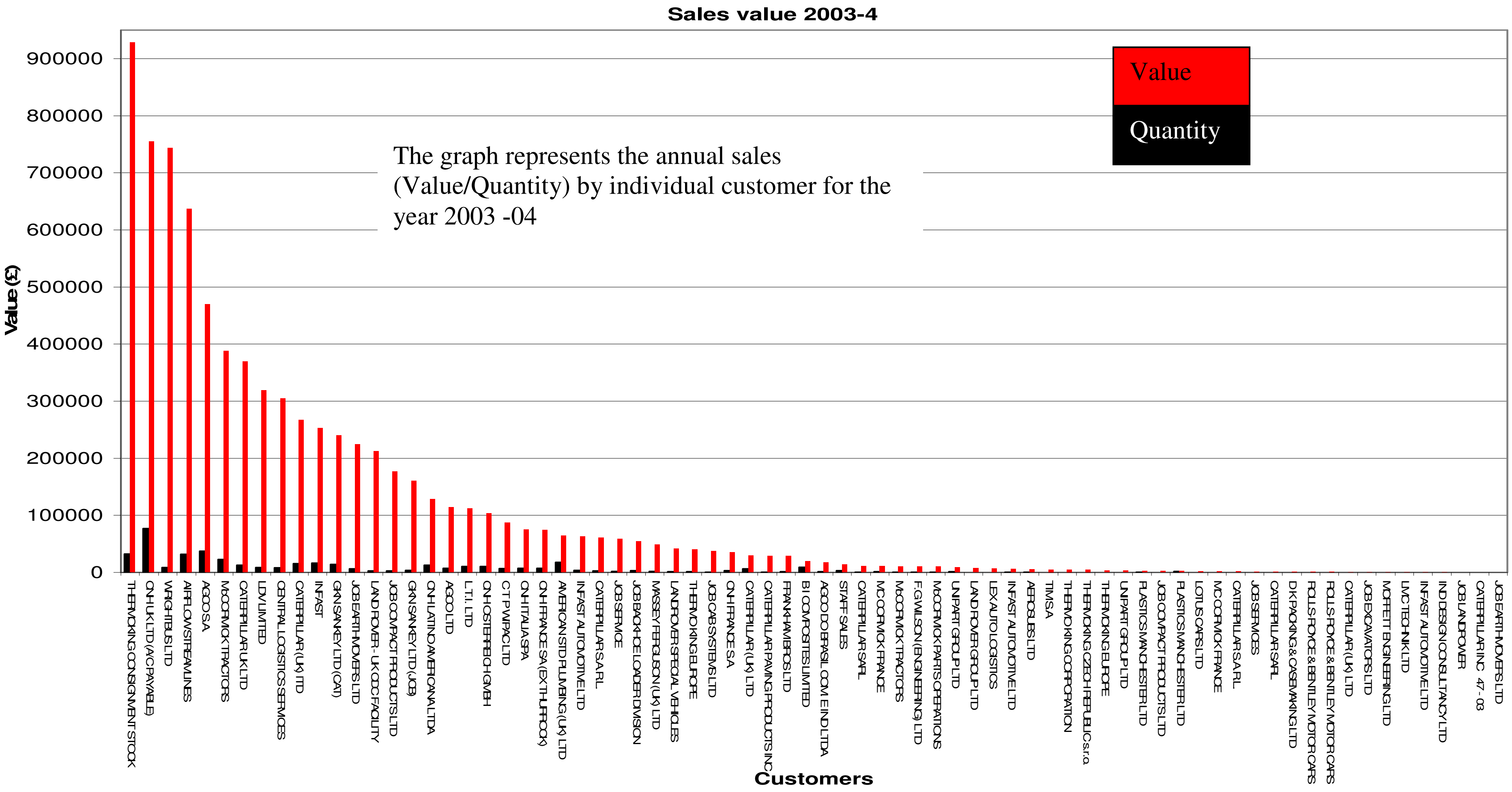
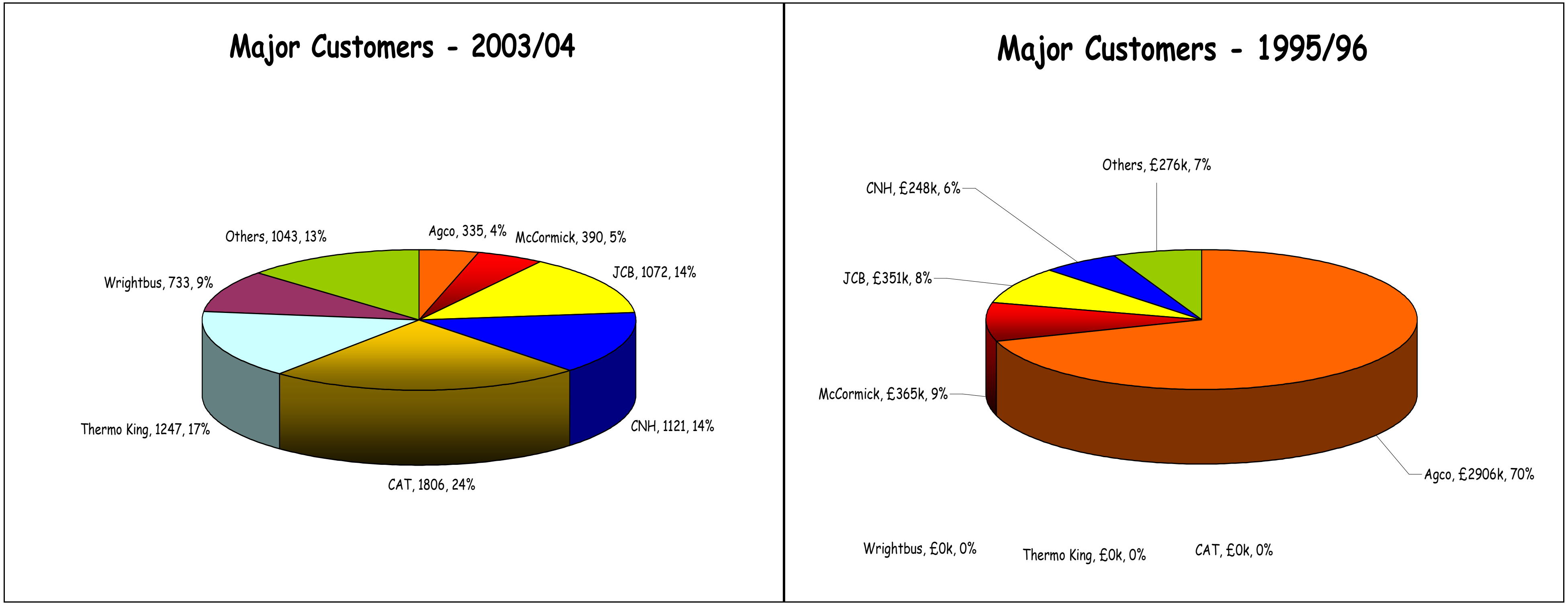


Figure 3.5 Sales chart (2003-04).

3.3.1. Customers Group

Perhaps more useful, is to combine the customers into groupings based on their parent company. This is illustrated in Figure 3.6 where the chart shows a different pattern to that observed for individual customers (Figures 3.4 and 3.5). The pattern shows eight major customers with % share of sales ranging from 4% to 25%. When compared to a similar analysis for sales data in the financial year 1996-97, Figure 3.6(b), the analysis shows a remarkable shift in behaviour of the company in question. The following inferences can be made:

- As a group, Caterpillar was the highest value customer for year 2003-04 (24%), whereas in the year 1995-96 it was not even a TP's customer. Similarly Wrightbus and Thermoking were both high turnover customers in the year 2003-04 and yet did not appear in the sales chart of TP for the year 1995-06
- It is interesting to note that in the year 1995-96, Agco was a significant customer contributing 70% of total sales. By the year 2004-04 the sales for this customer went down to 4%. This suggests that the market is extremely turbulent and unreliable and it is essential to penetrate into new markets and look for more opportunities to get more business and increase profits.
- An increase in turnover for customers JCB and CNH was noticed in the year 2003-04.



(a) (b)

Figure 3.6 Customers group sales (a) 2003-4 (total sales £4146k) and (b) 1995-96 (total sales £7747k).

3.3.2. Pareto Analysis on Sales

The sales figures for 2002/3 and 2003/4 exhibit a wide range of variation between sales for different customers. If a Pareto analysis is undertaken, Table 3.2, 20% of customers accounts for approximately 75-80% of sales. This perhaps highlights the view that not all customers should be treated equally. There is a clear need to maintain sustainability by ensuring these 20% of customers remain very satisfied. This is not to say that the remaining 80% of customers should be considered secondary. A more sophisticated yet simple strategy is required to provide customers with quality products by focusing any manufacturing activity based on sales.

Pareto Analysis		
Year	**Top Customers (%)**	**Sale (% Value)**
2002-3	**20**	**75**
2003-4	**20**	**79.4**
2003-4	**(By group) 20**	**69**

Table 3.2 Pareto analysis.

3.4. Identification of Issues in Maintaining Manufacturing Efficiency

Following the initial analysis, an exercise was undertaken by interviewing a range of employees to identify what issues there were in maintaining manufacturing efficiency. The initial task included observing the working of the factory from planning to production and then dispatch; also gathering data from the team leaders, managers, operators and other related staff. The data gathered revealed various shortcomings and waste in the processes being conducted, overall the general principles of manufacturing were not being practiced to the extent that they should be. A list was prepared of all those activities which probably did not add value and seemed to be wasteful from a manufacturing point of view. The list summarised below briefly highlights the areas that require further investigation, and which provide some of the inputs into a system analysis. The list is separated into functions for ease of analysis.

Planning

- Sales order booking involved the manual process of analysing and estimating the quantity to be manufactured.
- Sales/works orders were booked four months forward.
- No set production schedule – flexible until last minute.
- Information was not frequently updated – *i.e.* changes to CNC programs, material availability and defect or quality issues during or after production.
- Planner needed to control parts at every level of the product bill of material (BOM).
- Lack of communication, *e.g.* people in production may not inform quality of any minor/major quality issues.
- Extensive use of paperwork, *e.g.* production schedule printed at least three times a week.
- Whilst booking sales orders, WIP and capacity issues are not considered.
- No acknowledgement to customers of delivery dates.

Issues at Production

- Production schedule printed for a month: the following day the production schedule was different to previous schedule.
- Updated every day and printed about three times a week by production team.
- Lack of organisation and communication.
- Routes and BOM's are not updated on regular basis resulting in inaccurate capacity measurement.
- Complex tooling structure can make it difficult to set-up MRP system.

Processing

- Production manager decides the priority of orders every day.
- No set of rules for setting priority.
- Production progress of assemblies was not visible.
- Combining orders with similar set-ups even though they might have different delivery dates.

- At times, parts not required until production due date have been manufactured up to two weeks early.

Machines

- Moulding machines 1, 6 and 9 have high work load compared to 2, 5 and 7.
- Set-up times need to be reduced for small batch production requirements.
- Batch order quantity of as low as five units was produced.
- Jobs dating back one month awaiting trimming. This was because trimming is a one piece process while moulding can be multiple impression therefore to justify economies of scale 'X' number are moulded and only 'Y' will be trimmed and the remaining 'X-Y' will await trimming until required by the customer.

People

- Unnecessary movement.
- Inter-departmental training required so as to understand the manufacturing processes and importance and significance of up and downstream processes.
- Introduction of change agent (KTP scheme) gave both a good and a bad impression to the workers within the company. As always brings a factor of uncertainty and a feeling of insecurity specially at the ground or lower level of organisation.
- Inefficient utilization – *e.g.* one operator could operate two machines if feasible.
- Lack of communication between moulding-trimming departments.
- Key people like the production manager, production supervisors and planners spend a lot of time fire-fighting.
- People on the shop floor required training in order to focus on value-added activities.

Floor Space

- Introduction to 5'S (at the shop floor with special attention to stores).

- No dedicated space for parts from leisure side (impacts on TP (Hessle) activities).
- Obsolete tools holding substantial shop floor space.

Stores/Purchasing

- Excess material.
- No material stocking procedure in stores.
- No proper IT management.
- Material dating back to 1995 still in stores and been hardly used.
- Reject material dating back to 05/2002 still in the store area awaiting action.
- Unauthorised movement of material from stores.
- Re-order level report printed everyday includes obsolete material item list.
- No proper record of bulk issue material. Black hole.

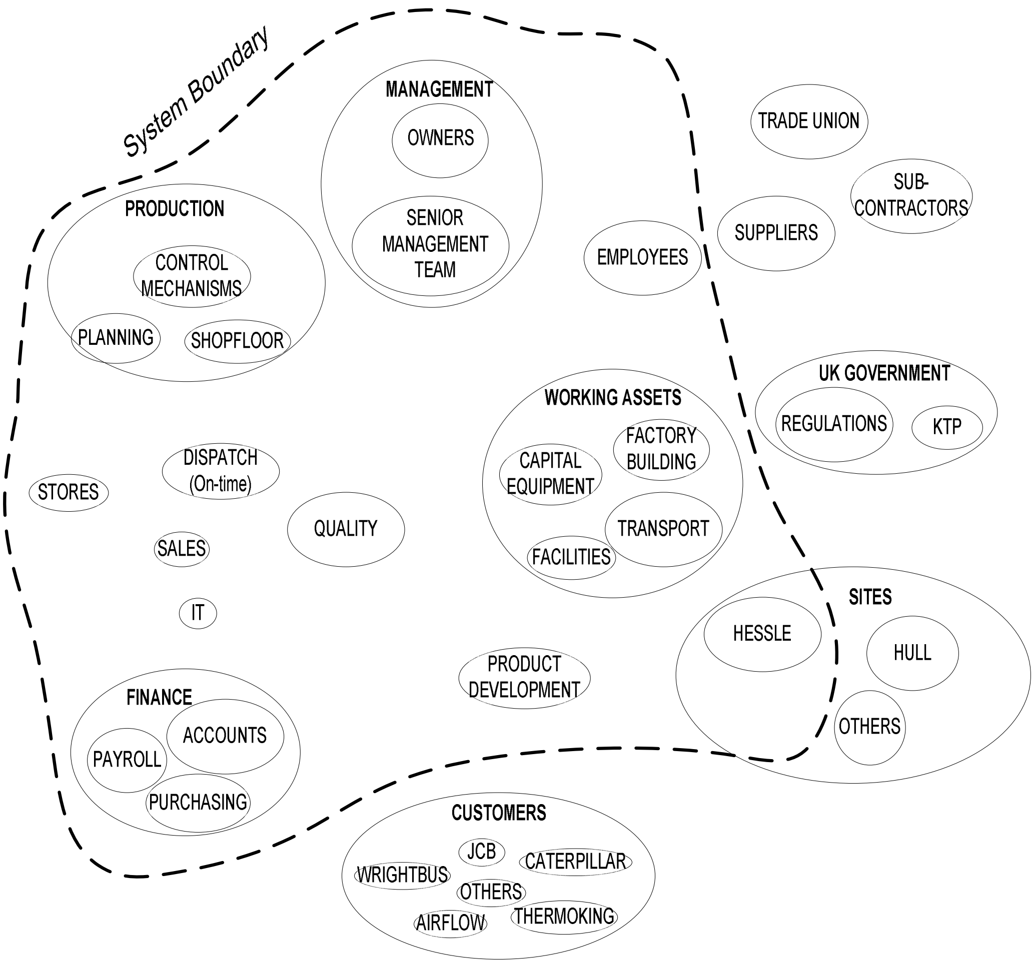
Inspection

- No regular checks at production stage.
- Training required so that no continuous batch of scrap is produced *i.e.* identifying rejects at early stage.
- Visual quality control procedures could be helpful in identifying and eliminating rejects.

It was difficult to define a particular person, department or unit that was responsible for the overall state of complication in the production system. The observations made from interviews with the various classes of workers led to the conclusion that a more detailed examination of the management processes operating within the company was required. On the grounds that manufacturing issues were identified at an initial stage, a need to further explore the causes of waste at different levels lead to the mapping and investigation of various activities at every phase of production system.

3.5. Soft System Analysis

As stated in Chapter Two, a hard system is an approach to solve a problem when the goal is predefined. It is focused on the study based around achieving the goal. SSM is applied when the goals are often obscure. There have been several tools used, including 'hard' systems, in the previous sections to understand the underlying issues in the production system at TP. It was also obvious that the problem existed in several departments and sections of the manufacturing system at TP and tackling any of these perceived problems could be expected to produce improvements. However with the existence of so many candidates, solving one issue may not impact the overall inadequacy in the problem situation and hence a holistic approach was required. The analysis was started by exploring and expressing the situation with the help of diagrammatic techniques and/or other pictorial maps.



<u>**Figure 3.7** A Systems map of operation at TP (Hessle) from the perspective of an analyser.</u>

The systems map presented in Fig 3.7 can be used to identify the major influence that may be occurring in the company in the form of an influence diagram, Figure 3.8. The influence diagram only shows the major influences and it is recognised there are many other minor influences not shown. It should also be recognised that the diagram is a partial view from the perspective of this analysis. For example, an employee may have a different view of the major influences. The diagram shows that a major system has feedback, as the control mechanism and procedures that operate between planning, production and purchasing. The diagram also shows the importance of on-time dispatch of future sales which primarily is a pre-requisite to long term sustainability in order to keep the customer satisfied.

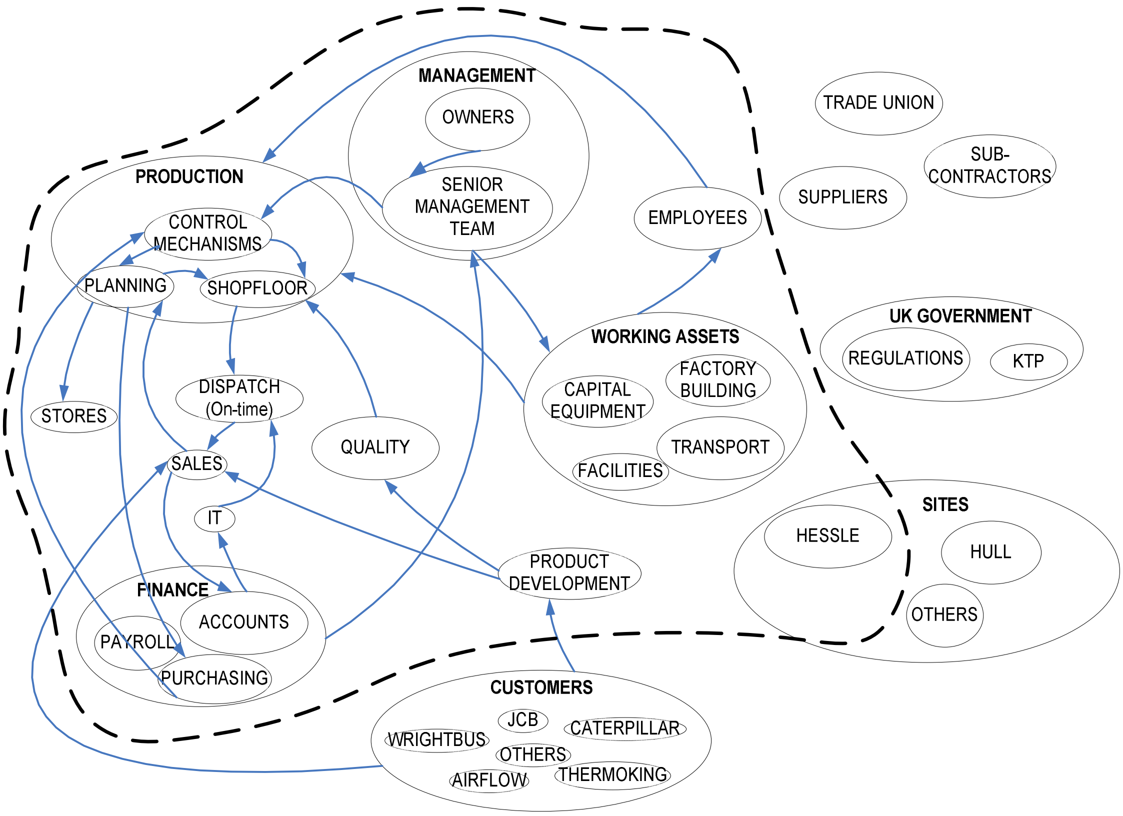


Figure 3.8 Influence map from the perspective of an analyst.

From the influence diagram and what has been learnt, a multiple-cause diagram can be generated which illustrates how some of the problems identified earlier arise. A key feature that could be seen as an intervention point in the system is the triggering of the system (input) by the customer with their requirements for products. As discussed, planning department processes customer orders and that initiates further processes within purchasing and planning systems. From previous analysis, the constant change of customer schedules causes disruption and chaos on the shop floor. The key focus seems to be on the regular uncertainty from customers causing internal instability in the production system. Figure 3.9 shows the interaction of elements within the system as a multiple-cause diagram. As can be seen, there are six feedback loops identified which relate to the following sub-systems.

- **Customers Orders**
- **Planning**
- **Purchasing**
- **Production**
- **Stores**

The multiple-cause diagram shows several key issues such as the impact of customer schedule changes and the resultant changes to the production requirements. As a result of changes in customer schedules it becomes difficult to precisely determine material requirement quantity and production *due by date*. Furthermore, the changes presented by the customer could cause production to react to this uncertainty and noise by altering the prioritisation of jobs.

The system model shows that there was a pursuit to exactly match the customer demand against daily production and in doing so triggering the continuous loop of activities within planning, production and purchasing with the consequences previously discussed. These activities do not add value to the production cycle and could in part be responsible for the regular fire-fighting (as identified in previous sections) as well as the confusion on the shop floor.

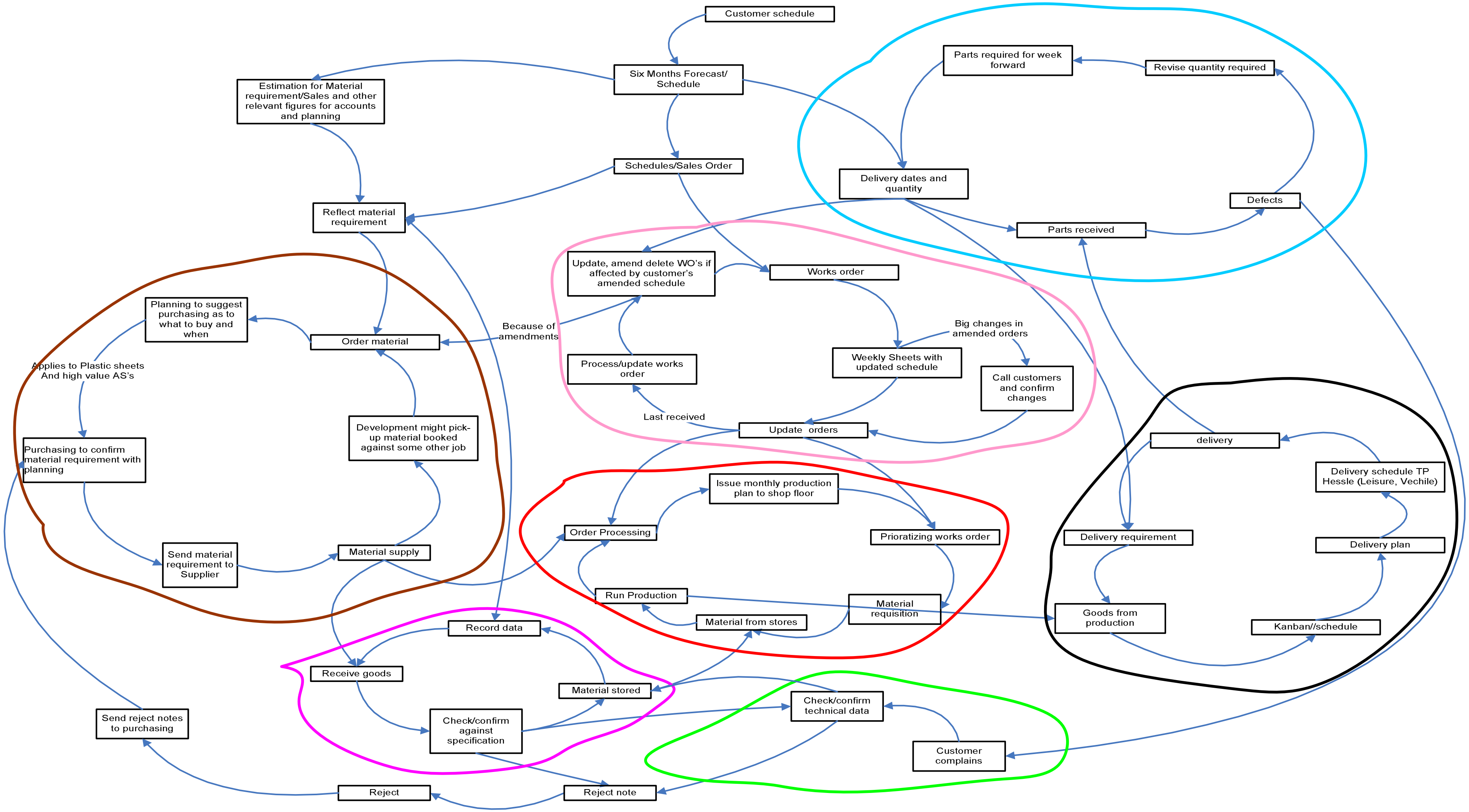


Figure 3.9 Multiple- Cause diagram showing the incidence of non-value activities in production from the perspective of the analyst.

In this study a value stream map (VSM) (Figure 3.10) was used to extend the ideas derived from the systems analysis and present an alternative view of the qualitative model. The value stream map, Figure 3.10, presents the route of the value-added activities in the supply chain from raw materials to delivery to the customer. At each stage the lead time is noted and subsequently used as a measure of performance both to further add value and remove inefficiencies in the process, in this particular case to reduce the lead time so as to ensure on-time delivery to the customer. At each stage of the value stream, ideas (lightening clouds) can be presented to suggest forward improvements. Furthermore, in Figure 3.10 the high lead time suggests the need for an improved production system that stabilises turbulent customer demand and that could potentially be achieved by 'Freezing' production schedules and focusing on imposing better production schedules to minimise the disruption due to customer schedule changes.

So far, the analysis and VSM has identified that the schedules from customers constantly disrupts the production system and thus escalates the effective lead time. It becomes evident that a production system is required that is more stable and isolated from everyday customer noise. In essence there is the possibility that a stable production schedule could improve customer service and reduce fire fighting on the shop floor.

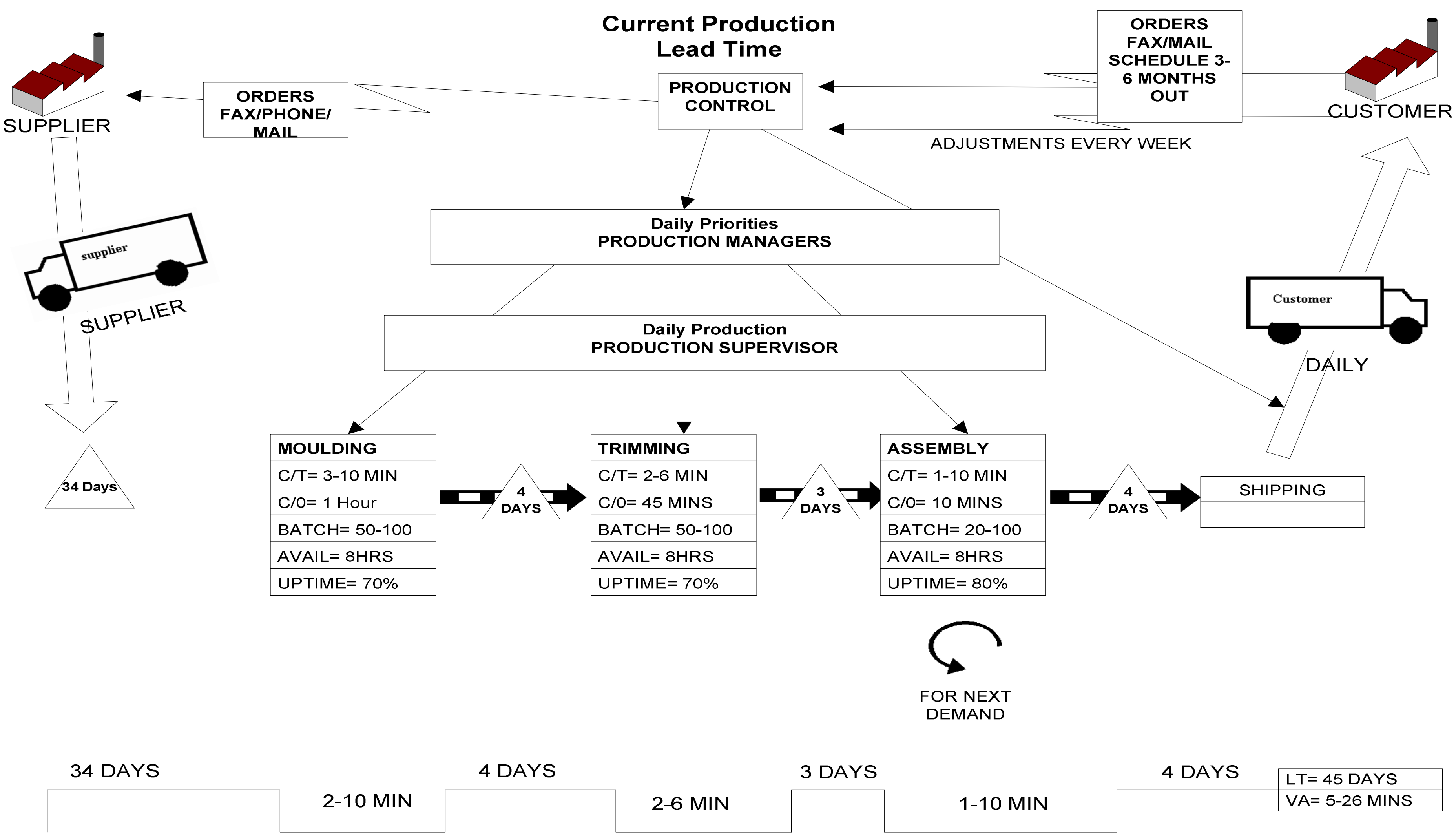


Figure 3.10 Value stream map – Production lead time.

3.6. Survey of Manufacturing Management Processes

Manufacturing management processes at TP have been largely driven by the knowledge and expertise of individuals who have been working in the organisation for a long time. Much of this knowledge is confined to individuals rather than a central knowledge base and this represents a significant risk to the organisation. In general terms, manufacturing activities within TP begins with receiving sales orders/schedules from the customer (Figure 3.11). These are then loaded onto the companywide ERP system by the planning department. This department was also responsible for raising works orders and then eventually issuing production schedules to the production department. Parallel to these activities purchasing refers to the system to order material for production. Production department further produces products which are sent to stores and then eventually supplied to customers. Figure 3.11 illustrates that customer schedules followed by production schedules are continuously changing and creating waste and confusion on the shop floor. To further understand the complexity of the situation different sections of the manufacturing system were analysed individually by adapting different perspectives in a systems analysis.

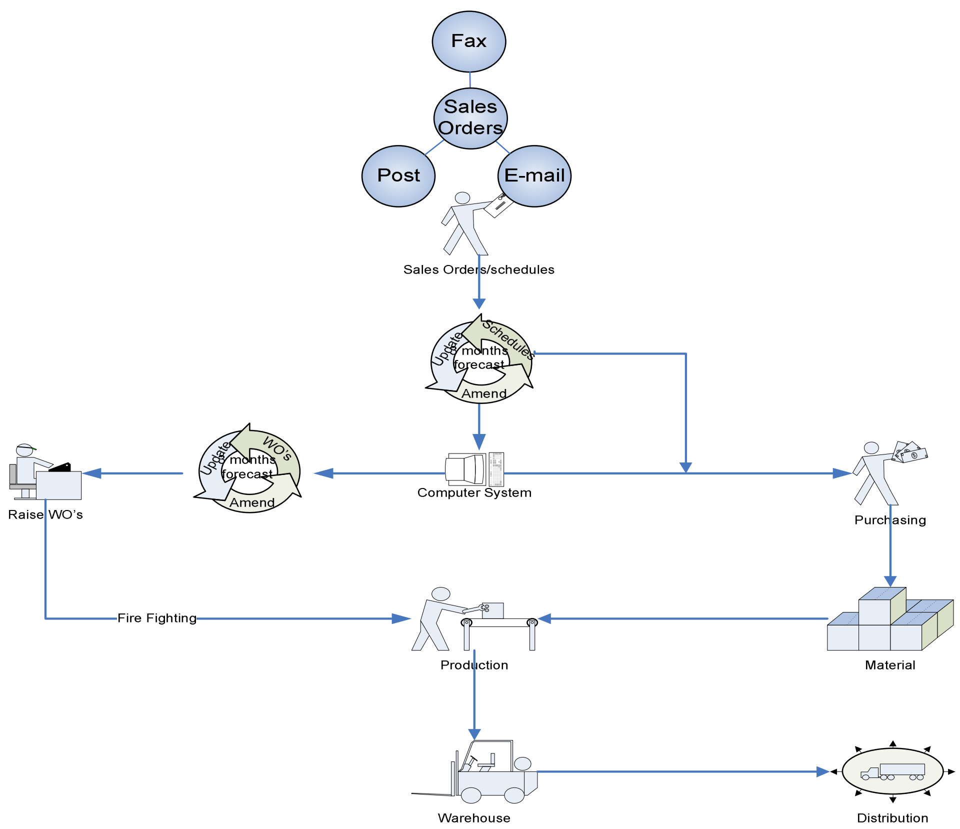


Figure 3.11 Diagrammatic representation of order processing in TP (Hessle) Ltd.

3.6.1. Production Work-centres

As stated earlier, TP has a typical functional layout (Figures 1.1 and 1.2). In a functional manufacturing set-up, all similar types of machine are divided into organisational units each of which specialises in a particular manufacturing process. In case of TP there are seven moulding machines namely; Geiss 1, Geiss 2, Geiss 5, Geiss 6, Geiss 7, Geiss 9 and the Formech (see Figure 1.2). These machines are grouped together to form a moulding department. Similarly, the trimming department was composed of six CNC machines; CNC 1, CNC3, CNC 4, CNC 7, CNC 8 and CNC 9 (as shown in Figure 1.2). Furthermore, there is also an LFPuR department which is an integrated cell that consists of CNC 5, LFPuR, Waterjet, Foam Press and a dedicated assembly area (see Figure 1.2). It should also be noted that there are band saws and other equipment to facilitate production activities within any department. From the information gained so far and a review of current management procedures, the flow of material within work-centres was determined and this is illustrated as a high level flow diagram in Figure 3.12. In the Figure 3.12 material from stores is supplied to the production stations as plastic sheets or other purchased components required to be assembled into parts. The material is processed at different production stations and finally finished goods are sent to stores. There are few products that are sent out to sub-contractors for specific requirements. From the review of the factory layout and also an understanding of material flow, the following inferences can be made;

- The existing layout results in large amounts of material handling, a large volume of work-In-Progress (WIP) inventory, excessive set-up times, and long manufacturing lead times.
- As a result of unstable customer schedule material requirement can not be precisely calculated resulting in material inventory levels becoming ambiguous against the actual requirement at the point of manufacturing.
- In many instances production seems to be unaware of the latest changes to the customer requirement and hence production quantities may not reflect the real customer requirement.
- The workers are presently divided into organisational units each of which is specialised in a particular process or part of a process and thus creating a ‘wall’ between departments. Furthermore, each organisational unit (team) is focused

on a particular process and not necessarily understanding the requirements at downstream levels of production.

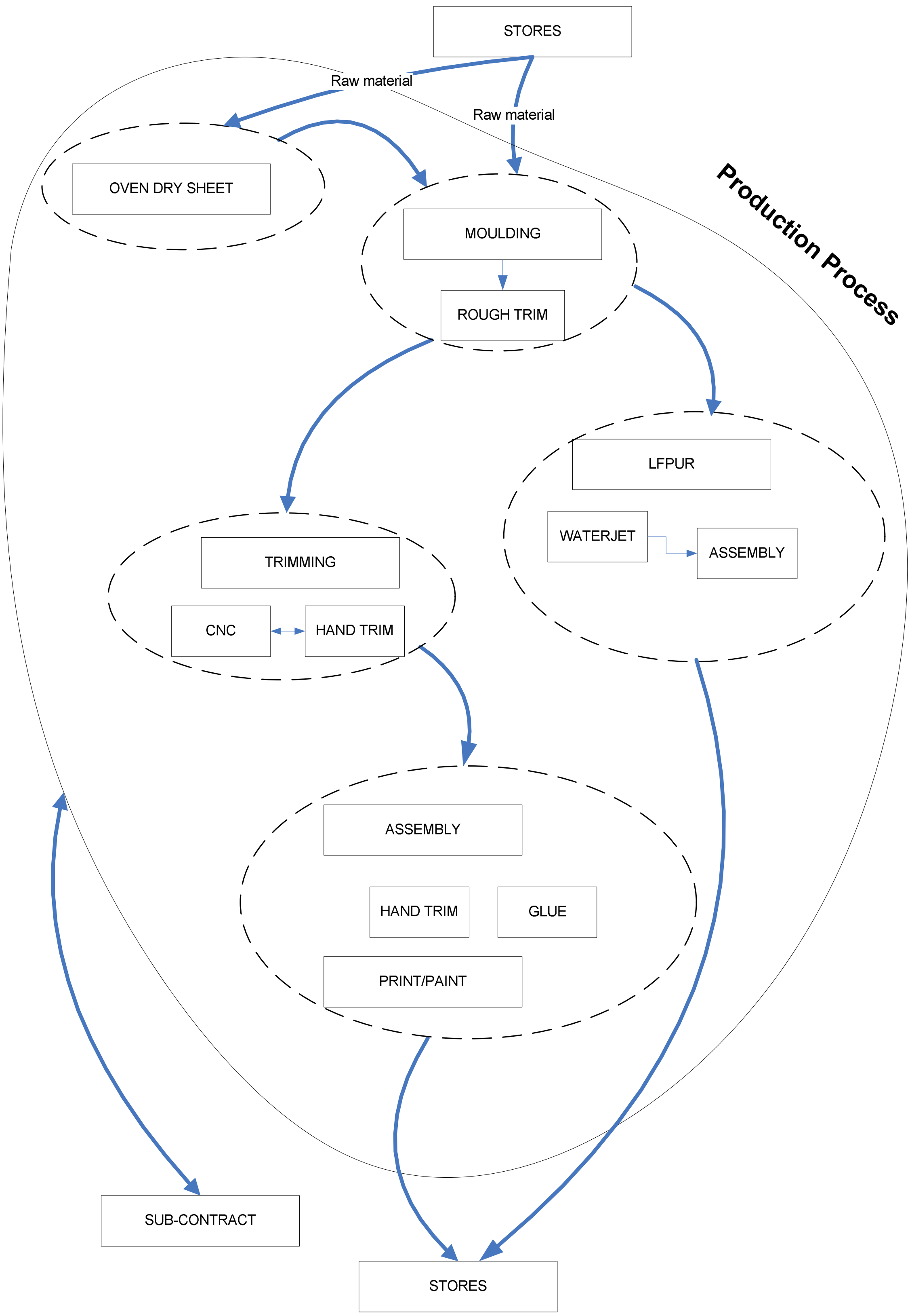


Figure 3.12 Material flow.

3.6.2. Production Planning

Planning department can be seen as the hub of production planning activities within the company. As sales orders/schedules are received from the customer, the information is used to process works orders to instruct the factory to manufacture products. The information provided by the sales orders/schedules supplied by the customer is entered into the company wide ERP system. The information supplied by the major customers is computerised broadly as illustrated in Figure 3.13, noting that the frequency and procedures for placing orders varies from customer to customer. For example, some customers provide schedules on a three month running schedule and then require 24 hour call-off while others may place firm orders for the following two months with expected delivery dates. Works Orders are then raised on the computer system for the subsequent three months for components to be manufactured.

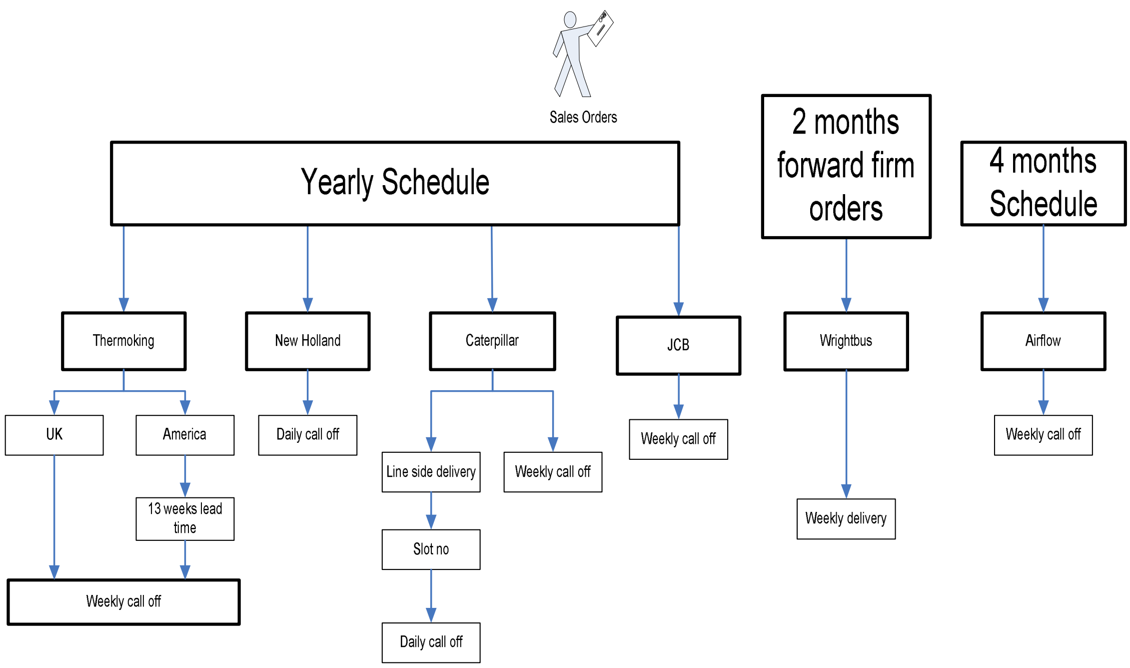


Figure - 3.13 Customer schedule patterns.

3.6.3. Booking Sales Orders/Schedules

In understanding the process by which schedules are converted to works orders on the ERP system, a basic understanding of booking schedules/sales orders is summarised from the information gained in an interview with the planner. Schedules, new or updated, are received from the customers at regular intervals and as per Figure 3.13.

The new product requirement schedules overrides any existing (previously loaded schedule on ERP system) schedules from the customer, any changes on the orders received are amended onto the system. If the volume of parts required by the customer is increased due to these amendments then any necessary variation in material requirement will also be raised. To fulfil the 'new' customer requirement, material is ordered based on the supplier lead time. In instances where supplier lead time is greater than production due date, customers are informed about the delay in supply for products and a new delivery date is provided to the customers.

3.6.4. Creating Works order

As stated previously, works orders are raised against the schedules/sales orders. Any changes to sales orders/schedules are reflected in the works orders until the production of the components is completed. Observation shows that there is constant amending and updating of production schedules due to constant changes from customer orders/ schedules. There are on average 1000 works orders raised every month (source: ERP computer system) and these works orders are updated and amended on a regular basis until they are closed when the parts are produced and allocated against the works order number.

Works Order Creation

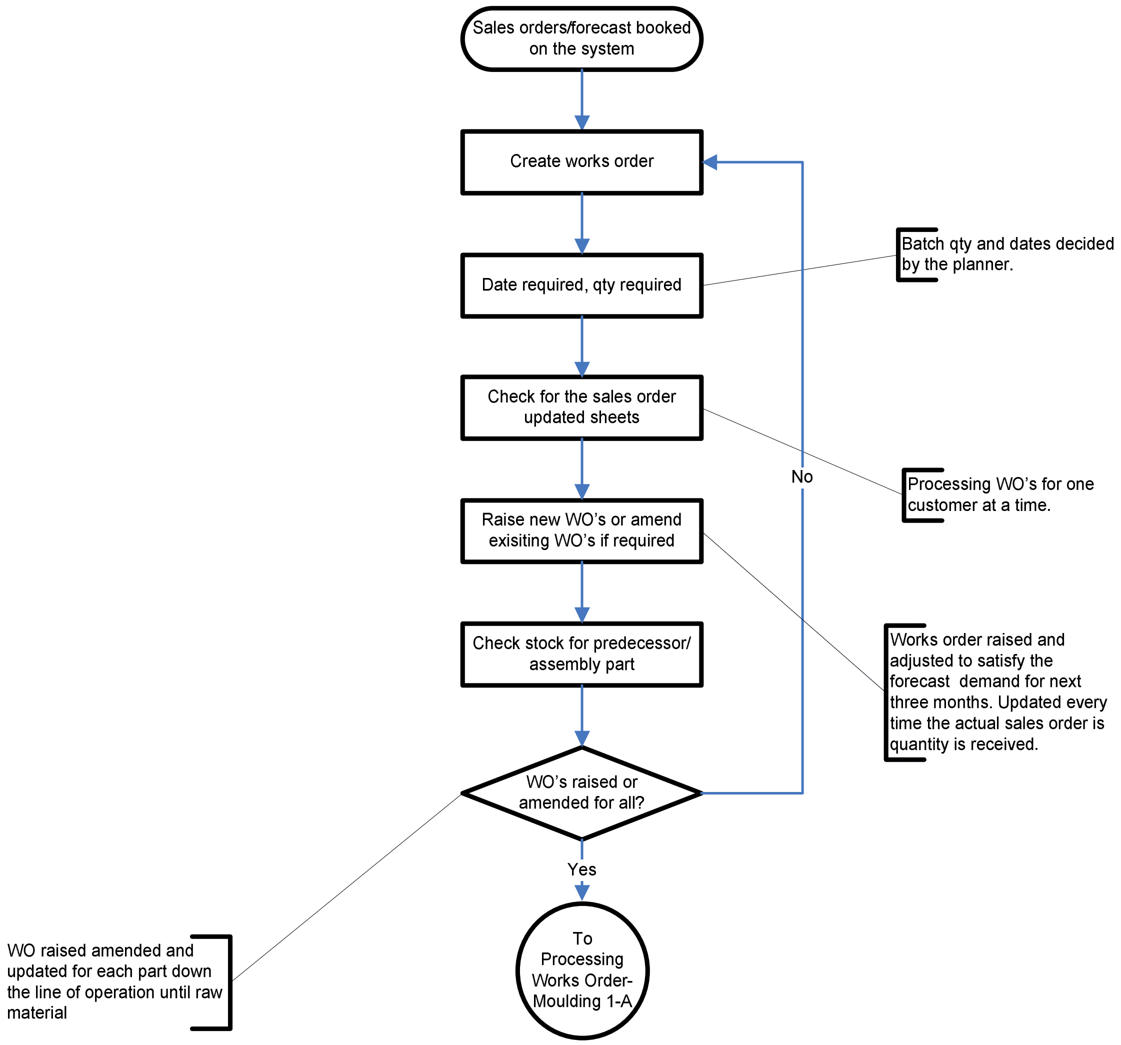


Figure 3.14 Creating works order.

In evaluating the flowchart, Figure 3.14, and from general observations of the planning systems the following comments can be made;

- Works orders were raised to provide necessary information (quantity to produce, due date *etc*.) to production to cover demand from customer.
- Works orders are updated when there are major schedule changes from customers.
- Works orders were raised for all the components in BOM. This is a lengthy process and as observed it does not necessarily allow sufficient time for production to schedule for any last minute changes.

- It was also interesting to observe that the batch quantities on works orders were decided by the planner and vary from one works order to another for the same component *i.e.* there is no rationale for deciding fixed batch quantities.

3.6.5. Production -Moulding

The Planning Department primarily interacts with customers and issues the production schedule to the production department on a regular basis. Planning also issues instructions to production based on customer priorities or due to any immediate changes on schedules. The first phase of production is moulding or thermoforming. The Planning Department issue a forward two week production schedule, updated weekly, to the moulding department. Moulding supervisors prioritise the jobs as per the instructions of production manager. Production managers continuously monitor customer requirements and react to customer 'noise' and issue a priority list to supervisors irrespective of the 'due by' dates issued by planning. In doing so the production team are always fire fighting and unable to focus on an efficient long term strategic approach to production management. In evaluating flowchart, Figure 3.15, and from the general observation in moulding department, the following comments can be made;

- Moulding production schedule is perceived only as a rough guide for production schedule.
- Moulding schedule is prioritised by production manager on a regular basis.
- Production reacts to short-term issues based on customer noise which may not be the most efficient and effective manufacturing strategy.
- Production quantities may not be followed as suggested by planning resulting in regular split batches.
- Set-up time on machines increases as a result of practising split-batch production.

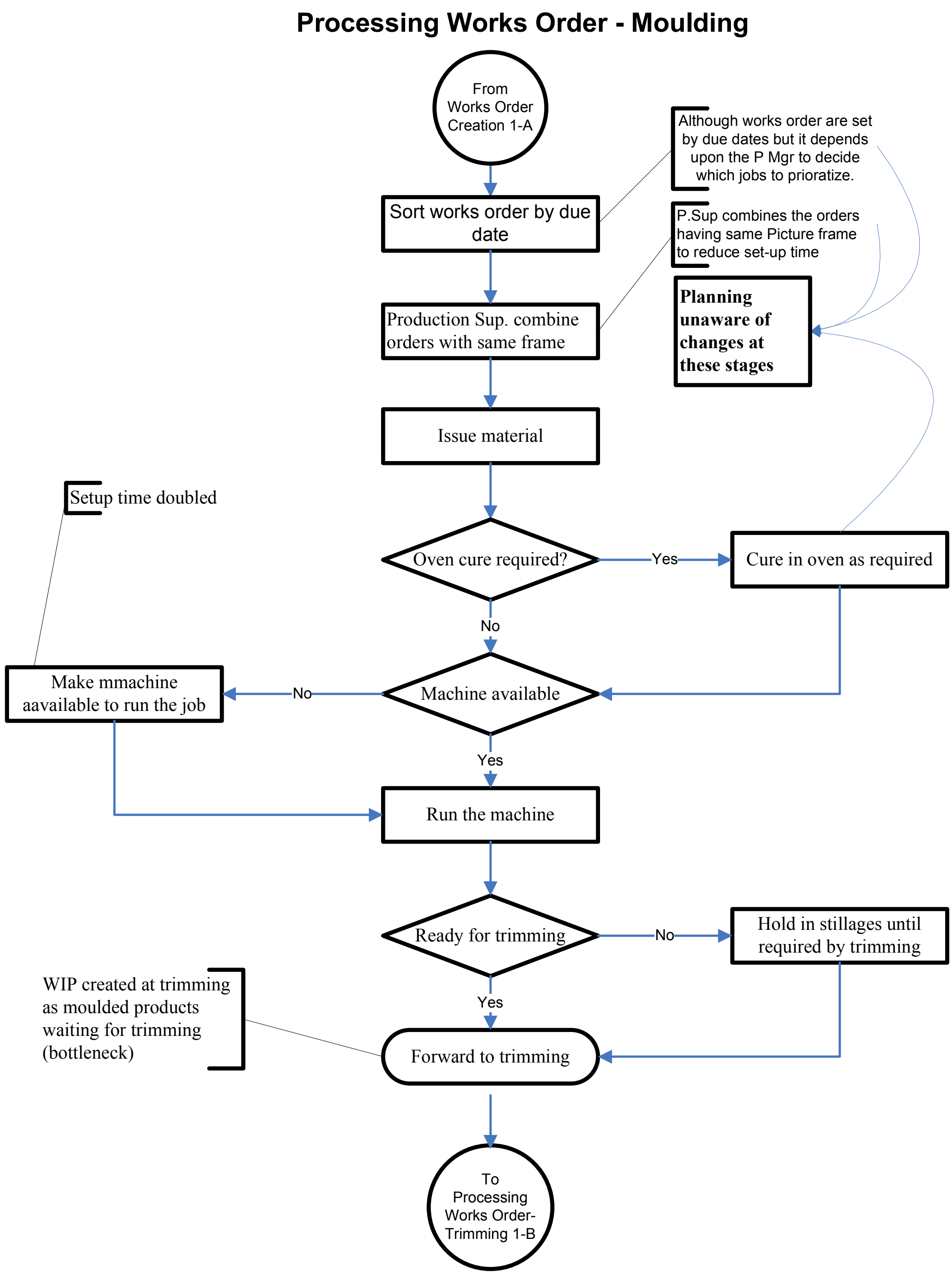


Figure 3.15 Production -Moulding.

3.6.6. Production -Trimming

After the products were moulded they were then either passed on to the trimming department or left in the stillages for future use. The processing of trimmed parts was similar to that adopted by the moulding department. Production managers were the key personnel in prioritising and allocating jobs to machines. Flowchart, Figure 3.16, shows the processing of works orders at the trimming department. Comments and observations from the flowchart (production-trimming) are similar to those derived from Figure 3.15 (production -moulding).

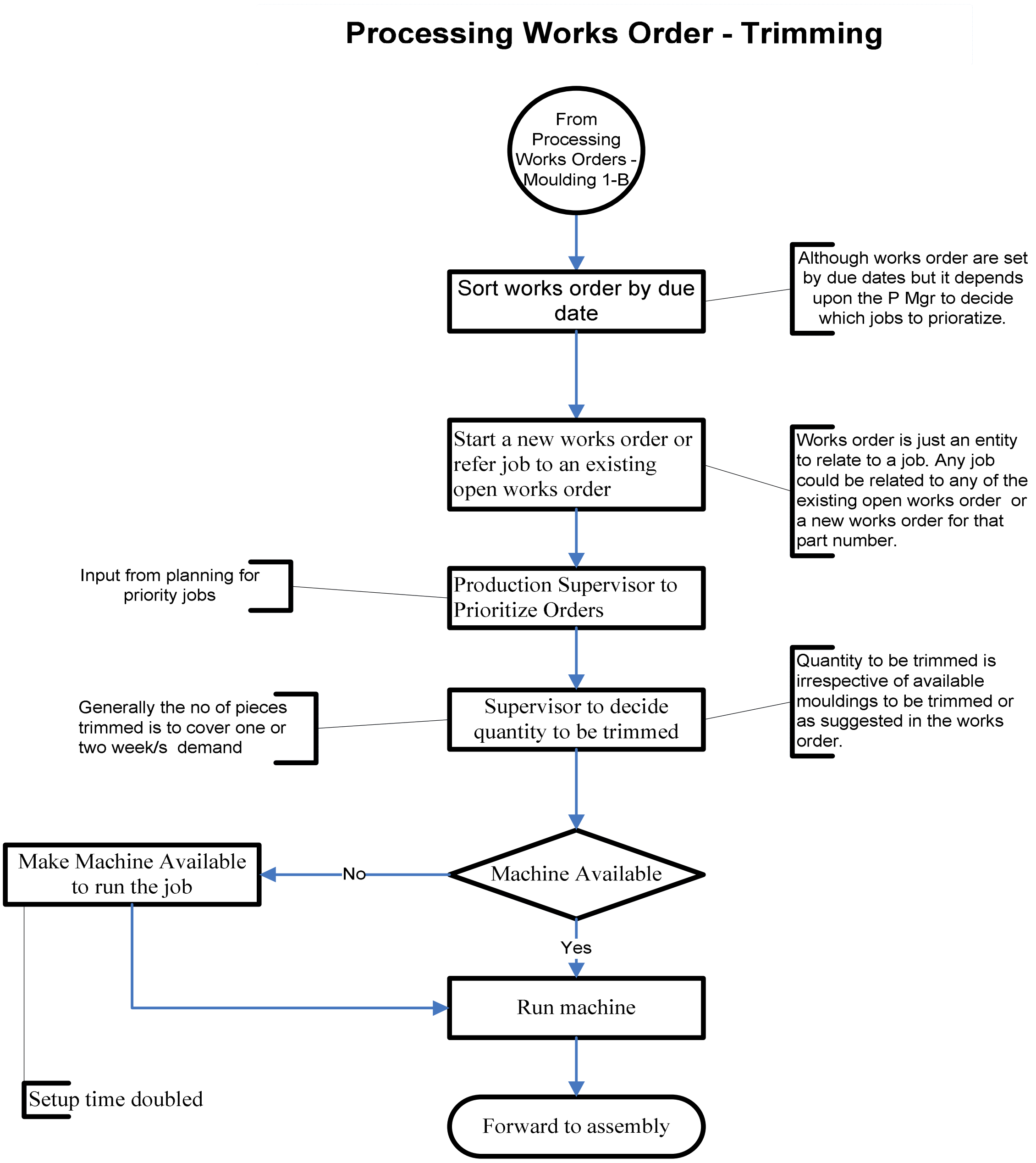


Figure 3.16 Production -Trimming.

3.6.7. Production-Planning Priorities

The production-planning process is a complex process influenced by a number of external and internal factors. The external inputs are likely to be outside the control of the planner. For example the raw material availability is outside the control of planner; although this may be included in the aggregate plan. The internal inputs on the other hand may be controllable in various degrees to suit the priorities of the organisation. For example, the regular breakdown of machines and equipment means an appropriate inventory might offer greater flexibility.

The internal inputs to the production-planning process are diverse and complex and that gives rise to the conflict as to what might be considered best practice in manufacturing, for example:

- Minimise costs
- Maximise profits
- Minimise inventory levels
- Minimise changes in work force levels
- Minimise use of overtime
- Minimise use of subcontracting
- Minimise changes in production rates
- Minimise number of machine set-ups
- Minimise idle time for plant and personnel
- Maximise customer service

The conflicts that arise are quite obvious. Minimising changes in work force levels and maximising customer delivery dates both conflict with minimising inventory. Maximising profits may not be possible without changing work force levels or on time delivery may not be efficient unless inventory levels are appropriate. The 'fire fighting' pattern observed at TP and discussed in earlier sections partially represents some of these conflicts. For example, the production team mostly concentrates on the short term production window, typically four to six weeks. The focus of the production team is usually on short term production rather than on building reasonable inventory level to smooth out customer demand over a longer period and hence to utilise resources effectively.

3.7. Overall Problem Situation

A study of the organisation in this chapter has showed that the constantly changing business environment and an ever-increasing customer demand to improve QCD had inadvertently created erratic delivery schedules which led to a serious imbalance in the production system resulting in material flow problems. Evidence for this observation included excessive inventories in subassemblies and/or raw materials and work-in-process being held up because of bottlenecks as well as poor information flow. The problem was also compounded by significant growth and also increased "product mix" complexity. Initial appraisal of the situation also showed that part of the problem included poor forecast information from the customer which ultimately caused scheduling and re-scheduling on an almost daily basis. These effects increased the level of operating expenses in addition to excessive work-in-process (WIP) and WIP queues. It is very likely that without effective change within the production management system, the eventual consequences will be:

- (i) losing business to competitors;
- (ii) high investment in overtime and premium manufacturing costs to ship 'surprise' orders or missed deliveries;
- (iii) quality issues with long-term and costly customer care and rework/repair practices;
- (iv) increasing safety stock inventories;
- (v) waste in manufacturing capacity and resources; and
- (vi) missing opportunities for market turn for future business and missing financial goals.

3.8. Summary

TP (Hessle) Ltd. had successfully run the business and has made reasonable profits in the past. As the customer expectations for better quality products at cheaper prices continues to grow, the future predominantly lies in changing the manufacturing strategies practiced at TP. The company is driven by strategies that may have been successful in the past, but due to ever increasing race for innovative strategies in the business world it may not be able to sustain its market share and profitability in future. The company is continuously observing a state of confusion and fire fighting on the shop floor, as a result of which the production system is often forced to incur additional costs. For example missing customer delivery dates incurs premium delivery charges to the company. These additional costs are affecting the overall profitability of the company. Many of the activities within the production systems were uncoordinated and people driven. With an increasing product variety and customer demand, it becomes paramount that manufacturing activities are driven by a system in a methodical manner. Several analyses were conducted to identify the root causes of inefficiency within the company. Firstly by examining the stakeholder analysis, then by SWOT analysis and then examining at the top level the sales portfolio. This initial analysis lead to a more detailed examination of perceived issues in production followed by a detailed systems analysis using systems thinking tools and value stream mapping. These studies provided a useful insight into the organisation and its requirements. The functional layout of the factory may also be affecting the smooth flow of material and encouraging high inventory as identified in the VSM. From Chapter Two, many researchers have suggested that the traditional functional layout has been replaced by the more 'fashionable' process layout. The principles of GT can be applied to TP in order to improve material flow and achieve other benefits as stated in Chapter Two. The results further highlighted the need for a more stable, organised and structured production system.

After an initial, more detailed, systems analysis, *i.e.* from Chapter Three the problem situation showed that ineffective planning of production occurred due to the "fire fighting" of the production team. A key tactical objective for the organisation, based upon robust strategic needs, is to achieve 100% on-time delivery performance with excellent customer service also being a high priority. Chapter Three analysed and discussed the problem situation and finishes with a strategy to improve and remove some of the unintended consequences of the current production system, essentially providing a more stable production schedule. This appears to be a straightforward action, but in reality is not for many reasons. Chapter Two presented two tools that could help formulate a tactical approach to the problem situation: *Multi-criteria ABC analysis* and *Production Flow Analysis*. In this chapter, these two tools are applied to recent production data with a view to developing an implementation plan that could overcome some of the manufacturing issues within the organisation.

4.1. Multi-criteria ABC Analysis

As stated, Multi-Criteria Analysis (MCA) was explained in Chapter Two. In the application of MCA, it is first necessary to decide upon at least two criteria or "criticalities" that should be used. Previously, it was stated that a key tactical objective for the organisation, based upon strategic needs, is the ability to achieve 100% on-time delivery. This means that the product lines have to be available in dispatch on the delivery dates declared. For this reason, it was decided that the first criticality should be "volume" (or more specifically the management of volume), *i.e.* it has the highest priority. However, it should not be forgotten that the goal of any organisation is to make money. This cannot be done unless attention is given to the value of the product lines. For this reason the value of the product line is the second criticality. Therefore to summarise, it is volume rather than value (at this time) that is the primary determinant from an operations perspective. This is not to say value is ignored, but rather dealt with below volume from a hierarchical view of criticality.

The two criticality criteria (volume and value) in the analysis were selected and in the next step data parameters were defined. The production data used for this analysis was extracted from the Sage® Line 500 ERP system (sales data between 29/03/2004 to

24/09/2004). The data include Product Code, Standard Cost of the product, Total Volume of the product sold to customer and Total Value of the products sold. Snapshot of data analysed is shown in Table 4.1. The complete data is provided in Appendix 2 (CD-ROM, File name: ABC combined view).

Product code	Standard Cost £	Quantity	Total Value £	Total Sales	Cumulative Sales
T2337B190	3.70	6704	24818.21	0.74%	0.74%
T1637C190	8.12	5417	43980.62	1.31%	2.05%
T8000A933	15.06	5359	80727.98	2.41%	4.46%
T2244A190	8.98	5239	47051.46	1.40%	5.87%
T0631A190	5.81	4577	26578.64	0.79%	6.66%
T0630A190	11.10	4181	46392.38	1.39%	8.05%
T2338B190	3.63	3227	11701.1	0.35%	8.40%
T2249A190	6.86	2960	20308.56	0.61%	9.00%
T2250A190	6.86	2960	20308.56	0.61%	9.61%
T0629A190	7.92	2808	22242.17	0.66%	10.27%
T2443A190	5.57	2648	14752.01	0.44%	10.72%
T2224A190	8.52	2618	22310.6	0.67%	11.38%
T1964B331	7.17	2444	17530.81	0.52%	11.90%
T2007A355	6.39	2361	15089.15	0.45%	12.36%
T1957A355	6.39	2347	14997.33	0.45%	12.80%
T1961A331	6.19	2323	14388.66	0.43%	13.23%
T1998B190	18.83	2296	43224.5	1.29%	14.52%
T1970B331	19.76	2265	44756.4	1.34%	15.86%
T2140A190	6.07	2255	13678.83	0.41%	16.27%
T2141A190	6.07	2255	13678.83	0.41%	16.68%
T1962B331	6.91	2201	15215.51	0.45%	17.13%
T2388A190	2.20	2201	4842.2	0.14%	17.28%
T0183D190	8.70	2093	18198.64	0.54%	17.82%
T2349B190	25.93	2059	53383.69	1.59%	19.41%
T0645A190	6.79	2048	13905.92	0.42%	19.83%
T2247A190	7.02	1980	13903.56	0.42%	20.24%
T2248A190	7.02	1980	13903.56	0.42%	20.66%
T0176C355	7.20	1862	13402.68	0.40%	21.06%
T0197C190	8.48	1789	15167.14	0.45%	21.51%
T1969A952	40.88	1736	70974.62	2.12%	23.63%
T1740A190	28.16	1709	48123.73	1.44%	25.07%
T2006C190	13.46	1551	20871.81	0.62%	25.69%
T1960C190	13.42	1551	20806.67	0.62%	26.31%
T1559C364	10.14	1526	15469.06	0.46%	26.77%
T2138A190	6.85	1523	10427.98	0.31%	27.09%
T2139A190	6.85	1523	10427.98	0.31%	27.40%
T2257B190	9.47	1503	14239.42	0.43%	27.82%
T1898C355	8.23	1500	12339	0.37%	28.19%
T2245B190	6.36	1485	9443.115	0.28%	28.47%
T1967A331	6.34	1482	9388.47	0.28%	28.75%
T1965A331	18.51	1459	27010.47	0.81%	29.56%
T1971B331	9.36	1459	13648.95	0.41%	29.97%

Table 4.1 Snapshot of example core data extracted from Sage® Line 500.

Prior to performing a MCA (Appendix 2: CD-ROM, File name: ABC combined view) described above, a more classical ABC analysis was performed on the production data. In this instance the lines were sorted by virtue of their total cost (volume x value). Summary of the results are shown in Table 4.2. The analysis shows that around 20% of the ranked product lines account for approximately 71 % of the total value. As stated above these top 20% lines are based on total value and total value is a product of volume and value. Product lines within this category of 20% lines may have different factors of value or volume. For example in this category of 20% there might be product lines ranging in value from £4 to £400, or in volume from 60 units to 5000 units and thus they should have different inventory management control. In summary, classical ABC analysis only provides a broad category which may not be sufficient to focus on significantly improving or streamlining production/inventory systems.

Thompson Plastics (Hessle) Ltd.
Classical ABC Analysis

Customers	ALL	
Time Frame	*From* 29/03/2004	*To* 24/09/2004

Lines Categorisation based on Total Value (volume * value)

			% Total Value
	A	*Product lines (20%)*	*71%*
	B	*Product lines next (30%)*	*24%*
	C	*Product lines next (50%)*	*5%*

0

TOTALS
Analysis by Line (First 100 Lines, Second 150, Third Rest)
Number of Lines 498
Total Volume 231566

Table 4.2 Summary of results for classical ABC analysis on production data.

Prior to performing a MCA for the production data in order to better understand the categories of product lines by merit of their volume and value the concept of multi-criteria is implemented by applying classical ABC analysis on volume and value independently and *Pareto* is established for the two criterion.

ABC categorisation by number of units sold

Product lines are sorted by volume sold within the date range in descending order. Applying classical ABC analysis on this arrangement will categorise product lines with high (20%), medium (30%) and low (next 50 %) volume categories. Following this, the same exercise is undertaken for sales categories as summarised below:

By Volume

Category A First 20% product lines by volume i.e. any volume below 100th product code (total 498 product lines with units sold in descending order) will be categorised as 'A'. From the data, product lines with sales volume above 792 units are categorised as 'A'.

Category B Next 30% product lines by volume will be categorised as 'B'. Product lines with sales volume under 792 and over 100 units fall into category 'B'.

Category C The remaining 50% product lines comprises of 'C' category product lines and these are all those product lines that have sales volume less than 100 units.
The three distinct categories of product lines (A, B and C) are formed by virtue of number of units sold.

By Value

Category A First 20% product lines by value will be categorised as 'A'. From the data product lines with standard value of above £40 are categorised as 'A'.

Category B Next 30% product lines by value will be categorised as 'B'. Product lines with value under £40 and over £12 fall under category 'B'.

Category C The remaining 50% product lines comprise of 'C' category product lines and these are all those that have sales value less than £12.

Thompson Plastics (Hessle) Ltd.

ABC Analysis (Product Value-Volume)

HIGH VALUE ORVOLUME IS BASED ON TOP 20% RANKED PRODUCT LINES BY VALUE/VOLUME.

HIGH VALUE ORVOLUME IS BASED ON NEXT 30% RANKED PRODUCT LINES BY VALUE/VOLUME.

HIGH VALUE ORVOLUME IS BASED ON NEXT 50% RANKED PRODUCT LINES BY VALUE/VOLUME.

Customers	ALL	
	From	*To*
Time Frame	29/03/2004	24/09/2004

Lines Categorisation based on 1st (By Value) and 2nd (By Volume) Analysis

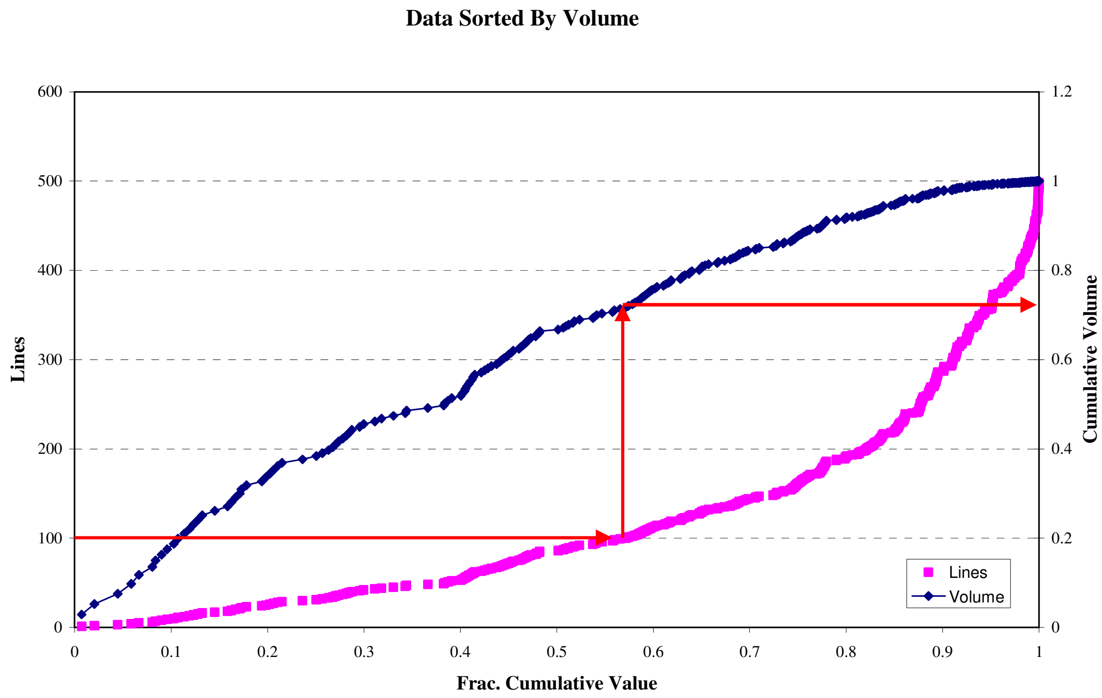
		VOLUME (First)					
		A/ lines	*% value*	B/ lines	*% value*	C	*% value*
VALUE (Second)	A	64	50.13	26	73.82	10	92.02
	B	35	57.13	79	86.14	36	96.94
	C	1	57.17	45	87.71	202	100
TOTALS		100		150		248	

Analysis by Line (First 100 Lines, Second 150, Third Rest)

Number of Lines	498
Total Volume	231566

Table 4.3 Result of ABC analysis on volume and value combined.

It is also interesting to note here, that elsewhere the typical ABC analysis is commonly undertaken on the basis of total value only, but the two variables as shown in the analysis can lead to very different results. If both volume and value are now analysed on the basis of MCA, some interesting results emerge as presented in Table 4.3 and Figure 4.1. There are 64 product lines (~ 13%) which qualify for the top 'AA' category, but these lines account for approximately half of the business undertaken by the organisation. There are 46 lines which account for the remaining 7% of value which the classical ABC analysis suggested 80% of remaining lines account for 53% of value. Therefore there is some justification for treating these product lines differently in the production schedule. At the other end of the scale, there are 202 product lines (~ 34%) which qualify as category 'CC' and only account for 3% of the organisation's sales. It follows, therefore, that if these product lines are treated equally with category 'AA' it may present a risk to the organisation. It is also interesting to note that the category with the highest number of product line is 'BB' with 79.



<u>Figure 4.1</u> <u>Pareto for ABC analysis on volume and value.</u>

As stated in earlier chapters, in a Small and Medium-sized Enterprise (SME), there is a wide variety of variables influencing inputs and outputs that affect the way the organisation performs. Here, so far, after following an *ab initio* approach, the analysis has presented to a variation of the classical ABC Pareto approach with the principal aim being the reformulation of the production process within the manufacturing system and thus reduce the influence of erratic customer demands and its consequential 'fire fighting'. The analysis so far has devised a pair-wise matrix of volume / value ranking to which belongs nine classes denoted as AA, AB, AC, *etc*. As an alternative to the above approach, and as a comparator to the analysis, it could be assumed that volume is of equal weighting to value. The question becomes is there any relationship that relates the volume of a product line to the value of that product line? From an analytical view point, it is intuitive to think that a "merit" rating for each line could be generated which relates the relative value and relative volume of a product line. Furthermore, if this were the case, the merit rating should form a response surface (z-axis) on the plane of volume (x-axis) and value (y-axis). There is nothing in the open literature which suggests the form of the response surface (*i.e.* empirical fitting equation) and indeed this appears to be a novel idea. The implication here is that both low and high value or volume lines can have high (or low) criticality. The criticality index has some equivalence to the merit rating proposed above. Given that this is accepted then there remains some ambiguity for the relationship between merit and the xy-plane. In this study, various models were investigated and fitted to a response surface with limited success. One of the more successful models, illustrated below in Figure 4.2, with $R^2>0.9$ is:

$$Merit = \left[\frac{Value - Value_{\min}}{Value_{\max} - Value_{\min}}\right]\left[\frac{Volume - Volume_{\min}}{Volume_{\max} - Volume_{\min}}\right] \qquad \text{Equation [4.1]}$$

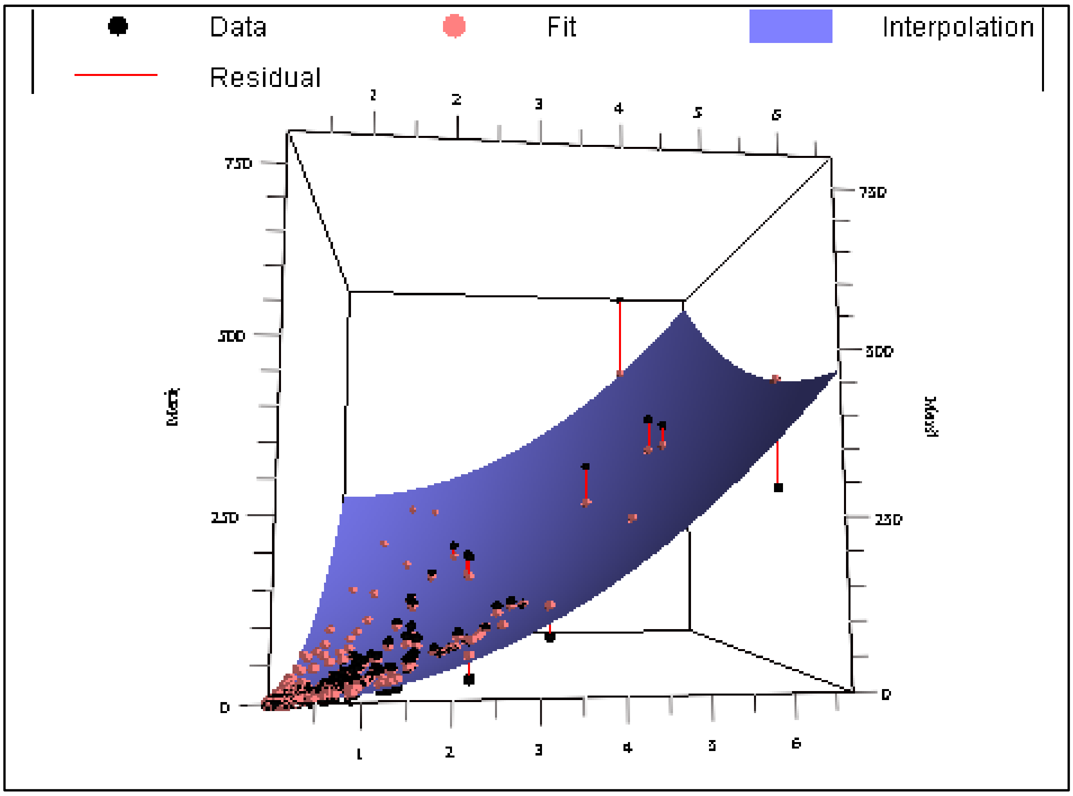


Figure 4.2 The response surface generated from Equation [4.1].

The evidence presented here shows that an empirical relationship of a new “merit” parameter can be determined by fitting a response surface to volume and value quantities. Indeed the technique can indicate which product lines are behaving in the market as expected and which are asynchronous with the market demand. However, whilst this technique may be useful in identifying misbehaving product lines, it does not help organise the product lines in terms of the production schedule.

ABC analysis on product lines by virtue of volume and value has provided two distinct sets of A, B and C categories. The two sets of categories are combined to form a new joint criteria matrix.

Thompson Plastics (Hessle) Ltd.
ABC Analysis (Product Value-Volume)

Customers	ALL	
	From	*To*
Time Frame	29/03/2004	24/09/2004

HIGH VALUE OR VOLUME IS BASED ON TOP 20% OF RANKED PRODUCT LINES BY VALUE/VOLUME
HIGH VALUE OR VOLUME IS BASED ON NEXT 30% OF RANKED PRODUCT LINES BY VALUE/VOLUME
HIGH VALUE OR VOLUME IS BASED ON NEXT 50% OF RANKED PRODUCT LINES BY VALUE/VOLUME

Lines Categorisation based on 1st (By Value) and 2nd (By Volume) Analysis

VALUE	**High**	No of Lines	%Total Volume	% Total Value	**Medium**	No of Lines	%Total Volume	% Total Value	**Low**	No of Lines	%Total Volume	% Total Value	**Total**
VOLUME	High	**6**	**2.96%**	***10.4%***	High	**24**	**15.23%**	***21.37%***	High	**70**	**53.54%**	***25.40%***	100
	Medium	**19**	**2.75%**	***12.9%***	Medium	**39**	**6.93%**	***9.66%***	Medium	**92**	**15.09%**	***8.01%***	150
	Low	**74**	**0.68%**	***9.6%***	Low	**85**	**1.16%**	***1.84%***	Low	**89**	**1.67%**	***0.87%***	248
		99	6.39%	**32.9%**		148	23.31%	**32.87%**		251	70.30%	**34.28%**	
													498

Table 4.4 Result of multi-criteria matrix.

In addition, also as an alternative to the previous approaches and to determine whether a different result would occur with value as the prominent criticality, a similar MCA exercise as the first was undertaken, but value sorted first and then volume. The result was presented in Table 4.4. In this particular case, there are only six product lines (accounting for 3% volume and 10% value) that qualify for the 'AA' category. This is in contrast to 46 lines in the earlier analysis. At the other end of the scale, there are 89 lines in category 'CC', with the highest category 'BC' having 92. As can be seen from table 4.4, this approach tends to be less discriminating in terms of how to treat certain types of product lines. However, in summary from Table 4.4 the following may also be said:

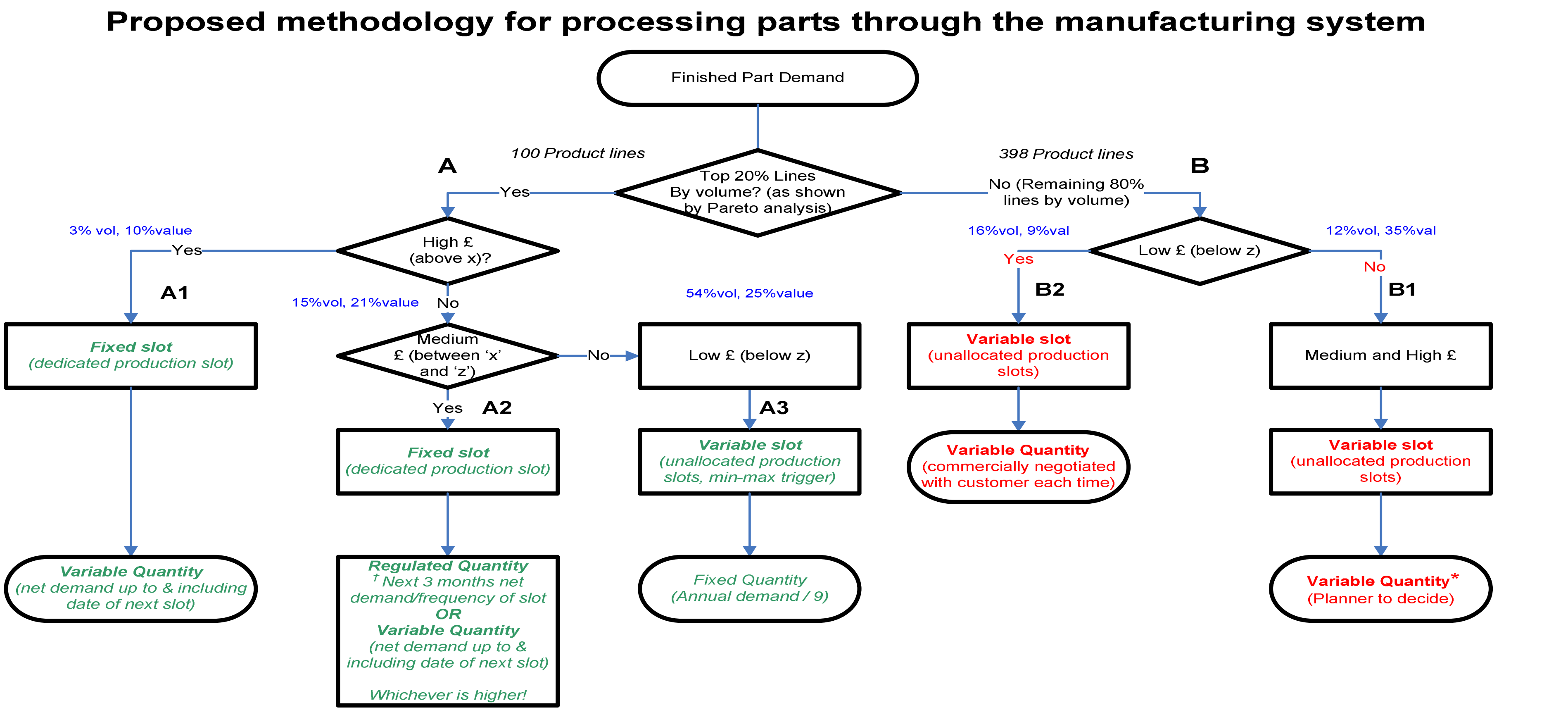
- 20% of product lines account for about 72% of volume sold.
- 50% of product lines only account around 3.5% of total volume sold.

The above analysis signifies that there are product lines with high volume and regular demand (runners), there are products which are not so frequent, *i.e.* medium volume sales (repeaters) and there are product lines with occasional low volume demand (strangers). Potentially if the product lines in their categories are managed in a systemised manner it could reduce some of the major concerns of the company, *e.g.* reduction in fire fighting and improvement in customer service. The information from the multi-criteria analysis can be used to derive a methodology. The issue at first glance is whether it is sensible to have nine categories, *i.e.* AA, AB, AC, BA *etc* or whether this could be reduced in any way. Whilst management of nine categories might yield some improvements, there will be costs associated with the micro-management.

		VOLUME		
LINES		A	B	C
VALUE	A	A1	B1	B1
	B	A2	B1	B1
	C	A3	B2	B2

Table 4.5 Reduction of the nine categories from MCA to the five categories for plant operation.

The principles applied to reducing the nine categories related to ensuring that the top 20% of lines that account for 80% volume are managed to a high degree of confidence. However since the level of management should be justified with the level of investment, it was decided that classes AA, AB and AC should be renamed A1, A2 and A3. However, it did not make sense to denote six categories to the remaining 20% by volume or 80% of lines. However, value remains important, especially since some items could be very high value but only required by the customer on rare occasions or on a low volume scale. In such circumstances, high value items could be sentenced to the finished goods inventory for long period or worst become obsolete. Therefore, classes BA, BB, CA, and CB were renamed B1 and BC, and CC become B2 on the basis of the investment arguments (see Table 4.5). Therefore, the analysis has shown that there are five logical categories to adopt. The next issue is how these five categories should be treated from a production management perspective on the basis of their attributes belonging to their respective category. In the case of high volume, high value items, the organisation know these items are in demand and are called off regularly by the customers. Therefore, it makes sense to make them at regular intervals. These intervals need to ensure minimisation of throughput times and synchronisation with market demand. In essence, this approach co-ordinates the supply chain, provides a high service level, reduces WIP, and should reduce the amount held in the inventory. The only high volume line where this should not be the case is for low cost items which can be made impertinently on a min-max approach since the risk associated with holding such items in inventory is small. This is also true for B2 product lines. This then only leaves B1 product lines which can be made using the more classical batch manufacture approach, but these batches need to be synchronised with the complete supply chain. This now provides a new methodology as illustrated in Figure 4.3. Product lines are analysed and segregated on the basis of their volume (annual demand) and value (standard cost). Note that, for the methodology, in the A category, the analysis will provide a threshold, £x, above which the product lines can be considered high volume - high value items, re-designated A1 lines. Equally, there will be a mid-range of high volume - medium value lines with a standard cost from £x to £z, designated A2 category. In addition, a third category of high volume - low value (below £z) product lines, designated A3.



- X and Z denote numerical value, £40 and £12, respectively (1st iteration).
- † Produce on every production slot unless stock covers demand until next slot. Smoothed over 3 months. Quarterly forecast demand/frequency of slot.
- * Variable quantity depends upon various factors like – stillages available, quantity ordered, future orders, consequences of high standard cost, etc.
- Stock Low value moulding assemblies for 'High' and 'Medium' value lines.
- Only produce on the basis of customer demand.
- Model does not consider promotion / demotion of lines.

Figure 4.3 Methodology for processing parts through manufacturing system.

As mentioned previously, the most important Key Performance Indicator (KPI) for the company in addition to a reduction in inventory and lead time is 'Delivery Performance'. The adopted methodology described here has to differentiate between product lines to ensure optimum lead time and inventory. Based upon the ABC analysis, information in the new methodology is thus used to prioritise the processing of parts through manufacturing system. Demand from customers for finished product lines must then be the starting point for the methodology. That is, because lines are made to order, data for finished lines from the last '12' months is collected and then used in a Pareto analysis on volume. The subtle issue which is perhaps not obvious is that for the system to work well an algorithm must be in place to constantly update product lines with their corresponding category, *i.e.* there will come a time when former A1 product lines become obsolete. Therefore, the product lines will be required to be updated in order to be promoted / demoted accordingly. It is suggested that the update frequency be around two weeks, although up to three months may also be feasible

The in-depth analysis shown here does have, perhaps surprisingly, support (& validation) from open literature, which was not initially apparent and which is not widespread, but what is present is robust. For example, in this analysis high, medium and low threshold for criticality criteria is derived from the 'Pareto Principle' of 20%, 30% and 50% ratio. A similar multi-criteria analysis was performed by Gupta (2004) whereby the four critical criteria were based on a subjective approach involved in dividing a criterion into four levels. It must be stressed that the philosophy, principles and practices reported have been developed somewhat independently from a logical and methodical approach with the specific application to the company. Therefore, some confidence can be held in the conclusions reached so far. It is also interesting to note that some papers in open literature have concluded that only two classes of lines (A and C) actually exist, whilst others have concluded, on the basis of lead time requirements, that there are in fact five classes of items (as is the case in this analysis).

The new methodology proposed above can be described as follows. A production planning (review) cycle takes place, the cycle represents a snapshot of the company's sales spanning a 52 week running period. However data collected over such an extended period will obviously be outdated by the time it is used. The algorithm is therefore applied at least every three months thereby focusing the analytical period resulting in the snapshot being more representative of the company's dealings over a much smaller period. This provides a more useful dynamic view of what is happening enabling a rapid system response to change. However it is possible to foresee difficulties involved with 'freak' customer requirements should the analytical period become too small. However, if this were the case, then the next period should correct the issue or expert knowledge could override such rare and freak requirements.

Furthermore, in relation to the methodology and particularly to Figure 4.3, the following comments can be made.

- A1 - first sub-category consists of **'high volume-high cost'** product lines. These product lines require the most accurate anticipation of future needs, i.e. a higher financial and commercial risk is associated with failure to satisfy demand of these lines than the others. For example, these high cost and high volume lines will have a substantial influence on inventory costs if they are not controlled at higher level. Batch sizes and time points need to be precisely determined in order to achieve accurate delivery time control. Key aspects are**:** (i) **fixed slots** - a dedicated production slot on a weekly frequency will be available to make parts in this sub-category. This sub-category will require accurate anticipation of the situation to keep minimum lead time; and (ii) **variable quantity** - this will be the quantity as required by the customer up to and including date of next slot (net of stock held plus 10% contingency).
- A2 - these parts are under high volume category but relatively lower in standard cost than A1. Thus key aspects are: (i) **fixed slots** - similar implication as in A1, the main difference being a (less frequent) fortnightly slot instead of weekly slot. Product lines will be produced on every slot; and (ii) **regulated fixed quantity** - a set quantity based on customer demand. The regulated fixed quantity will be - three months forecast demand/frequency of slot. This means if the three months forecast demands 600 parts and frequency of slot is fortnightly then the regulated fixed quantity will be 600/6= 100, *i.e.* 100 parts will be made fortnightly. If demand from the customer is between two slots and is greater than the regulated quantity for that slot quantity to produce the regulated quantity should be modified to suit the renewed customer requirement up to the date of next slot.
- A3 - although these product lines are high in volume, they are low in value and therefore do not necessarily require strict control over the quantity produced. Thus key aspects are: (i) **variable slots** - free production slots will be utilised

as and when required to satisfy demand from the "warehouse"; and, (ii) **fixed quantity -** our analysis indicated that the quantity equivalent to total annual demand divided by 9 is a suitable batch quantity to re-supply the "warehouse". Products are subsequently supplied to customer from stock on a call-off basis as and when required. For example, if the total annual demand for a product line is 5000 then quantity produced in a batch would be approximately one ninth (~556). However, it should be remembered that this quantity is amended by the configuration and set-up arrangements of the process plant.

In considering the remaining 80% by volume of product lines (Category B), as is the case with Category A product lines, the value will vary. The same threshold, £z, can be used to differentiate between two broad classes B1 and B2 product lines. Even though the B category accounts for 80% of lines, the volumes are such that there is little benefit to managing high and medium value product lines differently. Therefore, these 80% lines (493) are further sub categorised into 'Low - below £z' and 'high & medium - above £z'. In relation to Category B, the following comments can be made:

- B1 - high & medium value - product lines in this category are high in value so require controls on the quantity and instant of manufacture. These key aspects are: (i) **variable slots** - low volume on these lines limits dedicated slots hence these parts will be produced on a variable slot; and, (ii) **variable quantity** - production planners decide appropriate amounts to produce which primarily depend on customer orders and other factors such as transportation requirements, stillage availability, material availability, capacity, and the likelihood and quantity of future orders.
- B2 - low value and low volume product lines. These key aspects are: (i) **variable slots** - being low volume this will require variable slots in the production system; and, (ii) **variable quantity (justified quantity)** - this category is unusual in the sense that it is the only category that requires expert knowledge by the production planner. Therefore, any proposed production quantity requires endorsement given that the quantity produced will be based on commercial considerations *i.e.* set-up costs, non-specified material use, specific material purchase, *etc.* It may be that in terms of meeting any production costs, the customer is required to place a minimum order quantity.

In summary, the new methodology, giving priority to volume (through demand), should reduce WIP and thus mean shorter lead times and greater flexibility. This could be justified by the conclusion from Roper (1994) that focuses on high activity products (high volume) within a business providing the strategic focus required to simultaneously improve service, cost and inventory performance. The new system, implemented in the organisation under study, was monitored using the following measures of performance: (i) Delivery Schedule Achievement (and non compliance with time / quantity); (ii) raw materials inventory expressed in days in comparison with the rate of sales; (iii) WIP as a measure of investment; and (iv) lead time reduction.

4.2. Production Flow Analysis

Having established a methodology to handle the diverse product lines, the issue becomes whether the factory can be reconfigured to facilitate the new methodology. As mentioned earlier, the shop floor at TP (Hessle) is laid out in typical functional layout. It is believed that planning a functional layout is an easy task if the planner can differentiate between the machine types. The preparation of the layout is not complicated, however a functional layout configuration has two major disadvantages. Firstly, there are very complicated material flow systems which are difficult to control efficiently, and secondly, the responsibility for the quality of parts and completion by their due-date is split between several different foremen and groups of workers

The method of group and line layout for families of parts has exactly the opposite characteristics. It requires considerable skill to plan these types of layout, but the simple material flow system which are obtained with their use are very much easier to manage once they are installed, and the responsibility for the quality and output by due-date of each part can be allocated to one group of workers and one foreman. With all systems of production, decision making tends to be based on a set of assumptions or criteria which are supposed to be ‘right’ and unalterable. *The fundamental change with the approach of GT is that it does not accept the traditional assumption, but postulates in their place that an overriding requirement for economical production is the creation of a simple material flow system.* PFA is based on the premise that, in a factory, different groups of machines already concentrate on restricted families of parts. The problem, therefore, is to find the existing groups and families, and not to create them. In order to identify whether GT could be implemented at TP (Hessle), in terms of grouping machines, PFA was performed on the data with production route details. Initially the data selected for the analysis was high volume product lines, *i.e.* 'A' category product lines, as identified in Section 4.1 (multi-criteria ABC analysis). As stated in Chapter Two, PFA has three prominent stages; (a) Factory Flow Analysis; (b) Group Analysis; and (c) Line Analysis.

4.2.1. Factory Flow Analysis

In case of TP (Hessle), there are three traditional major processing departments; thermoforming, trimming, and assembly, Figure 4.4 illustrates the argument. In the figure, 53 product lines are selected randomly from category 'A'. Out of those 53, 52 product lines originate from thermoforming department (G12, G9, G2, G5, G6, G7 and G1) and one from trimming department (CNC 11). All moulded parts from thermoforming are then processed in trimming department (CNC 3, CNC 8, CNC 11, CNC 12, CNC 9, CNC 4 and CNC 7. The third department is assembly (ASS2, ASS1 and THERMO-A). All those components that are not finished at CNC department further follow the route to assembly department where components were finally assembled.

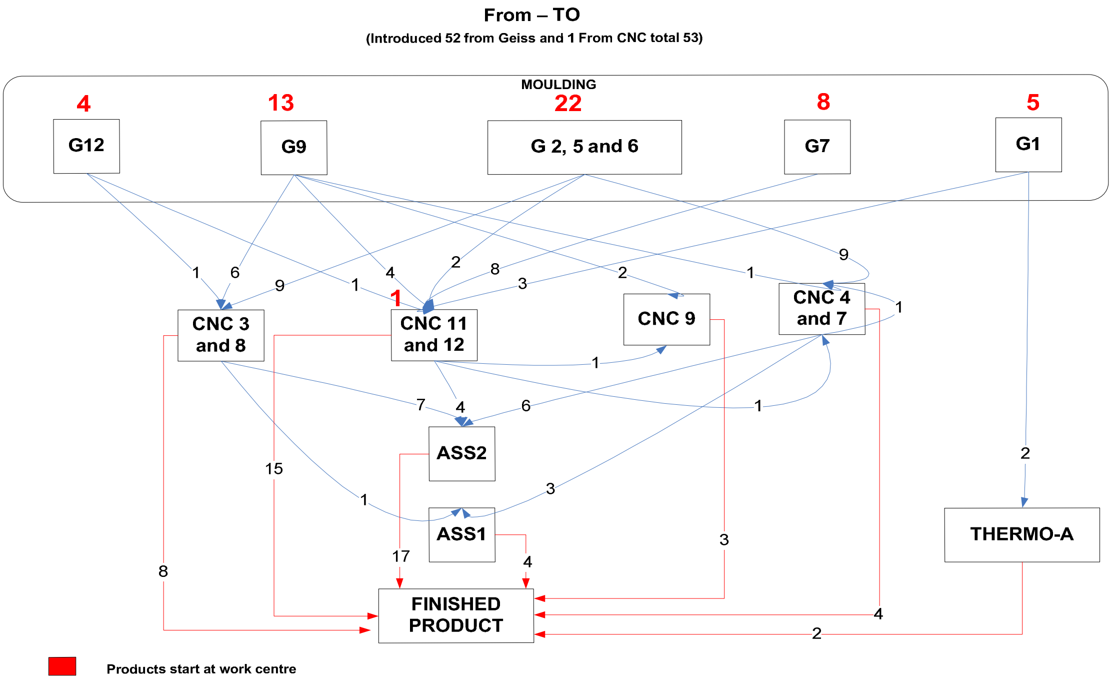


Figure 4.4 From - To flow of randomly selected 53 high volume (A category) product lines.

There were no instances in the case of these 53 product lines where they have to move to and fro between departments, *i.e.* the factory is organised into departments based on traditional process layout, and each department completes all the different components it produces at a particular processing stage and is fully equipped with all the necessary facilities it requires. At TP (Hessle) the primary machines are the moulding and trimming machines and there are only a small fraction of additional facilities required to finish components within that department. For example the thermoforming department has moulding machines as its primary resource for moulding plastic sheet as well as band saws to rough trim components. Components from the thermoforming department are then transferred to the next department (CNC). There are two major inferences that can be made at this juncture. The first is that there are no natural or obvious “broad departmental groups” that arise from this analysis other than LFPUR which currently exists. That is to say, in effect, the remainder of the factory is one “broad departmental group”. The second major inference is that the role/function of the moulding department appears to be a major controlling step.

4.2.2. Group Analysis

Group Analysis (GA) is considered here as the second stage of PFA and focuses on the manual rearrangement of the part/machine binary matrix. A part/machine matrix is a matrix that lists the machine population as rows and the part population as columns. If a part is processed by a particular machine, then the cell in the matrix for that part/machine is marked as 1 otherwise 0. The main objective of the GA is to form groups that:

a. can complete all the parts the groups make;
b. are provided with the facilities the groups need to make all parts;
c. use the existing equipment without any additional resources; and
d. use the existing processing methods with minor changes to eliminate ‘outlier’ operations.

The minimum data needed in the analysis are the Part Number, Operation Sequence and Machine/Work-centre code, which are contained on the ‘route card’. Each operation is usually associated with a particular machine, determining the operational sequence obviously also determines the machine sequence. Additional data such as, lot size, time standards and annual demand might be useful for designing machine cells of the required production capacity, but this is not considered here.

For the group analysis, for TP (Hessle) category 'A' parts, as previously described were tabulated in a part/machine matrix, as illustrated in Table 4.6. In all, 100 product lines were considered against 27 machines. At first glance, the part-machine matrix appears a random distribution on '1's. Although Table 4.6 shows all the machines, only 30 parts are shown for clarity. As can be seen from the table, a '1' is present if the criteria "the part 'a' requires processing on machine 'b'" is met, otherwise the cell is left empty.

Product Line	T8000A933	T2557A229	T2550A190	T2549A190	T2449A188	T2449A188	T2443A190	T2426A190	T2425A190	T2424B190	T2423B190	T2416A190	T2405A190	T2404A190	T2392A950	T2391A952	T2391A952	T2389A952	T2388A190	T2387A952	T2384C190	T2383B190	T2382B190	T2381C190	T2374A365	T2374A365	T2374A365	T2350B190	T2349B190	T2338B190	T2337B190
Sub-assembly		P2764A229			P2696A189	P2696A188										P2654A190	P2655B952								P2650A365	P2649A365	P2650A365	T2350B190	T2349B190		
Sub-sub Assembly																									P2649A365		P2650A365				
GEISS12																															
CNC9	1																				1	1	1	1							
ASS1		1			1														1												
CNC7												1													1						
Horizontal Band Saw																															
CNC3								1	1																						
CNC11										1	1																				
THERMO ASSY																															
CNC8		1				1									1	1	1	1		1											
CNC5																															
ESU																															
ESUA																															
GEISS9																1		1		1						1					
GEISS1	1		1	1									1	1																1	1
ASS2																1	1								1	1	1				
GEISS7								1	1	1	1				1						1	1	1	1							
GEISS2							1																		1						
GEISS5						1																					1				
GEISS6		1										1					1														
CNC4			1	1			1						1	1												1	1				
FORMECH																															
CNC12																															
PU																															
WATERJET1																												1	1	1	1
PU ASSY																															
ASSY																															
FOAMPRESS																												1	1		

Table 4.6 Part/Machine matrix snapshot for 'A' category parts.

4.2.2.1. Binary Ordering Algorithm

The next step was to reorder the matrix so that clusters, if they exist, can be formed. Parts are arranged into groups according to the similarity of their process routes. A procedure to sort and arrange parts into "packs" with identical routings was used. This processing technique was executed with the help of a Binary Ordering Algorithm (BOA). The process of arranging any N-column, M-row, binary (0-1) matrix to highlight "Groups" is known as BOA. BOA was applied on 'A' category part-machine matrix using the following steps as summarised by Neighbour (2001).

Step 1: Order machines/rows: Assign a value to each column *k* equal to 2^{N-k} where N is number of parts.

Step 2: For each row, obtain a sum by adding the 2^{N-k} value wherever a 1 appears.

Step 3: Rearrange rows in decreasing order.

Step 4: Assign a value to each row k equal to 2^{M-k} where M is the number of machines.

Step 5: For each column obtain a sum by adding the 2^{M-k} values.

Step 6: Reorder the columns in decreasing order of column sums.

Step 7: If the value of k in each column is not in descending order then follow step 1 to 3.

Step 8: If the value of k in each row is not in descending order then follow step 4 to 6.

An illustration of the results from the BOA is shown in Table 4.7. Please note that it is not possible to present the complete results here due to space constraints, but a full table can be found in Appendix 2 (CD-ROM, File Name: Cluster analysis for A category).

The BOA analysis showed that there are no natural cells that could be formed in order to implement GT unless capital expenditure on new duplicate equipment was approved, but this would be in excess of any likely benefits. This is because there are several machines that are common to large number of parts, *e.g.* CNC7. This may also illustrate that under the present management, the machines are likely to be bottlenecks. In addition, the moulding machines feed components to different CNC trimming machines and no trimming machines could be easily combined with a particular moulding machine to form a cell *i.e.* each part could not be produced by only one group of machines. Finally, it should be noted that any possible candidates for cells would be very large indeed and consequently unfeasible for large efficiency gains.

4.2.3. Line Analysis

Group analysis on 'A' category product lines did not provide satisfactory group of machines that could make sets of parts. However, further to this analysis, another approach to identify the similarity between machines was undertaken. This is achieved by applying Similarity Coefficient Method to form a group around key machines. These key machines could for example be those that are heavily used as described above in Section 4.2.2. The similarity coefficients method highlights machines that have a high percentage of common products processed by them. According to Vakharia (1986), McAuley was among the first researchers to propose the use of clustering techniques for forming machine groups. Rajgopalan and Batra (1982) use a theoretic approach to design cells. There analysis was based on the similarity coefficient calculated as follows:

$$S = \frac{X_{ij}}{X_{ii} + X_{jj} + X_{ij}} \qquad \text{Equation 4.2}$$

Where S = similarity coefficient of machines i and j

X_{ij} = number of components visiting machines i and j

X_{ii} = total number of components visiting machine i

X_{jj} = total number of components visiting machine j

Product Line	T0146C952	T0161C331	T0161C331	T1740A190	T1565B188	T2320B188	T2055C933	T2061C933	T2221D933	T1971B331	T2279B331	T1969A952	T2055C933	T2061C933	T2221D933	T1970B331	T8000A933	T2189A190	T2251A190	T2252A190	T2381C190	T2382B190	T2383B190	T2384C190	T0149D355	T0432D379
Sub-assembly		P0899A355	P0900A355	P1842A190			P2014B190	P2014B190	P2014B190			P2611A952	P2013B933	P2025B933	P2025B933	P2540B331									P0893B355	P1537B379
Sub-sub Assembly				P1481A190																						
GEISS12	1	1	1	1	1	1	1	1	1	1	1	1														
CNC9	1												1	1	1	1	1	1	1	1	1	1	1	1		
ASS1		1	1	1																					1	1
CNC7		1																								
Horizontal Band Saw			1																							
CNC3				1	1	1																				
CNC11							1	1	1	1															1	
THERMO ASSY							1	1	1				1	1	1											
CNC8											1															1
CNC5												1														
ESU												1														
ESUA												1														
GEISS9													1	1	1											
GEISS1																1	1									
ASS2																1										
GEISS7																		1	1	1	1	1	1	1		
GEISS2																									1	
GEISS5																										1
GEISS6																										
CNC4																										
FORMECH																										
CNC12																										
PU																										
WATERJET1																										
PU ASSY																										
ASSY																										
FOAMPRESS																										

Table 4.7 Result of BOC on 'A' category product lines (snapshot).

They further suggest that this approach works well in cases where the number of machines is small, and when $X_{ii} \cong X_{jj}$. However, in this case, it should be noted that this is not the situation with X_{ii} =100 and X_{jj} =∝ and thus there is a ratio of X_{ii} : $X_{jj} \cong$ S. This then provides a warning for any results generated. As suggested by Neighbour (2001), similarity coefficients of more than 50% between machines could be considered for grouping. Similarity coefficient clustering algorithm was carried out on the 'A' category product lines, the values for S_{ij} were calculated using X_{ij}, X_{ii} and X_{jj} from the PFA matrix used for BOA. An illustration of the results generated is presented in Table 4.8, with the full results available in Appendix 2 (CD-ROM, Fine name: Cluster analysis for A category). As can be seen, a similarity coefficient of more than 50% was only observed between machines 'PU' and 'PU Assembly'. The results also showed that there were a large proportion of machines with similarity coefficient of less than 10%. Consequently, there may not be major benefits of grouping machines with similarity coefficient less than 50%.

Cluster Analysis A1+A2+A3	GEISS12	CNC9	ASS1	CNC7	Horizontal Band Saw	CNC3	CNC11	THERMO ASSY	CNC8	CNC5	ESU	ESUA	GEISS9	GEISS1	ASS2	GEISS7	GEISS2	GEISS5	GEISS6	CNC4	FORMECH	CNC12	PU	WATERJET1	PU ASSY	ASSY	FOAMPRESS
GEISS12	0.00	0.04	0.11	0.03	0.08	0.18	0.15	0.13	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNC9		0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.09	0.09	0.03	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ASS1			0.00	0.03	0.05	0.04	0.03	0.00	0.05	0.04	0.00	0.00	0.02	0.00	0.00	0.00	0.13	0.12	0.02	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNC7				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.02	0.13	0.14	0.16	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Horizontal Band Saw					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNC3						0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.11	0.00	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNC11							0.00	0.10	0.00	0.00	0.00	0.00	0.02	0.11	0.02	0.21	0.03	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
THERMO ASSY								0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.18	0.03	0.00	0.29	0.00	0.00	0.00	0.00	0.00
CNC8									0.00	0.00	0.00	0.00	0.17	0.00	0.27	0.11	0.00	0.10	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNC5										0.00	0.14	0.20	0.03	0.00	0.03	0.00	0.00	0.13	0.00	0.00	0.13	0.00	0.08	0.00	0.00	0.00	0.00
ESU											0.00	0.29	0.08	0.00	0.00	0.00	0.00	0.07	0.08	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00
ESUA												0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GEISS9													0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.04	0.00	0.04	0.00	0.00
GEISS1														0.00	0.03	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.09	0.00	0.00	0.00
ASS2															0.00	0.00	0.02	0.12	0.24	0.04	0.04	0.00	0.00	0.00	0.00	0.04	0.00
GEISS7																0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00
GEISS2																	0.00	0.00	0.00	0.32	0.00	0.00	0.05	0.00	0.06	0.00	0.00
GEISS5																		0.00	0.00	0.31	0.00	0.03	0.03	0.00	0.03	0.00	0.00
GEISS6																			0.00	0.00	0.00	0.24	0.00	0.12	0.00	0.00	0.00
CNC4																				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FORMECH																					0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNC12																						0.00	0.00	0.00	0.00	0.00	0.00
PU																							0.00	0.00	0.50	0.00	0.00
WATERJET1																								0.00	0.00	0.00	0.14
PU ASSY																									0.00	0.00	0.00
ASSY																										0.00	0.00
FOAMPRESS																											0.00

Table 4.8 Result of similarity coefficient on 'A' category product lines.

4.3. Summary

From the understanding of current issues in the manufacturing systems at TP (Hessle) and reviewing the manufacturing system, two proven techniques (multi-criteria ABC analysis and GT) were applied to improve the efficiency of the production system. Multi-criteria ABC analysis is an advanced and sophisticated version of ABC analysis. Through the application of this technique, a simplified matrix was derived that incorporates the factor of volume and value to provide categories for product lines. In all, five categories A1, A2, A3, B1 and B2 were suggested. These categories were further analysed to devise a methodology to process parts in the manufacturing system. The methodology was aimed at improving customer service whilst reducing costs. GT is perceived to be the road to success in modern manufacturing. The technique of PFA was applied on the company data to identify group of machines to manufacture set of parts. The analysis revealed no apparent groups that could possibly be used to form cells. This led to the conclusion that out of the two lean manufacturing tools discussed in this chapter, the current issues and inefficiencies in the company could more appropriately be minimised through the application of multi-criteria ABC analysis. Hence the next few Chapters will discuss the application of the methodology. This also suggests that GT, although a very powerful tool for improving material flow, may not be applicable to all industries. The most important aspect of selecting any lean manufacturing tool is to understand the underlying issues within an organisation and to apply the most appropriate techniques that could result in maximum benefit with minimum use of resources. However, it was noted that the rate-determining step in the manufacture of goods appeared to line with the moulding machines.

Chapter Five Modelling the ABC Methodology Using Arena® Simulating Software System

In Chapter Four a methodology was derived for the processing of parts travelling throughout the manufacturing cycle, in its theoretical form the methodology provides an argument for improving the overall manufacturing efficiency of the organisation. This statement will be qualified in the following chapter where in the ABC methodology has been simulated using Arena® software, the model has been simulated using procedures examined previously in Chapter Two.

5.1. Problem Definition and Project Planning

The initial phase of the simulation deals with the gathering of information about the problem situation, Chapter Three provided an understanding of the key issues that were believed to be affecting the profitability of the organisation. Using a variety of analytical tools the following fundamental issues were identified as:

- Poor customer service (delivery performance);
- High WIP;
- Long waiting time in between major processes; and
- Poor resource utilisation.

Chapter Three indicated that the production system was very reactive to customer demands and hence specialised expertise was required at every level of production system to achieve the following objective; '*to supply quality products to customers on time and in full'*. In doing so, the production system had become heavily reliant on people and even with a high level of micro management customer service was often failing to achieve its goal.

The decisions made on the shop floor regarding the prioritisation of orders were primarily based on 'who (from customers) shouts the loudest'. This approach not only disrupts the planning system but also incurs unnecessary costs resulting from the increased number of setups and the intensive level of material handling.

The methodology proposed in Chapter Four focused on improving customer service by categorising product lines so that the manufacturing system works on a criterion that is logically based on the value and volume of a product line.

In Chapter Two several authors highlighted the benefits that could be expected from this type of methodology, these principles could be further tested by simulating the methodology model. The objective of this simulation is to demonstrate to TP & other suppliers with reasonable confidence how practical and/or viable the methodology is for the processing of parts through the manufacturing systems.

It is of utmost importance to define the problem situation and answer basic questions such as, what is this simulation for; why is it being conducted and how will the results be used? The simulation will reveal the impact the methodology has on key areas within the production systems before and after its inception specifically highlighting its effects on lead time, waiting time and WIP. This model will incorporate real operational data and include information collected from companywide ERP systems. The simulation will use actual production sequences and decision logic required to represent facility operations accurately. The finished model will allow an analyst to specify various operating scenarios within the factory and rapidly perform statistical analyses and simulation based experiments on them.

In summary, the aim was to simulate the flow of material within the factory, 'as is', after which demonstrate the benefits of the ABC methodology by applying the 'new' concept. It is important to note here that the Arena® software used in this simulation is under an 'Academic mode' licence and hence is used to demonstrate 'proof of principle' rather than fully simulate the workings of TP which would require the flexibility of the professional package.

5.2. System Definition and Conceptual Model Formulation

In this stage, the logic developed for the simulation was defined. An attempt was made to design a simulation that neither oversimplifies the system nor carries so much detail that it becomes clumsy, time consuming or overly intricate. The system logic was ascertained through interviews with technical staff on the shop floor and with the help of production process maps.

In this phase the system is divided into logical subsystems. Figure 5.1 (a) presents a conceptual model of the system being simulated. The simulation is divided into three sub-systems; manufacturing orders (input), manufacturing processes (system) and outputs (measuring point). Figure 5.1 (b) shows the detail of each activity within the sub-systems. For example, the input system involves the arrival of entities, production batches, and details of manufacturing orders, resources and materials.

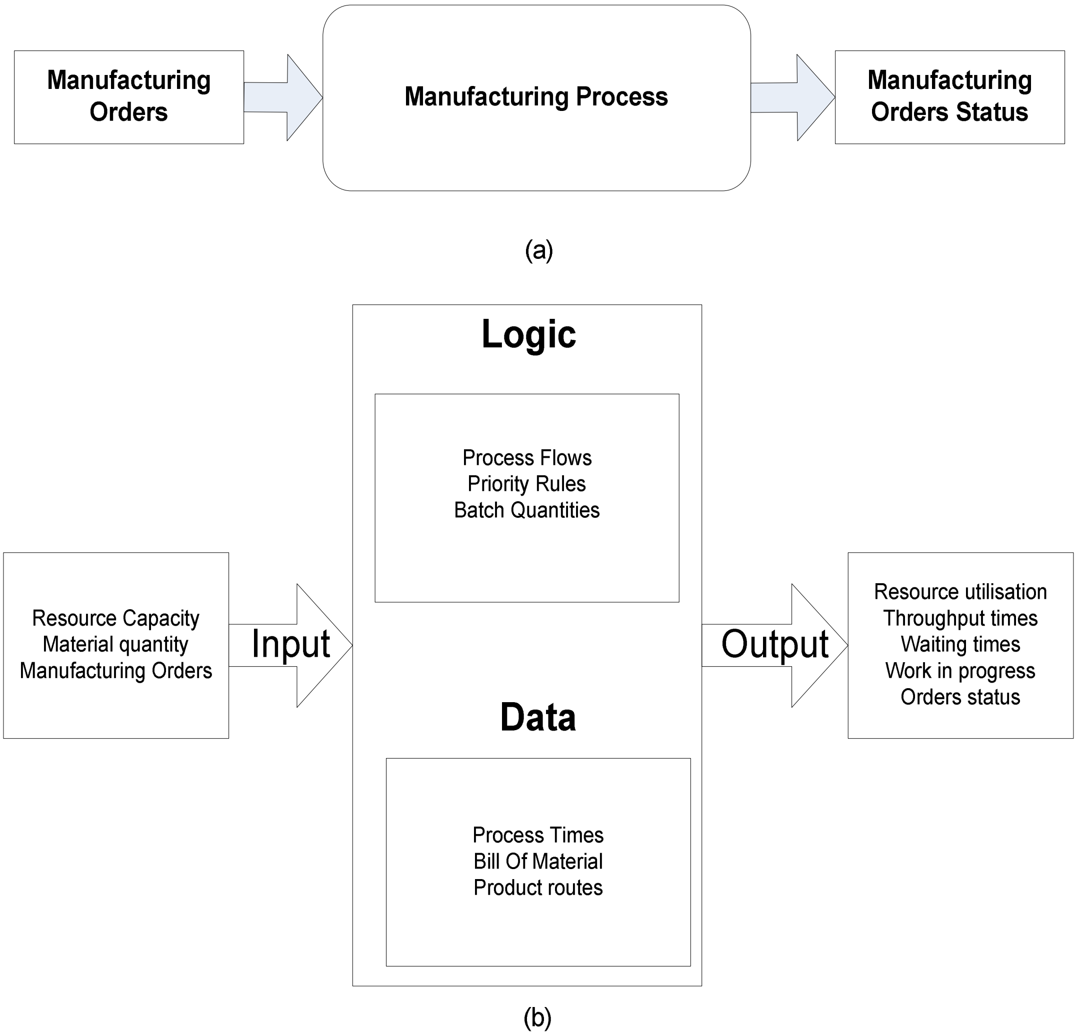


Figure 5.1 (a) Conceptual model sub-systems (b) Conceptual model with activity

The starting point for the simulation is the arrival of manufacturing orders from customers. Raw material is then processed by the first set of 'work-centres' that include moulding machines. By the process of thermoforming, these sheets are formed into plastic components. These components then travel to the second set of work-centres and are trimmed. Products from trimming machines are then sent to finished goods as shown in Figure 5.2.

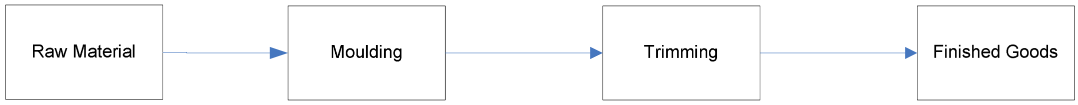


Figure 5.2 Flow chart showing flow of material through the work-centres.

At this stage it is more important to generate the concept rather than imitate the real situation. The basic inputs as identified in Figure 5.1 include resource capacity, material quantity (volume) and manufacturing orders. The logic involved in the simulation deals with the flow of material based on priorities. For the logic to be applied the data required for the simulation includes, manufacturing order details, processing times, work-centre details, product routes and batch sizes.

Conceptual model: From Figure 5.2 and as stated earlier raw material in the form of plastic sheets arrives into the system.

- The process begins with quantifying the volume in A1, A2, A3, B1 and B2 categories that will be processed within the simulation system. From Appendix 2 (CD-ROM, Fine name: Data set, Worksheet: VOLUME PERCENT), a total of 8258 units were processed in one month by five randomly selected moulding machines (G1, G2, G6, G7 and G12). As per multi-criteria ABC analysis 3% volume is A1 category product lines, 15% A2, 54% A3 12% B1 and 16% B2. This percentage is converted into volume units as shown in Table 5.1. For this simulation 15% of the volume (*i.e.* total 1239 units) was simulated over a period of five days (one working week). For example in the case of category A1 product lines, 37 units were simulated.

Product Category	Volume Percent	Volume Units	15% Volume Units
A1	3.00%	248	37
A2	15.00%	1039	186
A3	54.00%	4459	669
B1	12.00%	991	149
B2	16.00%	1321	198

Table 5.1 Volume percent

- The material was released in set quantities over a specific period of time. These set quantities were further collated into appropriate batches. Batch sizes for the categories were evaluated by averaging the actual production batch sizes from production history. Along with the average batch size, the standard deviation for the same was also calculated. For example, averaging the real production batch sizes for all those parts that fall under the A1 category provided an average figure that was used in the simulation as the batch size for A1 category. The concept was applied further to calculate batch sizes for A2, A3, B1 and B2 category product lines (Appendix 2 CD-ROM, Fine name: Data set, Worksheet: A1, A2, A3, B1 and B2). At least 25% of samples were taken from each category of product lines to determine the average batch size. In order to keep the simulation simple yet affective the batch sizes along with standard deviation were reduced to an appropriate level so that they do not exceed the software limitation of 150 entities at any instance within the simulation.
- Five moulding machines (G1, G2, G6, G7 and G12) and five trimming machines (C4, C5, C9, C11 and C12) were selected to demonstrate the concept of methodology.
- Batches move from batch station to moulding machines. The logic for batch movement to a particular moulding machine is presented in Appendix 2 (CD-ROM, Fine name: Data set, Worksheet: VOLUME PERCENT). 14.5% of batches were processed by G1, 26.1% processed by G2, 14.4% processed by G6, 27.4% processes by G7 and the remaining 17.6% processed by G12. Figure 5.3 shows the flow of material from batch station to mainstream processing.

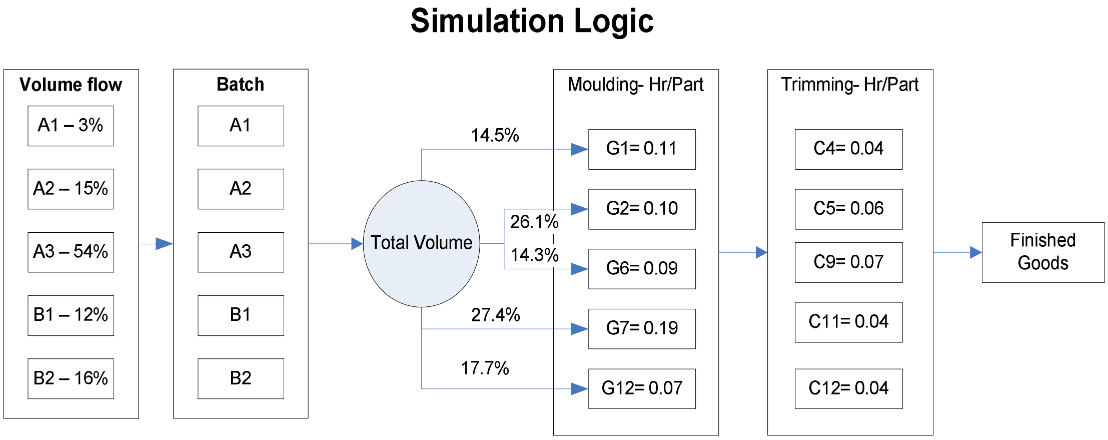


Figure 5.3 Simulation logic with data.

- The batches at the moulding station were processed by moulding machines. The process time for any moulding machine is evaluated by averaging the theoretical 'process time' for all the parts that are processed by a particular moulding machine. For example the average process time as evaluated for G1 was 0.11 hour per part (Appendix 2, CD-ROM, Fine name: Data set 1, Worksheet: GEISS). The standard deviation for the same was also calculated to achieve realistic results from simulation.
- Batches processed at moulding machines then move on to CNC trimming machines. The processing time for CNC machines is shown in Appendix 2 (CD-ROM, Fine name: Data set 1). The process time for CNC machines was evaluated using the same principle as used for moulding machines.

Assumptions: there were several assumptions that were made to simulate the methodology. These assumptions are as follows:

- Products moving from one station to another have no transport time;
- Machines have no downtime and do not fail;
- There were only two primary processes namely moulding and trimming;
- There were no operators to run the machines; and
- Setup time for all moulding machines was 60 minutes and for trimming machines 30 minutes.

5.3. Preliminary Experimental Design and Data Preparation

The data for the simulation is extracted from the company wide ERP system, Sage®. The total number of units produced by the thermoforming machines (G1, G2, G6, G7 and G12) for approximately six periods (six months) was evaluated. A total of 1239 units were selected for the simulation representing approximately 15 % of the total volume produced as shown in Table 5.1. The primary reason for selecting 15% volume was to keep the calculation sensible, and not allow the calculation to become excessively cumbersome.

Creating Entities: The starting point of the simulation was material arrival which arrives in batches after a set interval of time. The time interval of material arrival is random for the 'as is' simulation and for 'to be' simulation the time interval is constant. This is because according to the principles of the methodology A1, A2 and A3 category product lines need to be processed in the manufacturing system with a fixed time period.

Data Preparation: Average production batch size along with the standard deviation for the product line categories were evaluated as an average of batch quantities that were run by TP Hessle between 29/03/2004 to 26/09/2004. Appendix 2 (CD-ROM, Fine name: Data set, Worksheet: A1, A2, A3, B1 and B2) illustrates the production batch sizes for the categories in detail.

The pattern of material arrival before the implantation of the methodology is presented in Table 5.2, in the table categories A1 to A5 represent 15% of one period (approximately one month) volume. Average batch quantity was multiplied by a percent factor in order to keep the number of entities less than 150 at any instance within the system. Table 5.2 also represent the number of batches arriving in the system. Actual volume simulated within the system was a product of batch size and number of batches. For example the number of batches arriving in the system for A1 category product lines is 4, therefore the total number of units generated within the system was the product of batch size (9) and number of batches (4) *i.e.* 9*4 = 36. As stated earlier, the replication was carried over five days hence the frequency of batches arriving in the system is different between 'before' and 'after' methodologies.

Before	15% volume	Batch size	% of original batch size	Std dev	No of batch arrival	Actual volume	Frequency	Batch Arrival
A1	37	9	15	6.3	4	36	1.25	Random
A2	186	17	15	16.1	12	204	0.42	Random
A3	669	19	14	17.4	35	665	0.14	Random
B1	149	11	50	3.7	13	143	0.38	Random
B2	198	8	15	6.6	24	192	0.21	Random
Total	1239					1240		

Table 5.2 Manufacturing data for simulation for 'before' methodology implementation

- The criterion for frequency of batch arrival for product lines 'before' methodology is based on the random nature of batch arrivals. Batches arrive randomly in the system for A1, A2, A3, B1 and B2 product lines. For example for product line A1, a batch of nine units will be generated randomly every 1.25 days (5 days divided by 4 batches = 1.25).
- The criterion for frequency of batch arrival for product lines 'after' methodology is based on the principles of the methodology that suggests that the batches for category A1, A2 and A3 arrive constantly after a set interval of time. For example, from Table 5.3, for category A1 product lines, a batch of 7 units will arrive constantly everyday for five days (5 days divided by five batches = 1). The methodology also defines that for category B1 and B2, batches arrive randomly as in the case of simulation 'before methodology'.

Before	15% volume	Batch size	% original batch size	Std dev	No of batch arrival	Actual volume	Frequency	Batch Arrival
A1	37	7	15	2.4	5	35	1.00	Constant
A2	186	23	15	20.7	8	184	0.63	Constant
A3	669	59	14	30.4	12	708	0.42	Constant
B1	149	11	50	3.7	13	143	0.38	Random
B2	198	8	15	6.6	24	192	0.21	Random
Total	1239					1262		

Table 5.3 Manufacturing data for simulation for 'after' methodology implementation

Batch Formation: Entities are created in fixed quantities as described in the data preparation section of this chapter. These quantities then reach the batching station where a new set of batches are created.

- Batching criteria for the simulation 'before' methodology is derived by averaging the total batches produced between 29/03/2004 and 26/09/2004 these batches represent at least 25% of product lines within a specific category. Referring to Appendix 2 (CD-ROM, Fine name: Data set, Worksheet: A1, A2, A3, B1 and B2) for details of average batch sizes. The batches within the system are formed by using the Poisson probability distribution function. The Poisson distribution was applied as it is often used to model the number of random events occurring over a fixed interval of time, and since most of the batches arrive in this fashion this function was used to model the randomness of the batch sizes.
- Batching criteria for the simulation 'after' methodology was derived by applying the principles of methodology. In the methodology A1 category product lines are produced on a weekly basis in order to keep the inventory costs to a minimum. A2 category product lines are produced mostly on a fortnightly basis and A3 category product lines are produced, on average every six weeks. For B1 and B2 category product lines the same principles apply for batch formation as in the case of 'before' methodology. Hence in order to evaluate the average batch size for A1, weekly batch quantities were evaluated for 25% of product lines produced within the range 29/03/2004 to 26/09/2004. Similarly for A2 category product lines the average fortnightly batch quantities were evaluated and for A3 category product lines six week batch quantities were evaluated. In Appendix 2 (CD-ROM, Fine name: Data set 2) the average batch size for categories is presented.

Data Flow: Once the batches were formed they then travel through the system and were processed by thermoforming (G1, G2, G6, G7 and G12) and trimming (C4, C5, C9, C11 and C12) machines. Table 5.4 shows the percentage of volume flowing to different thermoforming machines. For example 14.5 % volume flows through G1. To evaluate the percentage of volume of material flowing through any thermoforming machine, the total volume for any one machine is divided by the total volume of material flowing through all the thermoforming machines. For example, from Table 5.4, the total volume of material processed by the thermoforming machines between the date range 29/03/2004 to 26/09/2004 was 49550 units. The number of units processed by G1 within the same date range was 7194 units hence the volume flowing through G1 is equal to 14.5% (7194 divided by 49550). Refer to Appendix 2 (CD-ROM, Fine name: Data set, Worksheet: VOLUME PERCENT) for detailed calculation.

Machine	Qty	% Volume flowing through Machine
G1	7,194.19	14.5%
G12	12,950.47	26.1%
G2	7,061.50	14.3%
G6	13,599.73	27.4%
G7	8,743.70	17.9%
Total Qty	49549.585	

Table 5.4 Percentage volume flow for (G1, G2, G6, G7 and G12) thermoforming machines.

Process Time and Setup Time

Table 5.5 shows the set-up time and process time for the products. It is important to note here that set-up time is in hours per batch while the process time is measured in hours per unit. In this simulation the average set-up time for moulding and trimming is considered to be 1.0 and 0.5 hours per batch respectively.

Resource	Set-up Time	Setup Time Units	Process Time	Process Time Units
G1	1.0	Hours Per Batch	0.11	Hours Per Unit
G2	1.0	Hours Per Batch	0.10	Hours Per Unit
G6	1.0	Hours Per Batch	0.09	Hours Per Unit
G7	1.0	Hours Per Batch	0.19	Hours Per Unit
G12	1.0	Hours Per Batch	0.07	Hours Per Unit
C4	0. 5	Hours Per Batch	0.04	Hours Per Unit
C5	0. 5	Hours Per Batch	0.06	Hours Per Unit
C9	0.5	Hours Per Batch	0.07	Hours Per Unit
C11	0.5	Hours Per Batch	0.04	Hours Per Unit
C12	0. 5	Hours Per Batch	0.04	Hours Per Unit

Table 5.5 Set-up and process times for the resources.

Process time is evaluated by averaging the actual process times for a particular resource. Along with the average process time standard deviation is also calculated.

Work-centres

In this simulation there are two sets of work-centres the first set includes five moulding stations; Geiss 1 (G1), Geiss 2 (G2), Geiss 6 (G6), Geiss 7 (G7) and Geiss 12 (G12). The next set includes five trimming work station; CNC4 (C4), CNC5 (C5), CNC9 (9), CNC11 (C11) and CNC12 (C12). As stated earlier product lines arrive randomly at thermoforming machines and these products are then processed by the corresponding CNC trimming machines. For example, from Figure 5.4, product lines processed by G1 were only further processed by CNC 4.

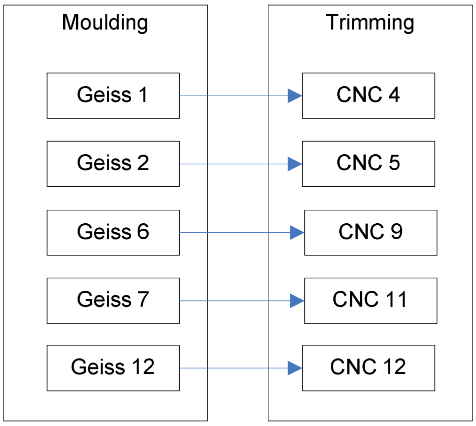


Figure 5.4 Material flow.

5.4. Model Translation

Once the conceptual model was decided upon and the relevant data organised the next stage was to describe or program the model in a language acceptable to the software. In Arena®, there are different window based modules that require inputs in a logical sequence to execute the scenario. The data collected was entered into appropriate fields within the software modules. In this analysis two models were simulated, first with a set of manufacturing orders based on information gathered prior to implementing the methodology (S1) using primary data from Table 5.2, the second is based on the implementation of the methodology (S2) using primary data from Table 5.3. The step by step translation to simulating software can be summarised as below:

Factory Time Patterns

The factory has been defined in terms of time pattern. In this simulation the factory was available for 24 hours and the data was simulated over a period of five days. It is assumed that there are no factory shutdowns or external factors that might affect the availability of resources.

Make Order

As the name suggests the make order module is used to define manufacturing orders. Batches arrive at the 'Make Order' module of the simulation. These orders are production batches that are released automatically into the model based on the process plan for each product. Figure 5.5 shows the manufacturing order module where the information about the manufacturing orders was entered.

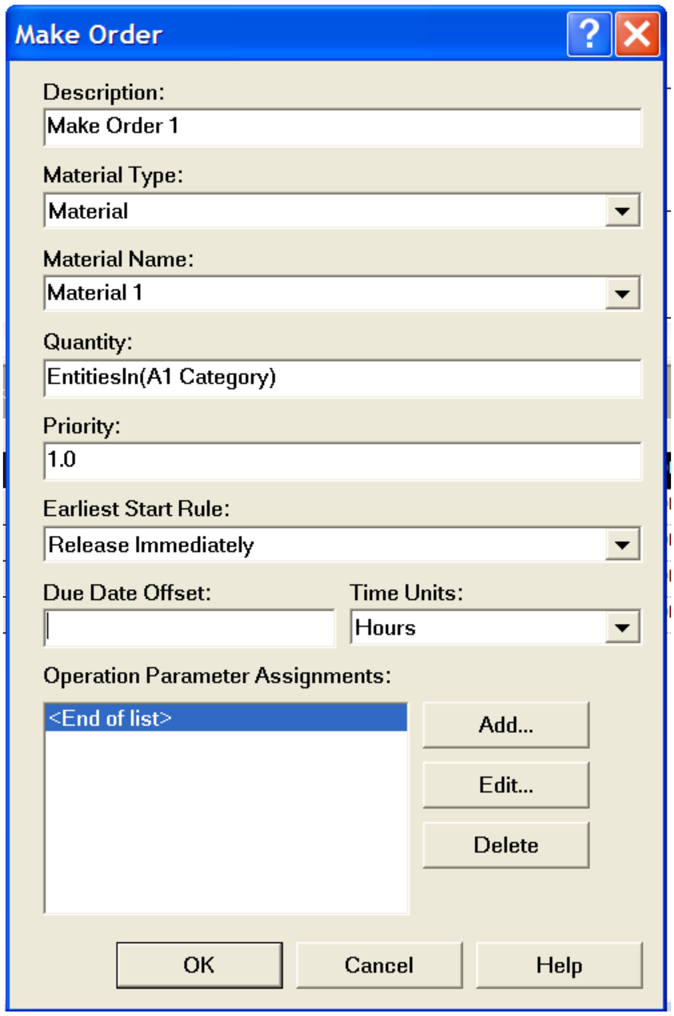


Figure 5.5 Make Order module.

Material Definition

The material module is used to define material that is either bought in or produced by the factory. These material descriptions were used by the Make Order, Material Arrival or Bill of Material modules. Figure 5.6 shows the material description for A1 category product lines. It is interesting to note that if the material can be manufactured, then the characteristics of a material's manufacturing process is also described which can include the process plan, entity type, BOM and others (see Figure 5.6).

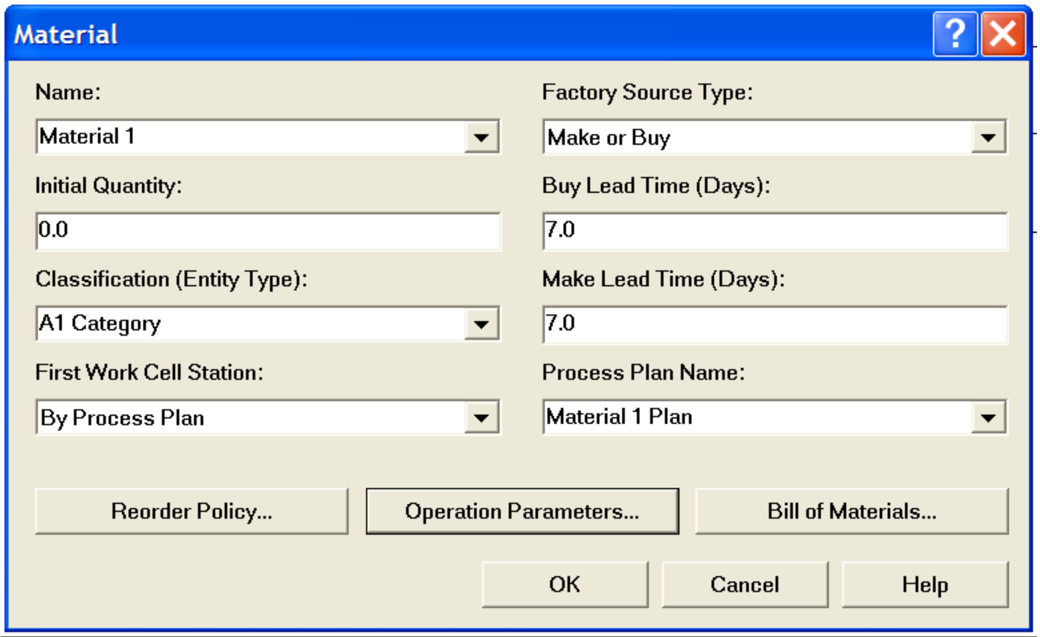


Figure 5.6 Material module.

Work Cell

This module controls the basic logic for an operation performed on a production batch at a work cell and is the main processing method used in the simulation. Production batches arrive at the work cell, wait in the queue until selected, are then processed through the work cell and then sent to the next work cell following their process plan. For example in Figure 5.7 Work Cell 1 was a work cell and GEISS 1 was the moulding machine. This was a station where parts arrive, are then processed and sent to the next station as per the process plan. It is important to note here that the production batches are released to the model by the Make Order module.

Process Plan

The process plan module defines process plans that are referenced by products. It is a collection of *Job Segments* that are performed at work cells. Figure 5.8 shows the process plan module for the 'Material 1 Plan'. The module further stores the information on the job segments that can be shown in Figure 5.9. In this figure, the material is processed in Work Cell 1 and the process details are stored in 'Segment Data Name' - Segment Data 1

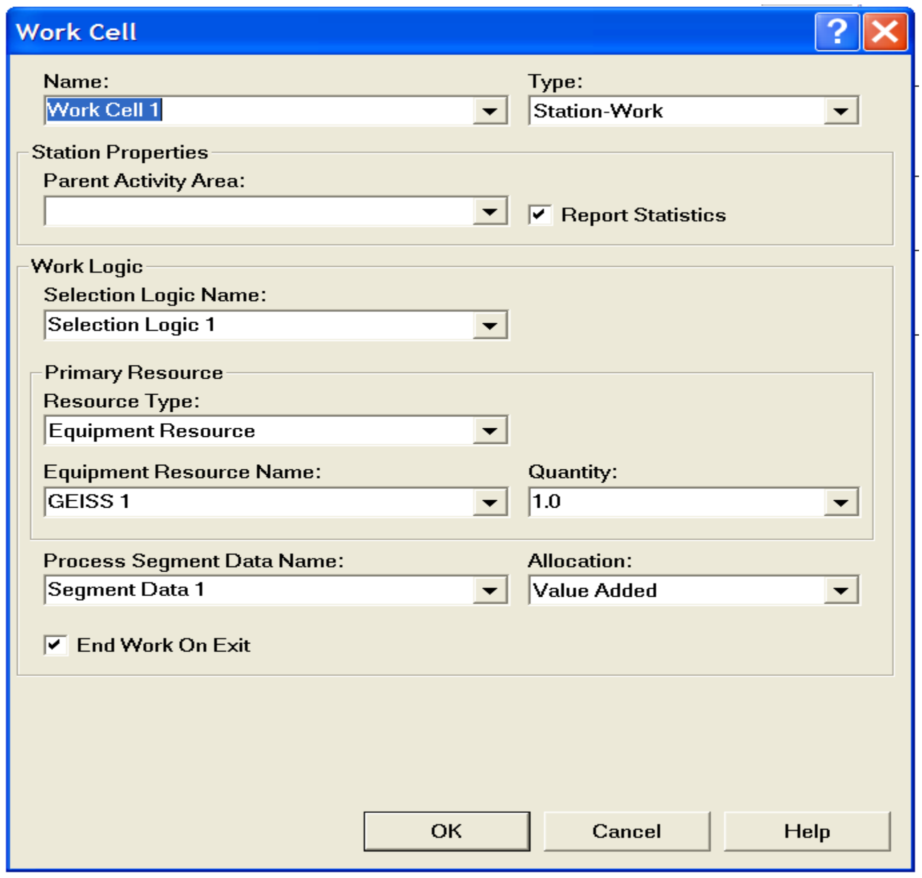


Figure 5.7 Factory Work Cell module.

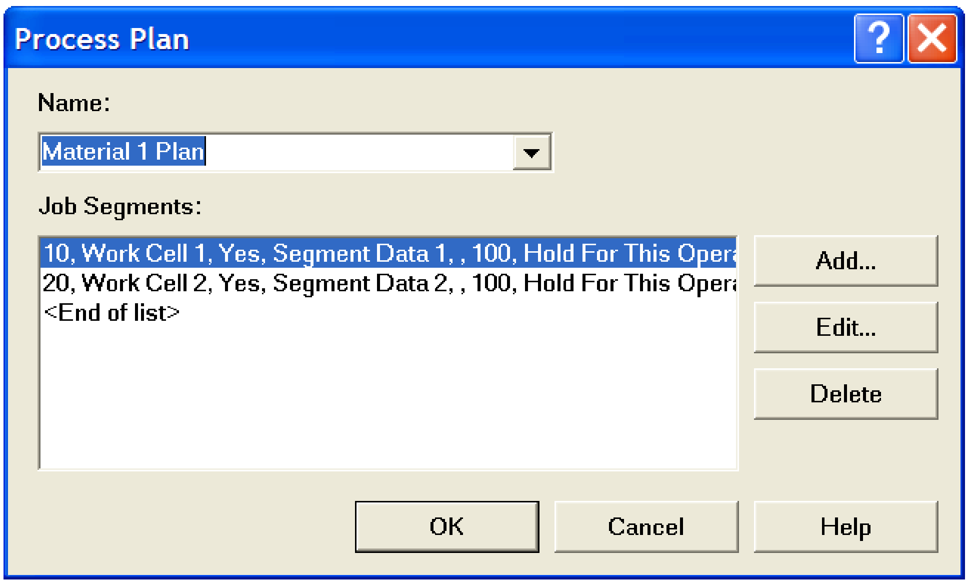


Figure 5.8 Process Plan module.

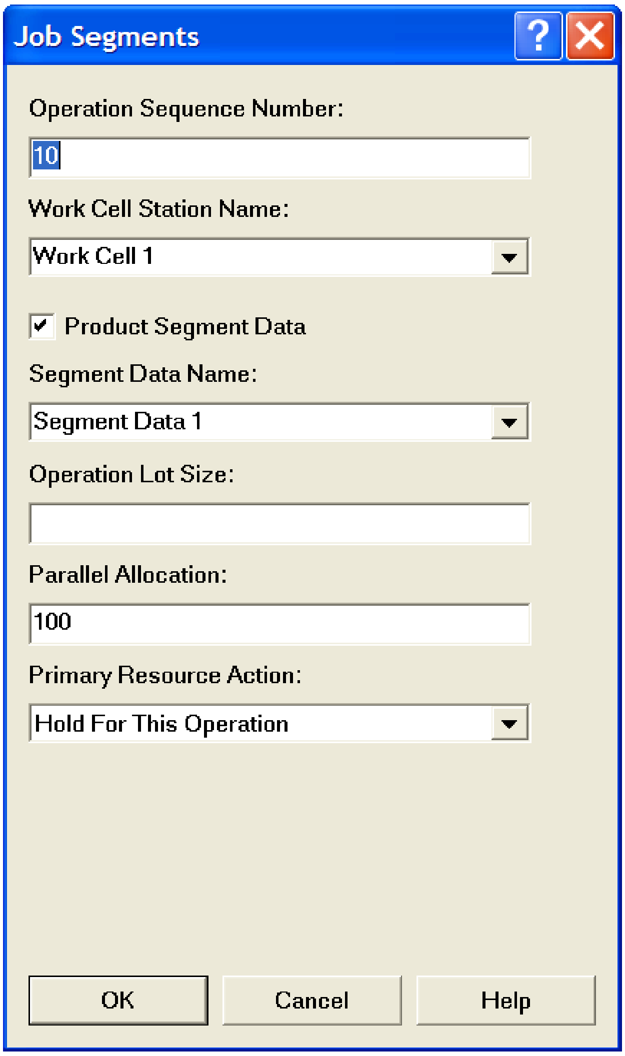


Figure 5.9 Job Segment module.

Segment Data

The segment data module is used to define a job segment that is referenced by process plan or work cells. The segment data includes phase times that are entered as two components: a *deterministic* plan time and a *multiplier* (Figure 5.10). A multiplier is used to introduce variation to the deterministic phase time specified. The process time is calculated as the product of the multiplier and the deterministic process time. It is important to note here that the deterministic plan times for processes were extracted from the ERP system. This is the average of process time for a particular resource. To calculate the *multiplier* the process time was plotted against the frequency to derive a graph pattern. For example, in Figure 5.11, frequency graph for Geiss 6 is skewed to the right. In such an instance the most appropriate probability distribution was 'Lognormal'. The lognormal distribution is used in situations where the quantity is the product of a large number of random quantities. From Appendix 2 (CD-ROM, Fine name: Data set 1), most of the graphs for resources follow the similar scenario and hence lognormal probability distribution was applied to process time *multipliers* for all other resources.

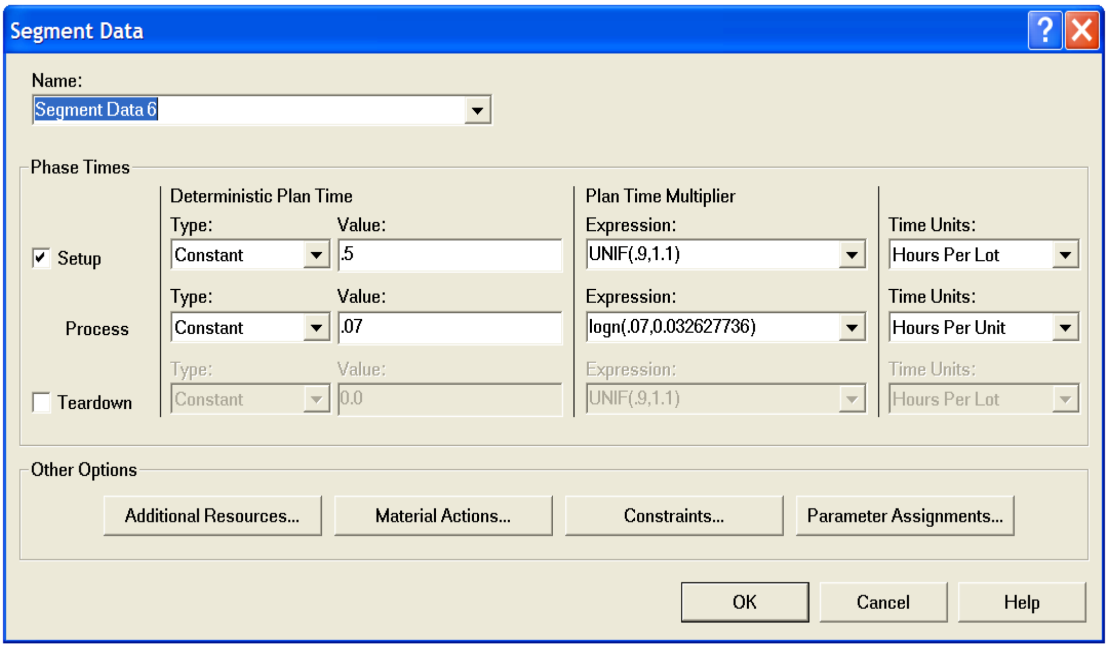


Figure 5.10 Segment Data module.

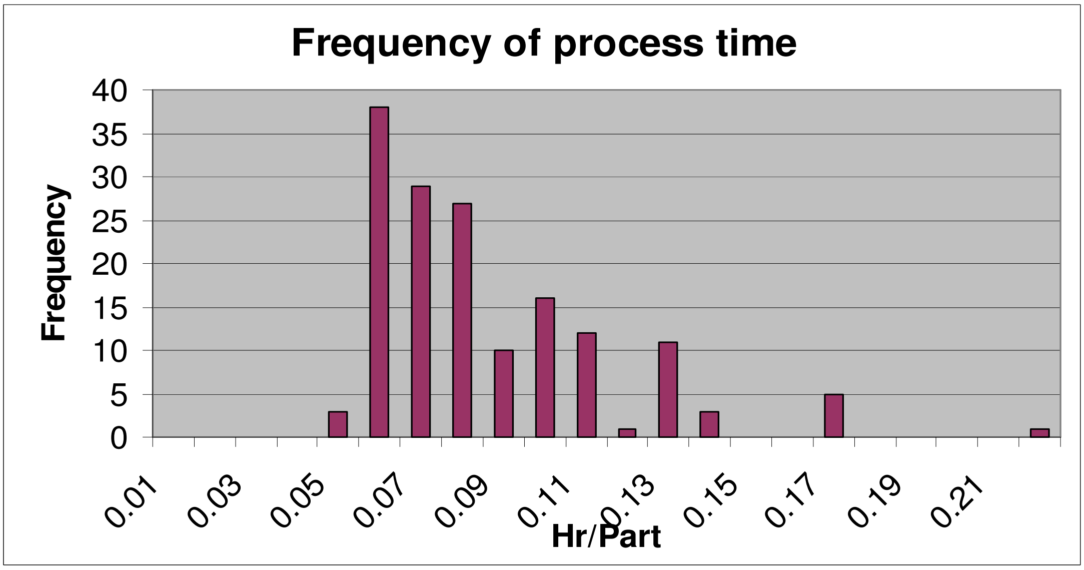


Figure 5.11 Frequency of process time for G6.

Selection Logic

This module is used to define the selection logic used by a work cell module, the function of which is to select the next production batch to work on as well as assign this production to the best possible resource. In this simulation the selection criterion is based on 'Earliest Due date' as illustrated by Figure 5.12.

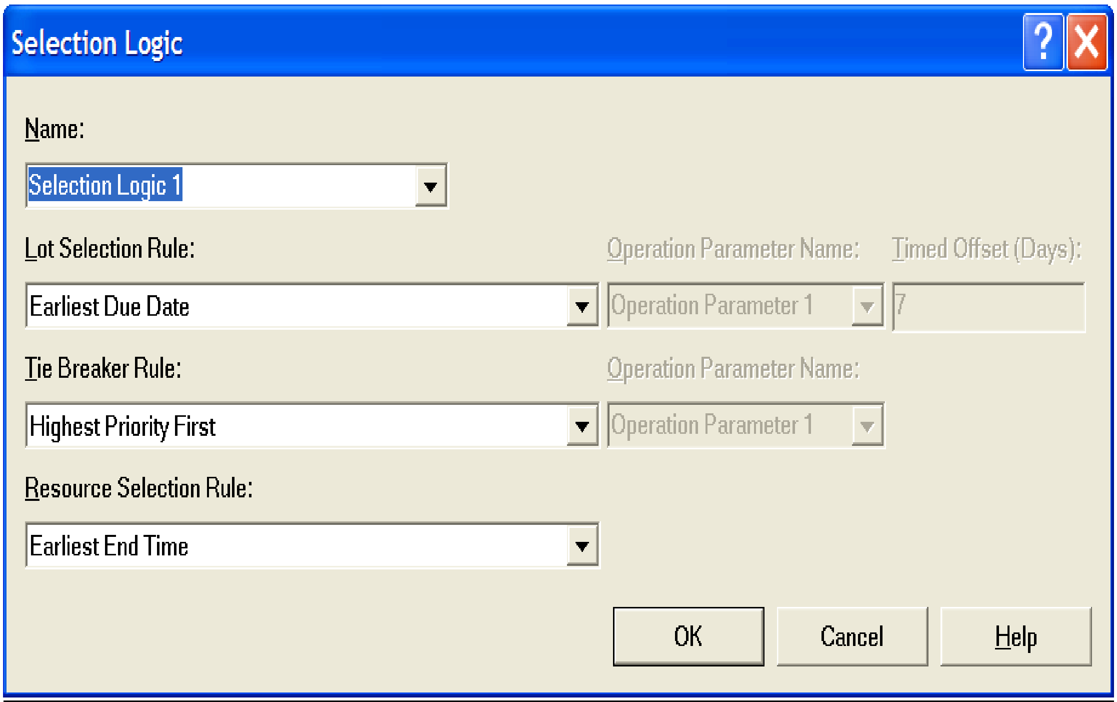


Figure 5.12 Selection Logic module.

Equipment Resource

The Equipment Resource module was used to define the equipment that was referenced as the primary resource in a work cell. The equipment resource model, Figure 5.13, defines machines that may or may not require additional labour resource for operation. In this simulation the equipment resource includes trimming and moulding machines. For this simulation the machines operate on an automatic cycle and do not require labour resource.

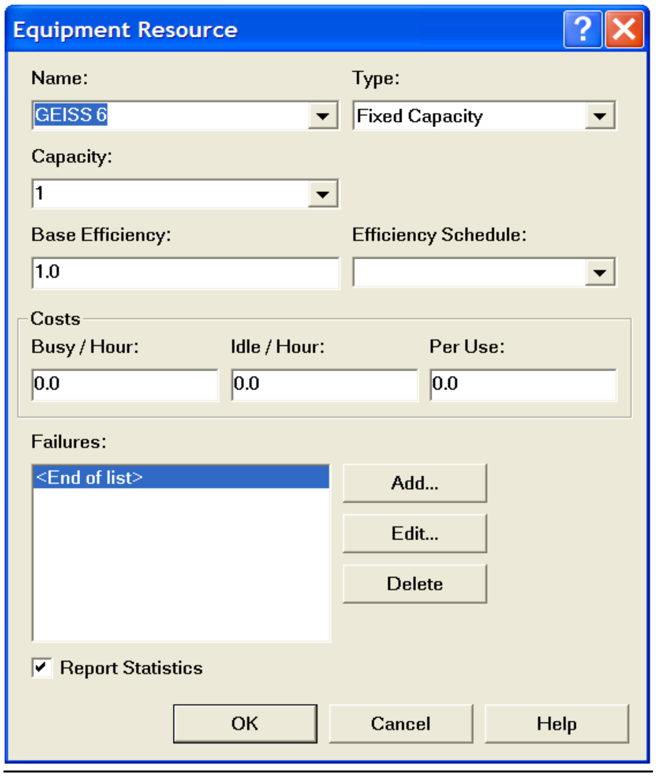


Figure 5.13 Equipment Resource module.

5.5. Verification and Validation

Once the simulation is programmed the next phase is to verify and validate the data. According to Kelton (2002), verification is the task of ensuring that the model behaves as intended, otherwise known as debugging. In this simulation the model has been checked to ensure that the system logic is applied correctly and that the model was accurately simulating the scenario described earlier in the chapter. For example, the initial stage was to design a model that simulates appropriate volumes approximately equal to 15% of one actual production period. It was also important that process times were realistic and to validate this both average process time along with standard deviation were evaluated. The process time figure was further tuned using an appropriate probability distribution function as a *multiplier*. The criteria used for selecting an appropriate probability distribution function was based on the frequency distribution graphs derived for each category of product line.

It is generally accepted that it is almost impossible to fully verify a complex model. In this simulation the author has performed various scenarios to verify the logic of each sub model within the main methodology model.

The two models simulated here are: *Simulation before methodology* and *Simulation after methodology* (Appendix 2 CD-ROM, Fine name: 'Combined Logic Before' and 'Combined Logic After'). Figure 5.14 shows the snapshot of simulation run. In order to validate the simulation model, the results need to be compared to real life system data.

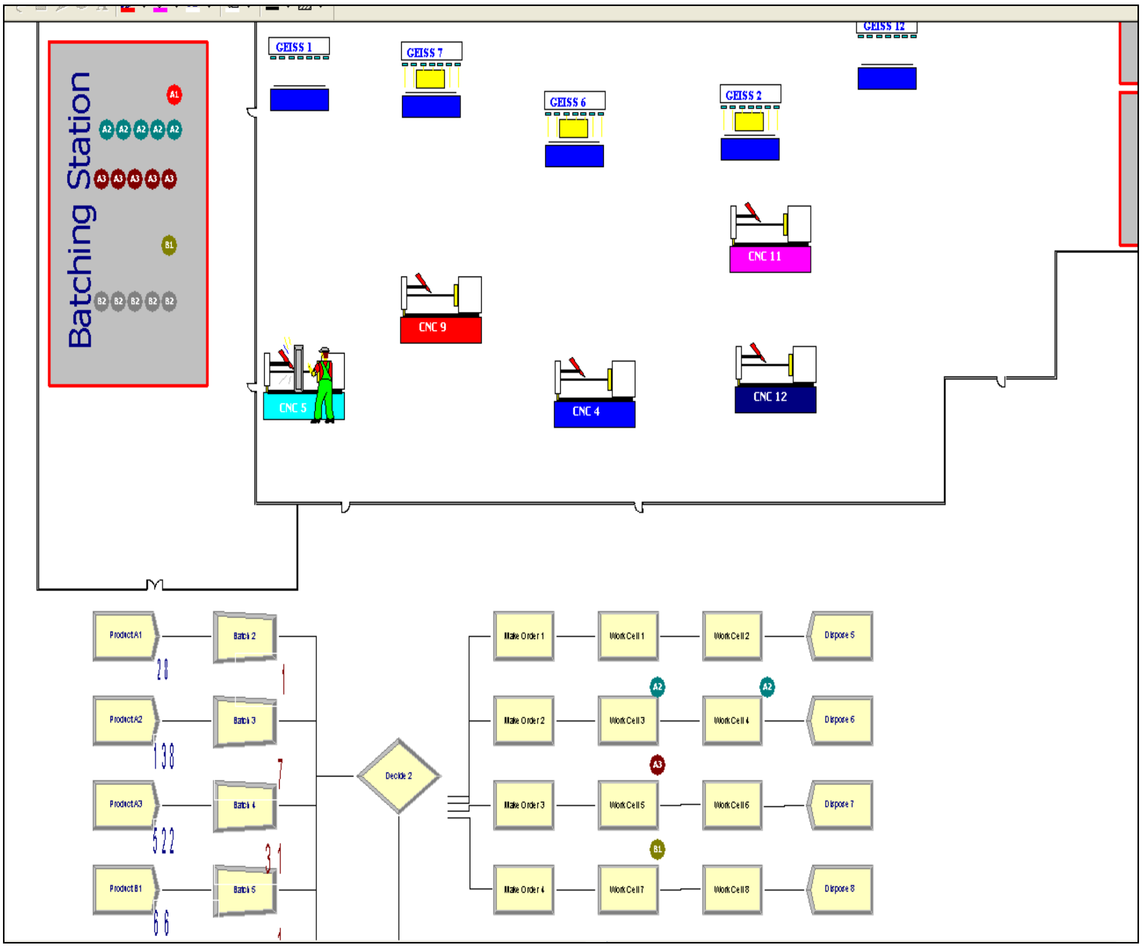


Figure 5.14 Snapshot of simulation run.

In the fist simulation, 'simulation before methodology' the data is extracted from the from ERP system, this may however not necessarily represent the real situation because the standard process time entered on the ERP system may not represent the actual process times observed on the shop floor. In this simulation the process times and other variables are converted into appropriate values to reflect the real situation (refer to Segment data section). It is also important to note here that the data variables within the two simulations (before and after methodology) are kept the same (with exception of batch sizes and frequency of batch arrival for manufacturing orders) providing confidence in the results taken from the simulation.

5.6. Final Experimental Design

As previously stated the simulation was performed twice, the first showing the factory 'as is', the second implementing concepts in line with the philosophy of this study. The simulation was replicated five times in order to improve the overall accuracy of the results. Due to the criteria for the flow of material being common to both systems under consideration variables such as operator scheduling, machine maintenance and failure did not require developing into the simulation and were therefore omitted for clarity.

5.7. Results from the simulation

The results from the simulation can be found in Appendix 2 (CD-ROM, File name: Results Comparision). The complete set of results with detail on resources can be seen after simulation run on the software. The simulation is run for five replications and summary of the results is presented in Table 5.6. From the results following conclusions can be drawn:

- Value added time: The average value added time for S2 was greater than S1. It is interesting to note here that even though the volume simulated in the model is similar for both simulations ('before' and 'after') there is a small difference between the value added times.

- WIP: A marginal increase in WIP as shown in the above is not unanticipated, batch sizes in Category S1 are small and although frequent in number there life as inventory is short in comparison to batches which fall into the S2 category. This is an expected outcome, considering the principles of lean manufacturing, small and frequent batches have low WIP levels.

- Wait time (entity): The wait time for S2 is comparatively lower than S1. This suggests that when the entities are not waiting for a long time in a system it may result in reducing the need for frequent intervention by production staff in terms of changing the priorities on the production batches. As identified from Chapter Three, prioritising production batches do not have a positive impact on the overall production system.

- Queue time ‘Waiting Time’ (at work cell): The total average number of entities waiting at ‘resource’ in simulation S2 was 8 as compared to 12 in S1. It must be stressed here that the methodology smooth out the demand from the customer for product lines (A2 and A3) and instead of following the demand pattern on week to week basis the production slot is dedicated and the quantity is fixed. In case of S1, the production staff concentrate on short term demand and regularly change the production quantity and production slots on the machines. As a result batches are split and this promotes ‘number waiting’.

Entity						
Time Units:	Hours	**S1 = Simulation before implementing methodology**				
		S2 = Simulation after implementing methodology				
Time						
VA Time						
	Average		Minimum		Maximum	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**
Total	17.52	18.23	14.28	16.12	20.51	19.79
WIP						
Number						
	Average		Minimum		Maximum	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**
Total	38.58	46.82	26.54	38.18	55.49	55.90
Wait Time		Time Units:	Hours			
	Average		Minimum		Maximum	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**
Total	23.36	9.59	3.09	3.37	48.70	15.24
Queue						
Time						
Waiting Time		Hours				
	Average		Minimum		Maximum	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**
Total	24.29	9.60	2.96	3.33	50.34	15.26
Number Waiting						
Number						
	Average		Minimum		Maximum	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**
Total	5.85	1.40	0.52	0.53	13.27	2.08

Table 5.6 Summary of results.

5.8. Summary

The principles of the methodology were applied to simulation S2 with fixed batch sizes and fixed production slots for A1, A2 and A3 product lines with B1 and B2 category product lines managed on different criteria. The simulation for S2 presented significant improvements in added value, queue time and waiting time. The results gathered from the simulation have validated the feasibility of the methodology proposed in this study and have gone some way to demonstrate that tangible improvements in efficiencies can be realised within the organisation as a whole. The data ascertained from the simulation also suggests that the complex planning and scheduling systems driven by localised expertise can be substituted by a simpler reality based system that follows the core principles of the work described in this document.

Chapter Six *Application of the ABC Methodology to Manufacturing and Delivery Issues within the Company*

Thompson Plastics (Hessle) Ltd. is continuously experiencing demand for low cost high quality products by a growing number of customers in a niche vehicle industry. Earlier chapters indicated that the company is unable to sustain its traditional ways of controlling and administering its manufacturing activities in line with the growth and increased complexity of the business. There are wide varieties of ever increasing product lines which vary in volume and value. In order to effectively utilise the resources and minimise waste, an efficient methodology for processing parts through the manufacturing system was devised using the technique of multi-criteria ABC analysis (as shown in Chapter Four). To simplify and streamline production, product lines were required to be categorised into groups based on their criticality. As stated earlier, product categorisation is a method of classifying items involved in a 'decision situation' on the basis of their relative importance. This may be on the basis of monetary value, the availability of resources, variation in lead time, the parts uniqueness, as well as the parts criticality to the running of the facility.

The most important criteria for TP (Hessle) Ltd. was product availability (*volume*) followed by the *value* of these product lines. To improve customer service/delivery it is paramount that products are delivered to customers on time and in the quantities that they require. This implies that the stocks are maintained at an appropriate level in stores with an approach that incurs minimum inventory costs as discussed in Chapter Four.

6.1. Application and Procedure for the Methodology

The methodology proposed to form groups of parts that were processed within the manufacturing system based on a set of rules reflecting the prominent business requirement *i.e. volume (improvement in customer delivery)* and *value (reduction in internal costs)*. In this section the concept of the methodology is explained with the help of examples using production data from the companywide ERP systems. As discussed earlier the top 20% lines by volume contribute to category A whilst the remaining 80% were classified as category B.

With reference to Figure 4.4, the analysis using the current data set shows that 20% lines (122) were sub categorised into 'High - above £20' (A1), 'Medium - between £20 and £6' (A2) and 'Low - below £6 (A3) categories.

The question is now, how to deal tactically with category A1. This sub-category consisted of **'high volume-high cost'** product lines. These require the most accurate anticipation of the future customer needs. Batch sizes and time points needed to be precisely determined to achieve accurate delivery time control. These parts being high cost and high volume will have a substantial influence on inventory costs if they are not controlled at a higher level. For example product AFT1969A952 falls under A1 category. According to the methodology this product should be made in line with the customer demand. Table 6.1 represents a snapshot of the proposed production schedule for the product against customer demand. It is interesting to note that the production schedule tracks the demand from customers on a week-to-week basis restricting inventory inflation for category A1 product lines. As suggested in the methodology these are to be produced on a dedicated production slot and in the quantities as required by the customer up to and including the date of next slot (net of stock held plus 10% contingency).

Week (T1969A952)	1	2	3	4	5
Quantity required	117	90	90	110	110
Production Plan	117	90	90	110	110

Table 6.1 Production schedule for AFT1969A952 against customer demand (snapshot).

The second sub category consisted of **'high volume medium cost'** product lines. These parts were under the high volume category but have relatively low standard cost when compared to A1. As suggested in the methodology these product lines were to be produced on every slot unless stock is available to cover the demand until the next production slot. Table 6.2 shows the production schedule for product demand. In the table product is produced on dedicated weekly slot even though the customer demand was slightly fluctuating on week to week basis. Unlike A1 category lines these have fixed production quantities, this is because being an A category product line there will be regular demand for this part and by smoothing out production it will ensure better customer delivery whilst reducing 'firefighting'.

Week (T1899B331)	1	2	3	4	5	6	7	8	9	10	11
Quantity required	81	63	72	72	72	81	81	81	81	81	81
Production Plan	155		155		155		155		155		155

Table 6.2 Production schedule for AFT1899B331 against customer demand (snapshot).

The third sub-category consists of **'high volume low value'** product lines. These parts being low in value but still high in volume do not require strict control over the quantity produced. Products in this category could be manufactured in appropriate quantities to ensure availability of parts. Table 6.3 shows the production schedule for A3 category product lines. The table shows the product line is produced almost every month in standard batch quantities.

Week (T2381C190)	1	2	3	4	5	6	7	8	9	10	11	12
Period	PERIOD 1				PERIOD 2				PREIOD 3			
Quantity required	4	62	59	-	54	50	4	10	59	37	77	28
Production Plan	150				150				150			

Table 6.3 Production schedule for T2381C190 against customer demand (snapshot).

The second category consists of the remaining 80% of product lines. These 80% consists of lines ranging in standard cost from £1 to £512. These 80% lines (493) are further sub categorised into 'Low - below £6' and 'high & medium - above £6'.

As stated earlier, high & medium value product lines comprises of B1 category. These products being high in value will require controls on the quantity to be produced as well as when to produce them. Table 6.4 shows the production plan for product line T1297B190, the low volume of these lines means a dedicated slot is not necessarily allocated unless the planning schedule has one available hence these parts should be produced in a variable slot and the planner decides on the appropriate quantities to be produce based on the availability of stillages, materials, machine capacity and visibility of future orders as defined on the schedule.

Week (T1297B190)	1	2	3	4	5	6	7	8	9
Quantity required	42	-	33	-	41	-	-	37	-
Production Plan	80				80				

Table 6.4 Production schedule for T1297B190 against customer demand (snapshot).

B1 category product lines are low in both volume and value. It is very necessary to have a near estimation and proper justification on the production quantities for these product lines. The quantity need to be justified on commercial considerations like set-up costs, non-specified material use, specific material purchase, EBQ etc. It may be required that the minimum quantity to be produced is negotiated with the customer. For example in Table 6.5, customer demand for product T1771A204 in week 1 is only 1 unit and it may not be economic to produce 1 unit as it is low value and low volume product.

Week (T1771A204)	1	2	3	4	5	6	7	8	9
Quantity required	1	-	-	-	-	-	-	-	-
Production Plan	Justified Qty								

Table 6.5 Production schedule for T1771A204 against customer demand (snapshot).

The methodology has the potential to improve customer service and reduce internal costs in theory. To put theory into practise, procedures for implementing and adapting the methodology within relevant sections of the manufacturing system were setup (Appendix 1). Appendix 1 details procedures and plans for implementing the methodology. In those procedures sections are broken down in detail integrating the current ERP system to allow individuals to follow the methodology in easy and simple steps. The appendix also includes detailed flow charts for various tasks and examples with explanations of actions on different scenarios.

The implementation of the methodology has the potential to reduce the lead time considerably. Value Stream Map (Figure 6.1) shows the overall intention in reduction of lead time for A1, A2 and A3 category lines. It is interesting to note from the Figure 6.1 that the lead time for A1 category product lines is expected to be three to four days while for A2 and A3 category lines it is acceptable to be a bit longer. The concept fits in line with the principles as suggested in the methodology. As it was suggested that the high value product lines (A1) should have a tight inventory control policies due to high monetary value associated with it, hence the low lead time. On the other hand A2 and A3 category product lines have lower value so it may be desirable to hold inventory at an acceptable level to support customer service, therefore the lead time for these products is comparatively higher than A1. In the figure, there are several lightning clouds suggesting improvements tasks that are required to reduce costs by improving efficiency. For example, the lightning cloud 'Reduce setup' signifies the need to reduce setup times on machines in order to reduce downtime and encourage frequent, yet low volume of batches to reduce inventory levels. It is important to note that these low yet frequent batches will reflect the overall reduction in inventory costs and will reduce chances of obsolescence.

6.2. Results

The methodology was implemented on the production system and benefits to the company were evaluated. The development and application of the methodology had initiated the improvements in the delivery performance (Figure 6.2) of the company. Prior to the methodology being implemented, the delivery performance was running at 30%, but post-implementation (July 2005 onwards), there was a sharp increase and the delivery performance was running at approximately 60%. Customers were getting products more frequently, on time and in correct quantities. There was a sense of stabilisation in the manufacturing process at planning and production with less fire fighting and production schedule intervention on the shop-floor.

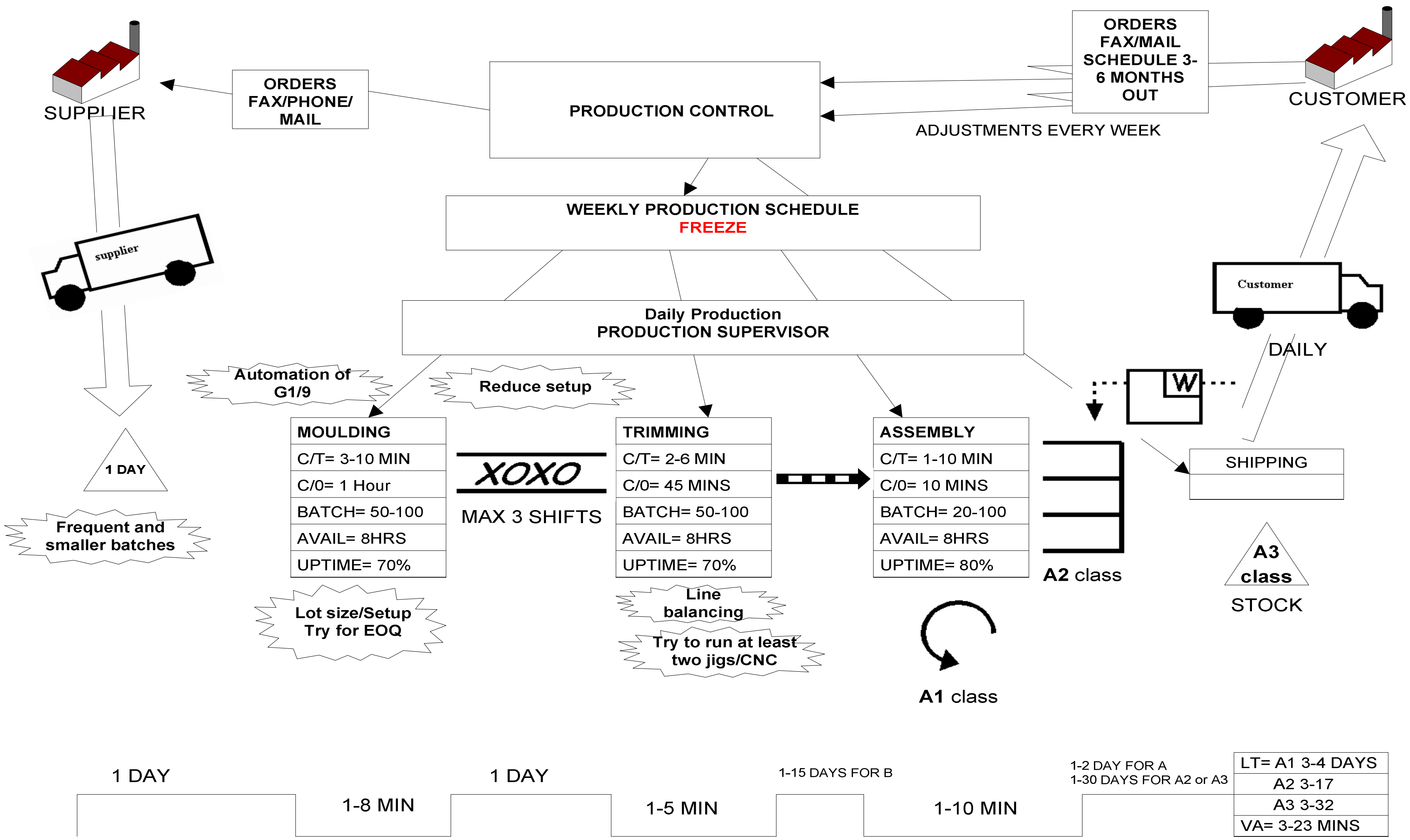


Figure 6.1 Value stream map -Future state.

6.3. Limitations and Problems

The only major limitation to this methodology is the validity of the items in a particular category over a period of time. Due to the dynamic nature of the business the items in the categories require regular monitoring so that they can be assigned and then shifted into appropriate categories from one production period to the next.

In terms of issues while implementing the practical aspects of the methodology, the major concern was the ‘people’ issue. As emphasised in earlier chapters, the organisation was mostly driven and dominated by people who have been working in the company for a long time and during that period they had, rightly or wrongly, developed their own way of managing and controlling manufacturing activities. It turned out to be very difficult to change the mindset of various people and to impose the methodology ‘whole heartedly’. The methodology was supported by higher management and they were fully convinced with the theory behind it. They were confident of its capabilities and potential benefits. Though, there was still a factor of hesitation and a concern about the ‘unknown’. The higher management, in their comfort zone, were more tolerant towards policies that did not necessarily reflect the methodology practiced by middle/shop floor management. Middle management strongly believed in their ways of managing the production activities and did not fully follow and implement the principles of methodology. If this is referred in context to the ‘change management’ then the behaviour could possibly be explained by the fact that some key decisions makers in the production system enjoyed the ‘thrill’ and ‘excitement’ of all the confusion and fire fighting taking place around them. It makes them feel important and because they can adequately support customer service in this state of commotion their practices and/or strategies become supported by higher management. The implementation was affected by several other internal factors some of those reasons are listed below;

- Lack of stillages availability to stock products.
- High reject rates affected the standard production batch quantities and encouraged variable batches.
- Booking product details and quantities on the computer system were unreliable and inaccurate this did not help in providing precise stock and WIP levels.

- Lack of space in stores restricted the full implementation of A3 category product lines.

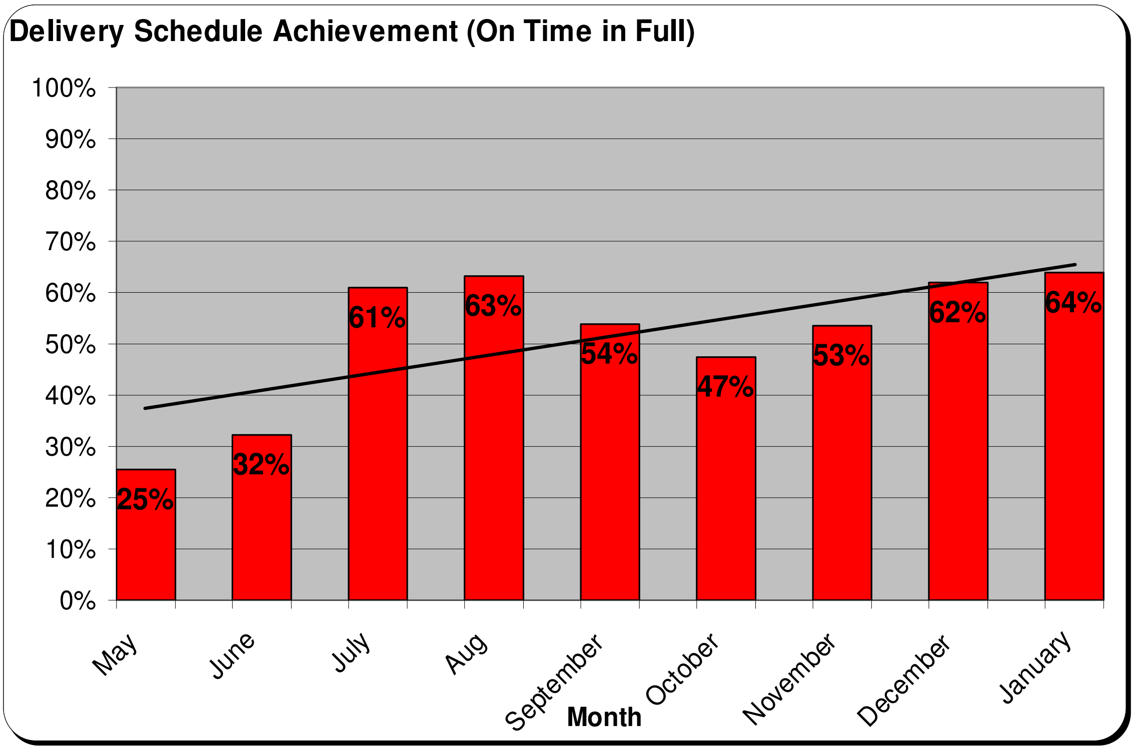


Figure 6.2 Delivery performance 2005-06.

6.4. Summary

The technique of multi-criteria ABC analysis was cleverly used to target some of the issues in the manufacturing systems at TP. The methodology devised on the basis of this analysis was used to process parts in the manufacturing system. The methodology has a potential to improve customer service and reduce internal costs in theory. To further apply theory into practise, procedures for implementing and adapting methodology within relevant sections of the manufacturing system were setup. Appendix 1 details procedures and plans for implementing the methodology. In those procedures sections are broken down in detail integrating the current ERP system to allow individuals to follow the methodology in easy and simple steps. The appendix also includes detailed flow charts for various tasks and examples with explanations of actions on different scenarios.

Chapter Seven Conclusions

This chapter summarises the impact the methodology has on the company's manufacturing system and discusses the issues and complications arising from its implementation. The chapter suggests areas for future work expanding on the accomplishments of this study.

This study focused on reviewing the manufacturing systems unique to a plastic thermoforming manufacturer. The study suggested the importance of customer service and a need for a high velocity supply chain performance. On-time delivery and customer service go hand-in-hand. Customers can, and will, change suppliers when they are unable to get the goods they want at the right time and in the right quantity. An essential objective of any manufacturing organisation is to ensure systems are in place to meet these customer demands. Several analytical tools were used in the thesis to identify some of the inefficiencies within the business. The analyses provided insight to the issues that were affecting the profitability. Customer service, in terms of delivery performance, was identified as a paramount issue. To find the best solution to the issues in the organisation two proven lean manufacturing techniques were applied; multi-criteria ABC methodology and Cellular Manufacturing. In the future production systems in the automotive industry will become more and more complex, with the manufacturing systems they use requiring more innovative thinking. The methodology developed in this study for off-highway and niche vehicle industry demonstrates contemporary thinking and business expertise. The essence of the methodology is to provide stability to the plant whilst improving delivery performance and this is practically achieved by placing high volume parts (A1 and A2) on a repetitive manufacturing schedule with dedicated capacity allocated over a fixed interval of time. The manageable number of core product lines allows the schedule to be rigidly followed providing better control over inventory levels. Whilst the core product lines are processed conceptually on an automatic basis with fixed manufacturing slots, this allows the freeing up of the production management resources that could be utilised to improve the low and medium category volumes (B1 and B2) that require more attention and understanding. The methodology presented here has the potential to streamline the planning process and production processing system with the help of the proposed "merit" rating. This improved KPI's in terms of delivery performance, lead-time and inventory levels. The results show an increase in delivery performance and improvement in manufacturing management activities on the shop floor. The grouping provided management with a more effective means for specifying, monitoring and controlling system performance, since strategic objectives and organisational factors can often be represented more naturally in terms of strategic groups. The development and application of the methodology has initiated the improvements in the delivery performance of the company. Furthermore, there is a sense of stability in the manufacturing process, both in planning and production.

In order to further reinforce the benefits of the methodology, a simulation study was undertaken to analyse the effect of methodology on the manufacturing system using the Arena® simulating software. The simulation proved to be a powerful tool for systems analysis. The result from an extensive analysis of the system showed a positive impact of the methodology on the production system with benefits like, reduction in value added time, waiting time and lead time.

An approach was also made towards implementing CM, but the results did not approve of its implementation within the organisation unless some major modifications were to be made on allocations of product lines to specific machines. It was not unusual to find that the techniques of CM do not imply to every sector of industry. In evaluating and implementing any tool to improve manufacturing efficiency is important to understand the costs and benefits associated with each technique. This should not mean numerous applications are identified and classed as management philosophies and because they are currently 'fashionable' may be the ultimate solution to a problem. The approach should focus on techniques that are applicable to specific well-defined problems. In the future it may not be straightforward for organisations to increase their profitability without adopting innovative techniques and methodologies that can maximise customer service and reduce internal costs.

In essence, the conclusion can be summarised in the following points;

- Thompson Technik (Hessle) Ltd. was operating in a turbulent market with ever increasing product variety and fluctuation in demand.
- The primary aim of the organisation was to improve delivery performance and provide a stable and more rational production schedule geared to improve efficiency on the shopfloor.

- An intensive research was undertaken in order to identify tools that could help resolve some of the issues experienced by the organisation. Two proven techniques in lean manufacturing were applied to the current production setup at TP Hessle to improve delivery performance and efficiency on the shopfloor.
- Multi-criteria ABC analysis was used to derive a methodology that was aimed towards improving delivery performance and overall efficiency on the shopfloor. The primary criterion was ‘volume’ and the secondary criterion was ‘value’.
- The data from multi-criteria ABC analysis was further used to identify any manufacturing cells by applying the techniques of PFA. The analysis revealed that there were no natural group of parts that could be processed by a set of machines *i.e.* no natural cells could be identified.

7.1. Further Work

Further benefits to the methodology could be achieved by applying more appropriate criteria to suit the specific requirements within the manufacturing system. For example it would be interesting to see the affect of an additional criterion to the multi-criteria ABC analysis. This criterion could be the frequency of parts produced. In other words the analysis could be based on value, volume and frequency of production. This will provide a group of parts based on their frequency of production, volume and value. If priority is given to the criterion of ‘frequency of item production’ then that will help to focus on those parts that are produced more frequently and subsequently a methodology could be devised to effectively manage, control and operate groups based on the frequency of production, volume and value. The simulation presented in the thesis can also serve as a ‘springboard’ for future investigations into other aspects of the manufacturing system within TP.

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GLOSSARY OF TERMS AND ABBREVIATIONS

ABC "A class" inventory will typically contain items that account for 80% of total value, or 20% of total items.
"B class" inventory will have around 15% of total value, or 30% of total items.
"C class" inventory will account for the remaining 5%, or 50% of total items.

KTP Knowledge Transfer Partnership

TP Thompson Plastics

CNC Computer Numerical Control

IT Information Technology

ERP Enterprise Resource Planning

PFA Production Flow Analysis.

GT Group Technology

SSM Soft System Methodology

OM Operation Management

WIP Work in Progress

ORG Operation-Related Groups

AHP Analytic Hierarchy Process - AHP is a process for developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria.

EBQ Economic Batch Quantity: the optimum batch size for the manufacture of an item or component, at the lowest cost.

CM Cellular Manufacturing

QCD Quality, Cost, Delivery as used in lean manufacturing measures a businesses activity and develops Key performance indicators.

VSM Value Stream Map

SWOT SWOT Analysis is a strategic planning method used to evaluate the **S**trengths, **W**eaknesses, **O**pportunities, and **T**hreats involved in a project or in a business.

LFPuR® Long Fibre Polyurethane Reinforcement - A specialised manufacturing process.

BOM Bill of Material

MCA Multi-Criteria Analysis

SME Small and Medium-sized Enterprise

KPI Key Performance Indicator

BOA Binary Ordering Algorithm

Appendix 1

INDEX

Figures

Tables

Introduction

The document is a summary of an in-depth study of the production data for Thompson Plastics (Hessle) Ltd. A multi-criteria ABC analysis was carried out to form group of parts which are then processed in our manufacturing system based on a set of rules to reflect the prominent business requirement *i.e. volume (improvement in customer delivery)* and *value (reduction in internal costs)*.

The document contains all the necessary procedures and setups required to implement the ABC multi-criteria methodology.

Procedure 1.1	**Performing Pareto analyses on product lines.**
Purpose:	To perform Pareto analysis to categorise products into A1, A2, A3, B1, and B2 category product lines.
Reference:	1.1/0
Date:	29/07/2005

- Download last six months sales data from crystal report in excel format.
- Go through the list to confirm validity of the product lines *i.e.* if still current product lines.
- Delete product lines (with details) that have expired within last 6 months.
- Add/Amend new product lines with relevant details. For *e.g.* if a new product line is introduced within last two months (AFT1234A123 total qty sold in last 2 months=300) then adjust the quantity to reflect 6 months sales ([300/2] *6 = 600) or sales quantity can roughly be predicted by data from customer schedules forecast.
- Load current data into master file named 'Finished Part ABC'.

3.1. Customer Schedules - Schedule entry on Sage system

Excessive change in production schedules, often referred to as schedule nervousness, caused by uncertainty in demand or supply is an obstacle to effective execution of material requirement planning and processing. It leads to increased cost, reduced productivity, lower service level, and a general state of confusion at the shop floor.

The major cause of production nervousness is regular changes in customer requirement. Following procedure could be applied to the planning system to stabilise production schedule nervousness caused due to continuous change in customer forecast.

- At the first instance when schedule from customer is received, load the schedule for the next three periods (1 period is roughly equivalent to 1 month).

- In situation where customer provides weekly updated schedules; update and confirm only next two orders on the computer system, every week, for next three weeks (remaining 10 weeks schedules are left unchanged). On receipt of forth week updated schedule from customer update the schedule on the computer system for next three periods (12 weeks) and so on.

- If schedules are received irregularly, only update next two orders and once every period update for next three periods.

Further practical explanation of procedures to enter customer schedules is provided in the Table 1.1 (Customer Schedules - Schedule entry on Sage system). On the spreadsheet the continuous colour band of row is the schedule entry for next three periods while the other mixed colour band rows are updating schedules for next two orders only.

Applying above principle will stabilise the schedule nervousness while avoiding frequent changes in our multi-stage production systems.

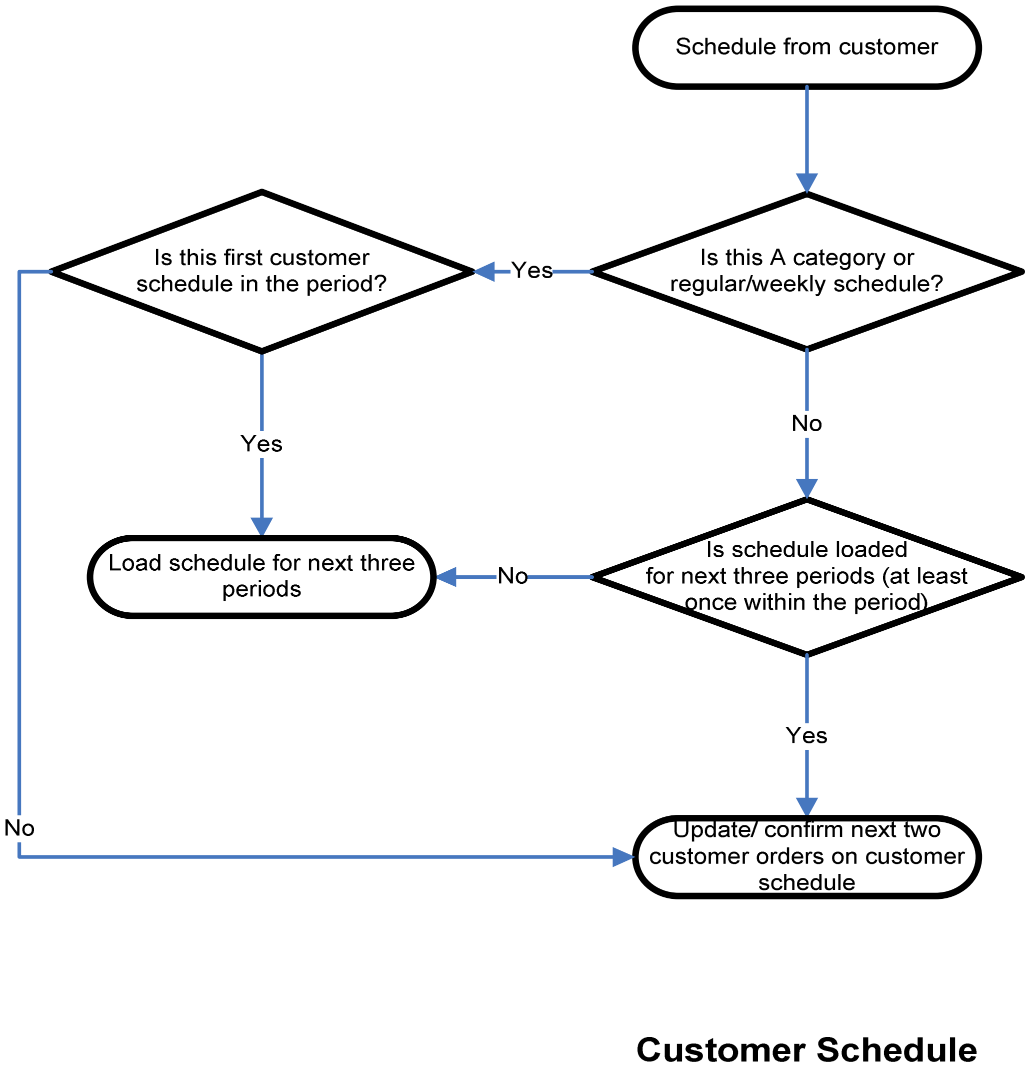


Figure 1.1 Customer Schedules - Schedule entry on Sage system.

Customer Schedules - Schedule entry on Sage system

Proposed - 12/07/2005

Regular Weekly Schedules

			Period 1				Period 2				Period 3				Period 4			
Schedule Forecast Frequency	Schedule Loaded	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4
Period 0, Wk 4	Next 3 Periods	**12**	**3**	**6**	**16**	**12**	**17**	**11**	**15**	**12**	**13**	**15**	**18**	**16**				
Period 1, Wk 1	Next two orders		5	7	16	12	17	11	15	12	13	15	18	16				
Period 1, Wk 2	Next two orders			8	10	12	17	11	15	12	13	15	18	16				
Period 1, Wk 3	Next two orders				12	14	17	11	15	12	13	15	18	16				
Period 1, Wk 4	Next 3 Periods					**10**	**15**	**10**	**12**	**18**	**15**	**20**	**18**	**15**	**8**	**19**	**11**	**16**
Period 2, WK 1	Next two orders						14	8	12	18	15	20	18	15	8	19	11	16
Period 2, WK 2	Next two orders							7	12	18	15	20	18	15	8	19	11	16
Period 2, WK 3	Next two orders								10	20	15	20	18	15	8	19	11	16

Example -1

Irregular Schedules -1

			Period 1				Period 2				Period 3				Period 4			
Schedule Forecast Frequency	Schedule Loaded	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4
Period 0, Wk 4	Next 3 Periods	**12**	**3**	**6**	**16**	**12**	**17**	**11**	**15**	**12**	**13**	**15**	**18**	**16**				
			3	6	16	12	17	11	15	12	13	15	18	16				
Period 1, Wk 2	Next two orders			8	10	12	17	11	15	12	13	15	18	16				
					10	12	17	11	15	12	13	15	18	16				
Period 1, Wk 4	Next 3 Periods					**10**	**15**	**10**	**12**	**18**	**15**	**20**	**18**	**15**	**8**	**19**	**11**	**16**
Period 2, WK 1	Next two orders						14	8	12	18	15	20	18	15	8	19	11	16
	Next two orders							8	12	18	15	20	18	15	8	19	11	16
Period 2, WK 3	Next two orders								10	20	15	20	18	15	8	19	11	16

Example -2

Irregular Schedules - 2

			Period 1				Period 2				Period 3				Period 4			
Schedule Forecast Frequency	Schedule Loaded	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4
Period 0, Wk 4	Next 3 Periods	**12**	**3**	**6**	**16**	**12**	**17**	**11**	**15**	**12**	**13**	**15**	**18**	**16**				
Period 1, Wk 1	Next two orders		5	7	16	12	17	11	15	12	13	15	18	16				
Period 1, Wk 1	Next two orders			6	15	12	17	11	15	12	13	15	18	16				
Period 1, Wk 2	Next two orders			8	12	14	17	11	15	12	13	15	18	16				
Period 1, Wk 3	Next two orders				12	14	17	11	15	12	13	15	18	16				
Period 1, Wk 4	Next 3 Periods					**10**	**15**	**10**	**12**	**18**	**15**	**20**	**18**	**15**	**8**	**19**	**11**	**16**
							15	10	12	18	15	20	18	15	8	19	11	16
Period 2, WK 2	Next two orders							7	12	18	15	20	18	15	8	19	11	16
Period 2, WK 3	Next two orders								10	20	15	20	18	15	8	19	11	16

Example -3

Table 1.1 Customer Schedules - Schedule entry on Sage system

Procedure 2.1 **Schedule entries for A1, A2, B1 and B2 category parts.**

Purpose: Procedure for customer schedule entry on SAGE line 5000 computer system for A1, A2, B1 and B2 category parts.

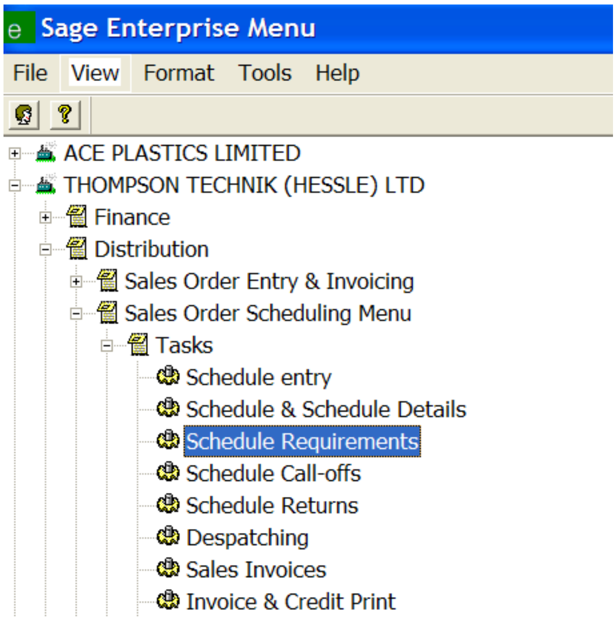
Reference: 2.1/0

Date: 29/07/2005

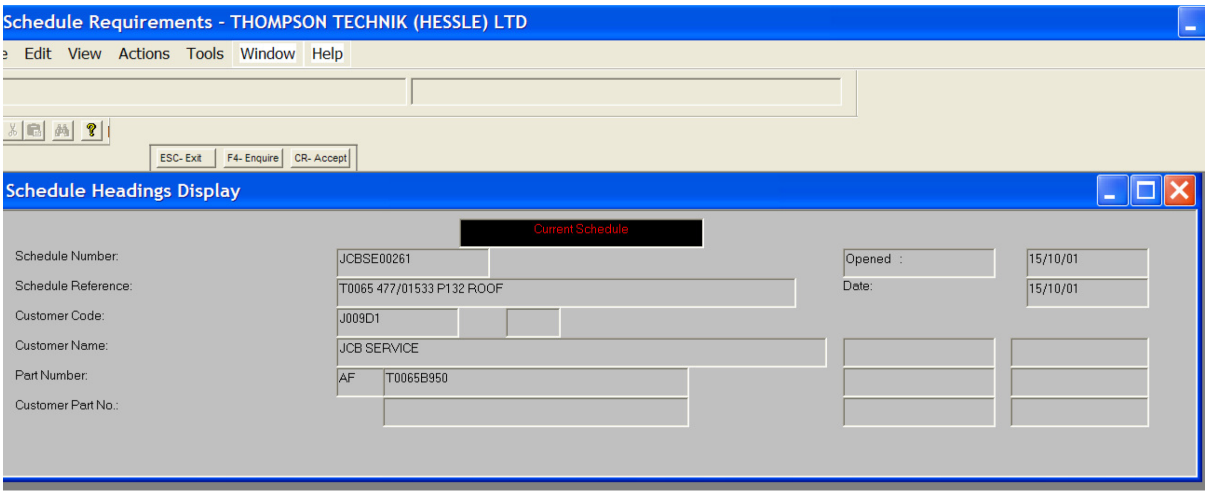
Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.

- Access schedule entry menu on the system.



- Under 'Schedule Reference' header on 'Schedule Headings Display', observe the last two values (adding categories code in process).



- If last two values are A3 then load next two customer orders on the system whenever schedule is received.
- If last two values are A1, A2, B1, or B2 and if this is last week of the month then load up to next three months of customer schedules on system and print date on hard copy of customer schedule and file in relevant customer schedule files.
- If this is not the last week of the month then update only next two customer orders on the system for that product line.
- If schedules from customer are not updated at least once for next 3 months within last 4 weeks then update schedules on the system for next 3 months else update next two customers schedules only.

Note:

- *If you notice any abnormality on schedules for order quantities then please inform and discuss issue with factory personnel and senior manager.*

Procedure 3.1 **Schedule entries for A3 category parts.**

Purpose: Procedure for customer schedule entry on SAGE line 500 computer system for A3 category parts.

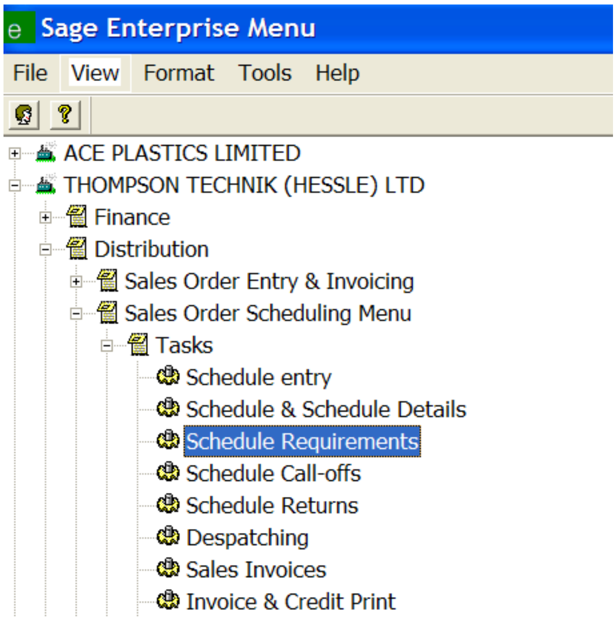
Reference: 3.1/0

Date: 29/07/2005

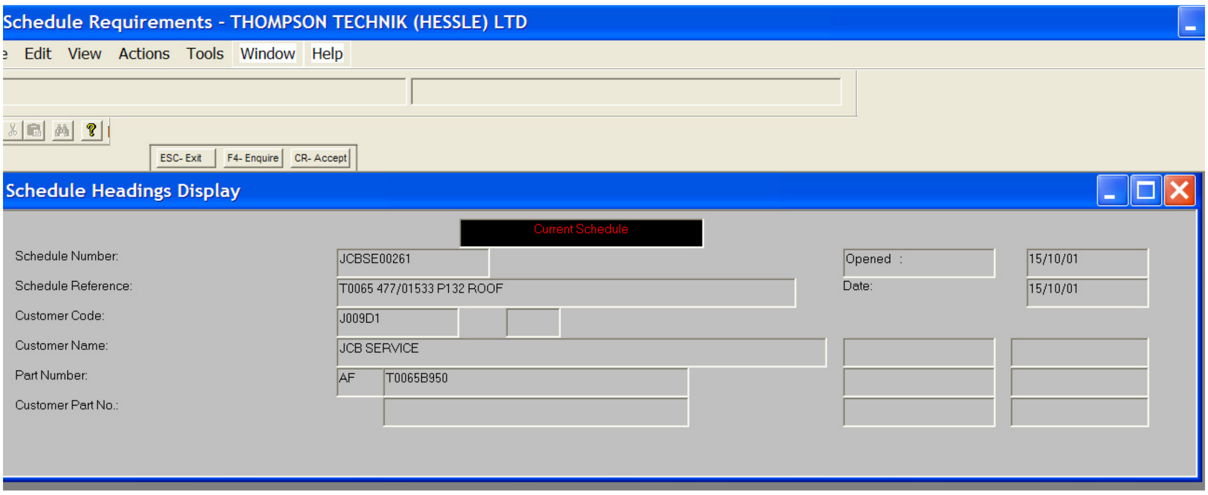
Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.

- Access schedule entry menu on the system.



- Under 'Schedule Reference' header on 'Schedule Headings Display', observe the last two values (adding categories code in process).



- Enter/update next two customer orders when you receive schedule from customer.

Procedure 4.1	**Works orders for A1 and A2 category parts.**
Purpose:	Procedure for setting works order for A1 and A2category parts on SAGE line 500.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.

- Review customer demand for next three months for each separate product line (part number).

Note:

- *For next step determine the frequency of production slot. Discuss the feasibility of slots with production personnel.*
- Divide total quantity required by customer in three months by frequency of slot as determined in above step.
- Raise works orders for next three months on the system. Production dates to be in line with frequency of slots.
- Amend works order quantity for A1 category parts to match actual customer demand between each two production slots *i.e.* schedule requirement up to next slot less finished goods stock + 10% contingency.

Note:

- *SOP may delete works orders if enough stock is available to cover customer demand up to and including next two slots.*
- *Do not amend production date or production quantity (within three months time span) unless necessary.*
- Check if there are in-house sub-assembly components required for manufacturing A1 or A2 category lines.
- Process sub-assembly component as per A2 or A3 processing rules.
- Delete works orders for A2 category parts on the system when requested by production and allocate production slot to manufacture other priority lines if required.

Procedure 5.1	**Works orders for A3 category parts.**
Purpose:	Procedure for setting works orders for A3 category parts on SAGE line 500.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.

- For each separate product line review customer demand for next three months.
- Multiply next three months demand by 0.45. This is batch quantity for that product for next three months.
- Set-up this batch quantity on system. (Refer *Procedure 5.1.1*)
- When request for A3 product line generates from stores, raise works order with a fixed batch quantity and earliest available production slot.

Note:

- *Do not raise works order on the system unless triggered by stores/dispatch.*

Procedure 5.1.1 **Setup batch quantity for A3 lines on system.**

Purpose: Procedure for setting-up batch quantity for A3 category parts on SAGE line 500.

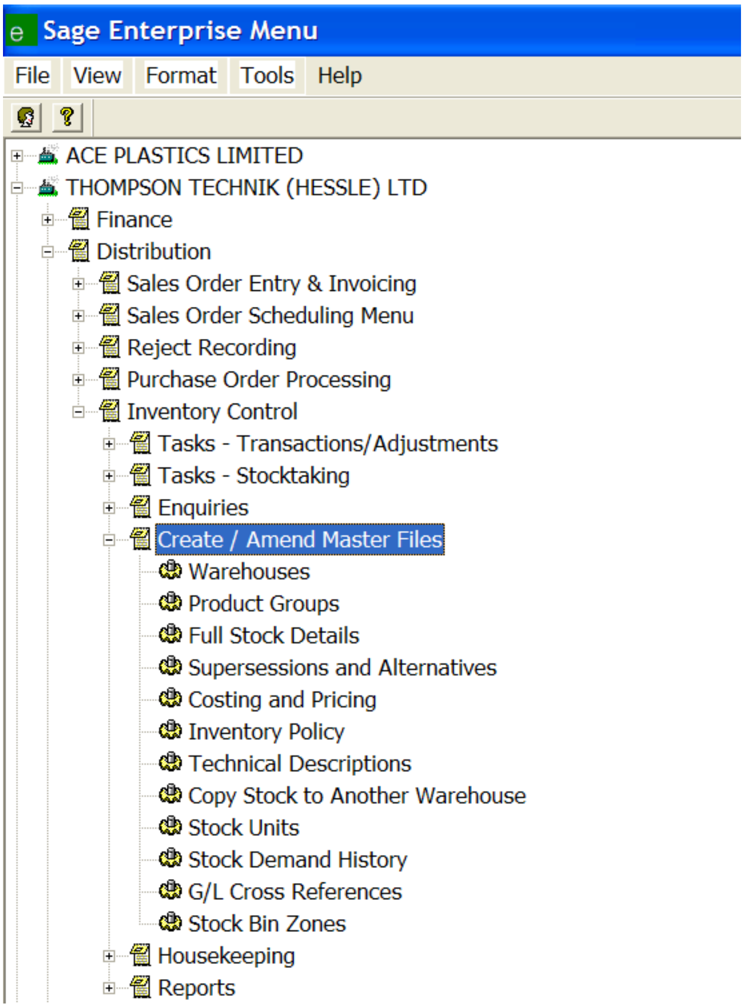
Reference: 3.1/0

Date: 29/07/2005

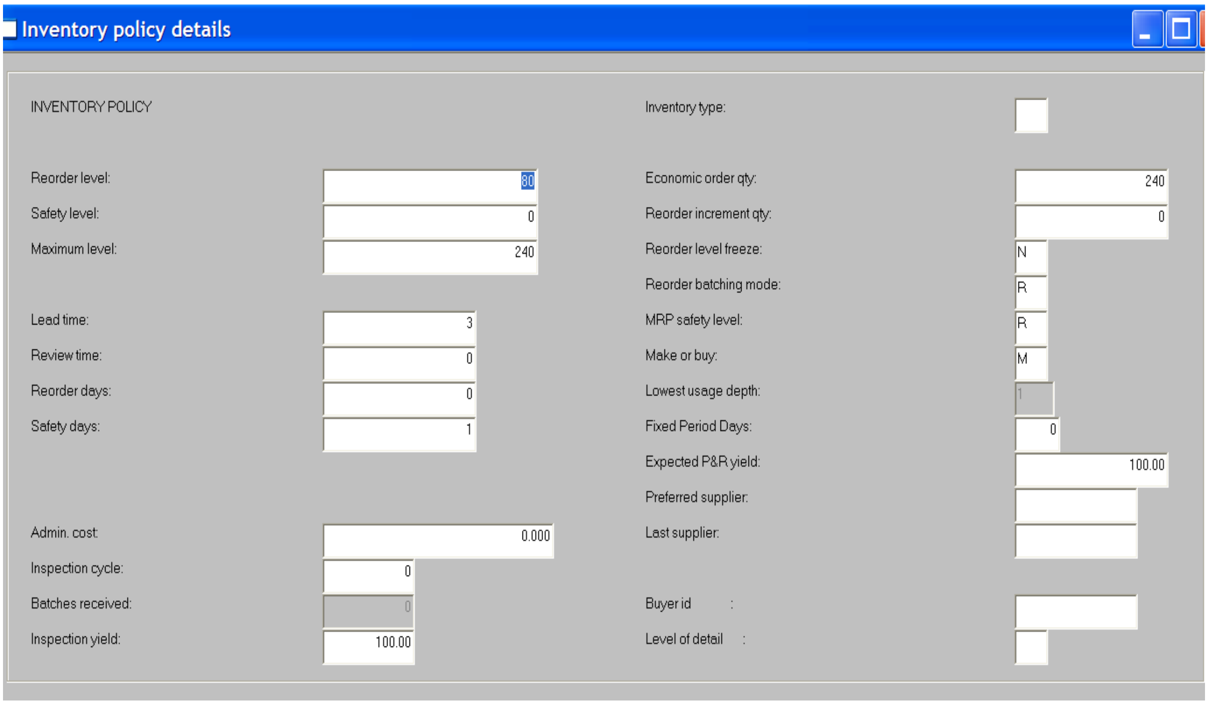
Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.

- For each separate product line evaluate batch quantity for A3 category product lines (refer to Procedure 5.1).
- Discuss and decide following details with planning and production personnel;
  1. Minimum stock quantity
  2. Maximum/Production batch quantity
- Under Distribution menu on system select *Inventory Control* and then *Create / Amend Master Files*.



- Select *Full Stock Details* form.
- Enter Product line code
- Select '*Next*' option on menu bar three times until you see 'Inventory policy details' form like the one below;



- Enter following details in the form for each product line;
  1. Reorder level - This is min stock quantity or safety stock.
  2. Maximum level - This is maximum production quantity
  3. Economic order qty - This is production batch quantity

Note:

- Review minimum stock quantities and batch quantities every 3 months

Procedure 6.1	**Works orders for B1 category parts.**
Purpose:	Procedure for setting works orders for B1 category parts on SAGE line 500.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.

- Calculate demand from customer for each product line.

Note:

- *These are low volume product lines; planning and production of these product lines require high knowledge of constraints and variables that are associated with these product lines.*
- Calculate excess stock [(current stock + total qty to be produced in the period) - customer orders in the period].
- Calculate next period demand at the beginning of every month.
- Subtract excess stock from total demand.
- Raise works orders for the most appropriate due dates and quantities.

Procedure 7.1	**Works orders for B2 category parts.**
Purpose:	Procedure for setting works for B2 category parts on SAGE line 500.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.

- Check customer demand/forecast
- Review customer quantity requirement for next 3 months.
- Can required quantity be justified for production?
- If yes, then raise works orders for B2 category parts based on local (planner) knowledge. If production quantity can not be justified for production then contact senior planner or senior manager for assistance.
- Enter works order due date for most appropriate slot available on the production plan.

Procedure 8.0	**Production Plan.**
Purpose:	Procedure for manufacturing lines in line with production plan.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.
- *On the works order check for category of product line. E.g. A1, A2, A3, B1 or B2.*

- Obtain weekly production plan from planning department.
- Review production plan.
- Select jobs that run on same tools and group them for consecutive production
- Run A1 and A2 jobs on dedicated slots. Aim to start every job on date planned.

Note:

- *Plan machines to accomplish weekly plan.*
- *Jobs can be prioritised within the week if necessary*
- *Contact senior planner/production manager if you have any questions regarding the weekly production plan.*

Procedure 8.1	**Production A1 category parts.**
Purpose:	Procedure for manufacturing A1 category parts.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.
- *On the works order check for category of product line. E.g. A1, A2, A3, B1 or B2.*

- Check works order details.
- Produce quantity as suggested on the works order.
- Produce on dedicated production slot for that product line.

Note:

- *Do not split batch.*
- *Produce no less than quantity as suggested on the works order.*

Procedure 9.1	**Production A2 category parts.**
Purpose:	Procedure for manufacturing A2 category parts.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.
- *On the works order check for category of product line. E.g. A1, A2, A3, B1 or B2.*

- Check works order details.
- Produce quantities as suggested on the works orders.
- Produce on dedicated production slot for that product line.

Note:

- *Do not split batch.*
- *Produce no less than quantity as suggested on the works order.*

Procedure 10.1	**Production A3 category parts.**
Purpose:	Procedure for manufacturing A3 category parts.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer systems.
- *On the works order check for category of product line. E.g. A1, A2, A3, B1 or B2.*

- Check works order details.
- Produce quantities as suggested on the works orders.

Note:

- *Do not split batch.*
- *Produce no less than quantity as suggested on the works order.*

Procedure 11.1	**Production B1 and B2 category parts.**
Purpose:	Procedure for manufacturing B1 and B2 category parts.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer system.
- *On the works order check for category of product line. E.g. A1, A2, A3, B1 or B2.*

- Check works order details.
- Produce within the week of production date as suggested on the works order.
- Produce quantities as suggested on the works order.

Note:

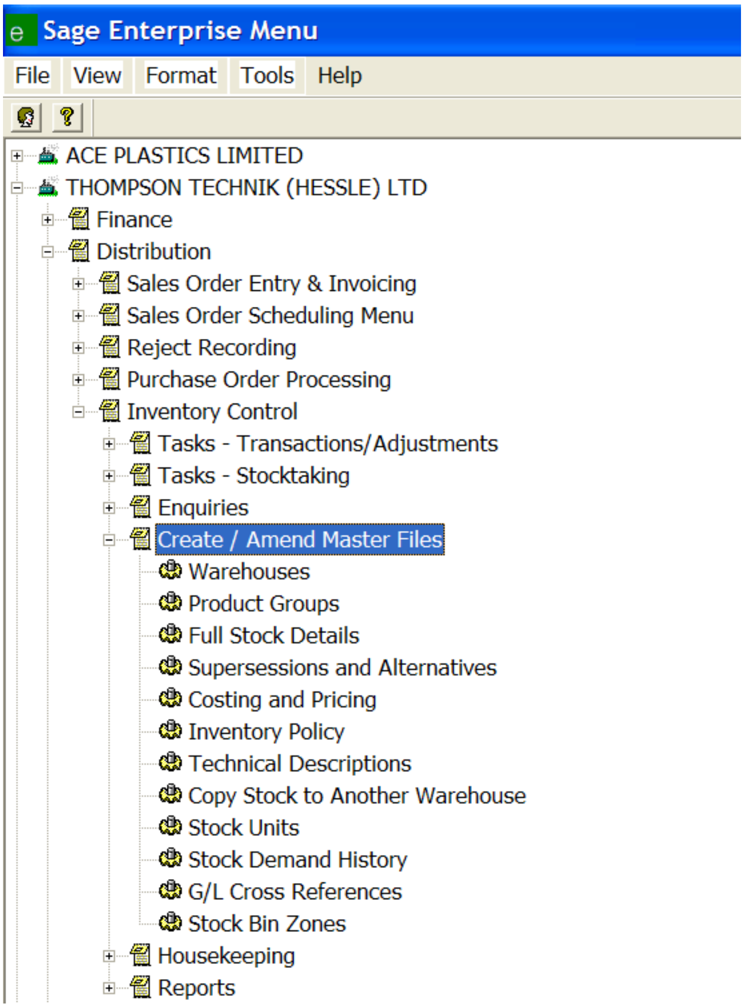
- *If there are any constraints or manufacturing issues regarding production of product lines then contact planner and inform about the situation.*
- *Do not split batch.*

Procedure 12.0	**Material code setup on system.**
Purpose:	Procedure for setting up code for material management on the system.
Reference:	3.1/0
Date:	29/07/2005

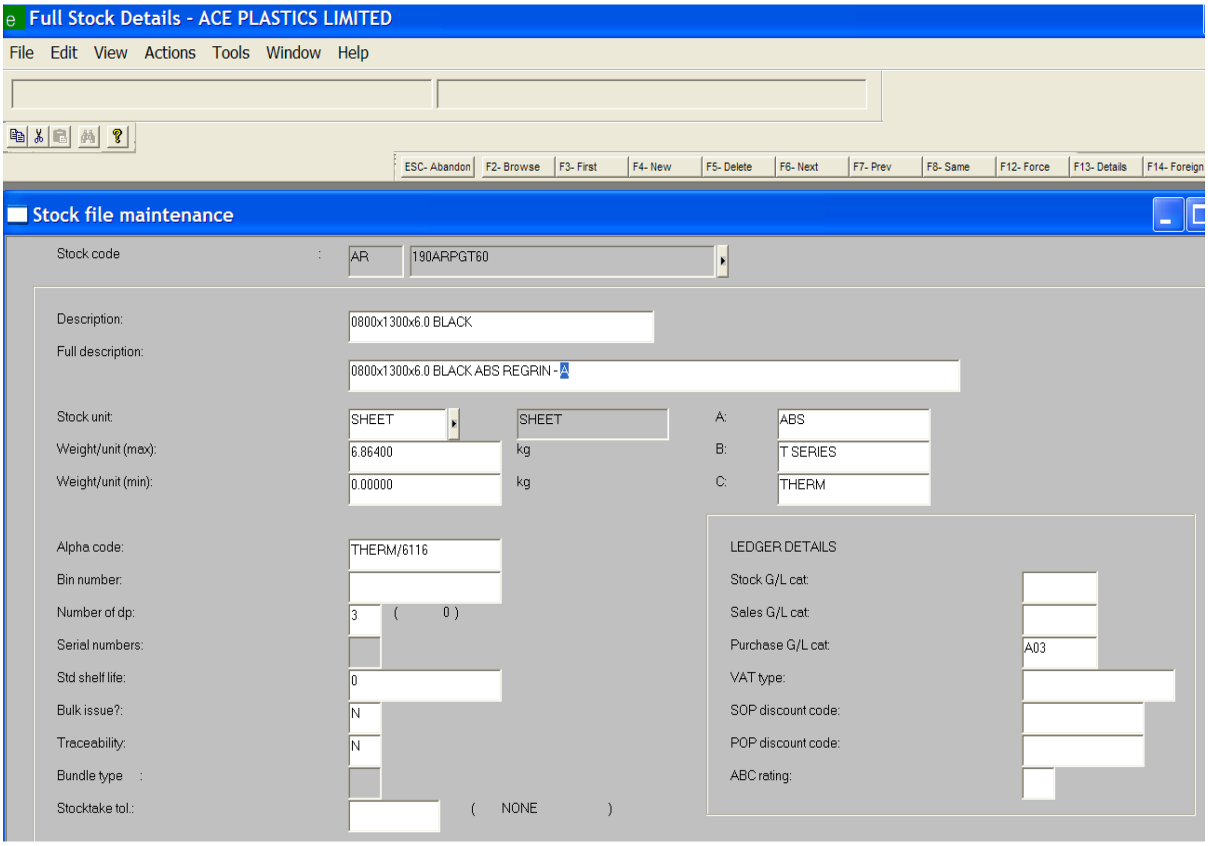
Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer system.
- Material requirement category A1 and A2 are collectively known as 'A'.
- Material requirement for A3 is based on KBN (Kanban).
- Material requirement category B1 and B2 are collectively known as 'B'.
- Material on consignment is called CON.

- Request list of Material with codes (A, B, CON and KBN) from planner.
- Under Distribution menu on system select Inventory Control and then Create / Amend Master Files.



- Select *Full Stock Details* form.
- Enter Product line code
- Select '*Accept*' option on menu bar until you see 'Stock file maintenance' form like the one below;



- Under *Full description* heading on the form enter '-' and then code (A, B, CON, or KBN) after the description on the form. For *e.g.* if code 'A' need to entered for material line '*AR190ARPGT60*' with full description '*0800x1300x6.0 BLACK ABS REGRIN*', then add space after full description and then type '-' and then type 'A' (0800x1300x6.0 BLACK ABS REGRIN -A)

Procedure 12.1 **Material Management for A1 and A2 category parts.**

Purpose: Procedure for planning material requirement forA1 and A2 (A) category.

Reference: 3.1/0

Date: 29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer system.
- For material requirement category A1 and A2 are collectively known as 'A'
- *For material requirement plan check for category of material code. E.g. A, B, CON (Consignment) or KBN (Kanban).*

- Check supplier lead time
- Calculate material required within the lead time.
- Calculate excess stock quantity
- Subtract excess material in stock from material required.
- Order material to match delivery frequency with the production frequency and in batch quantity to match production batch quantity

Consider the example below;

Surplus material from wk-0 to wk-3

Current stock	100									
Order quantity for week 4-8 (ordered in week 0)	200									
Frequency of material supply for week 4-8	2									
Week		wk-4	wk-5	wk-6	wk-7	wk-8	wk-9	wk-10	wk-11	wk-12
Production works order (units)			100		100		100		100	
Material Order (units)	100 for week 5-8	100		100				100		

Material order quantity in week 0

- *Aim for frequent batches of EBQ. E.g. if 400 units of sheet material is required for 1 month in EBQ of 100, then order 100 units each week and not 400 units in 1 month.*
- Order net material requirement in multiple pallet quantity for production batch quantity *i.e.* ensure material requirement is ordered for delivery in appropriate pallet quantity in line with production batch quantity.

Procedure 13.1	**Material Management for A3 category parts.**
Purpose:	Procedure for planning material requirement forA3 (Kanban) category.
Reference:	3.1/0
Date:	29/07/2005

Note:

- For material requirement, category A3 is based on 'Kanban'
- *For material requirement plan check for category of material code. E.g. A, B, Consignment or Kanban.*

- Set up kanban/min-max level for material and communicate with stores.
- Dedicate kanban/min-max area for A3 material in stores
- Set-up kanban/min-max visual system in stores.
- Request generated from stores for 'Kanban' material replenishment.
- Inform buyer for replenishment.
- Check kanban/reorder quantity on the system.
- Order kanban/reorder quantity for material.

Procedure 14.1	**Material Management for B1 and B2 category parts.**
Purpose:	Procedure for planning material requirement forB1 and B2 (B) category.
Reference:	3.1/0
Date:	29/07/2005

Note:

- *The word 'System' in this procedure refers to SAGE LINE 500 ERP* computer system.
- For material requirement category B1 and B2 are collectively known as 'B'
- *For material requirement plan check for category of material code. E.g. A, B, CON (Consignment) or KBN (Kanban).*

- Check supplier lead time
- Calculate material required within the lead time.
- Calculate excess stock quantity
- Subtract excess material in stock from material required.
- Check if required material quantity is justified against production quantity.
- Contact senior manager if purchase quantity cannot be justified and demand from production. For *e.g.* if production quantity is 10 units in a month and MOQ for sheet material is 100 units then purchasing 100 units has to be justified and authorised.
- Order net material requirement in multiple pallet quantity for production batch quantity *i.e.* ensure material requirement is ordered for delivery in appropriate pallet quantity in line with production batch quantity.

7. Implementing Methodologies and policies for A1 Category Parts.

In our methodology 'A' category parts are high volume and high value parts. Although the number of product lines is small (4%), it account for 10% total volume and 24% total value (std. cost) of product sold.

Processing of A1 category product lines are defined on top level in our *methodology of processing parts through manufacturing system*. The second tier of rules and policies to facilitate the overall understanding of this methodology particularly in respect to A1 category production criteria is summarised in the headings below;

Forecast schedule: For customer schedule entry rules on Sage system, please refer to document 2.1.

Production schedule/plan: A1 category parts will have a variable production quantity and fixed production slot.

- Variable Production Quantity: This refers to production planning that these product lines will be produced with a variable production batch quantity. The variable batch will cover customer demand up to and including the next production slot and additional 10% safety stock. For *e.g.* if .customer demands 100 in a week and fixed production slot is weekly then production quantity will be 100 + 10 (10% safety stock).
- Fixed Production Slot: This will be determined by the planner. The criteria for fixed production slots will be based on factors like; work-centre capacity, holding cost, machine set-up cost stillages availability and other physical constraints known to the planner. The fixed production slot could be weekly, fortnightly or monthly.
- Some of A1 category product lines will require further assembly parts. These assembly parts will be processed as per A1, A2 and A3 methodology. For *e.g.* if an assembly part is high value part it will follow A1 methodology rule; if a part is medium value it will follow A2 rule and if it is low value it will follow A3 rule.

Works Order: Initially works orders will be raised for next 3 months on fixed batch quantity and frequency of production in accordance with dedicated production slots.

Works orders for the next production slot will be amended to reflect actual quantity required by customer between next two slots, at that moment of time. In the example below initial works order quantity was setup to be 110 in week 0, but after customer changes the new production quantity is 75.

Part - AFT1234ABC	Week - 0	Week -1	Week -2	Week -3	Week -4
Quantity required by customer		75		100	
Initial Works order setup Amended works order	110 75 +8 (10%)=83		110 100		

Stock: Stock will be monitored closely for A1 category parts due to their high value content.

Material Replenishment: Based on production schedule. Order material quantities to match multiple of production batch quantity i.e. if production batch quantity is 100, then order 100 or 200 sheets. Aim for smaller and frequent batches.

	Week - 0	Week -1	Week -2	Week -3	Week -4
Production Slot (units)		100		100	
Material in stores (units)	100		100		

The possible benefits that could be achieved by implementing the methodology and above policies include;

- Production will be controlled from front end (stores).
- Higher control on inventory will reduce inventory costs and improve material flow.
- This will standardise the production system and reduce firefighting.

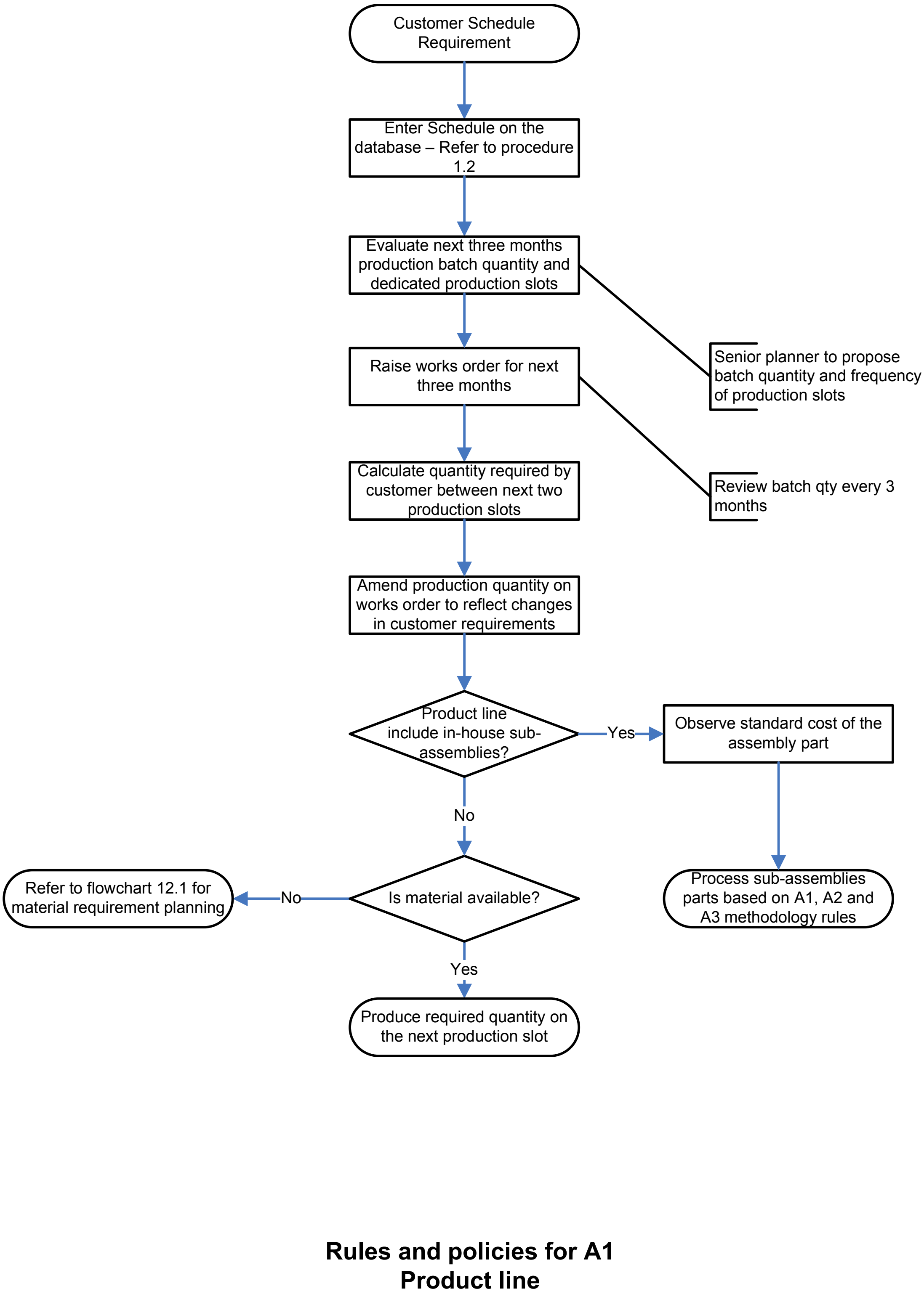


Figure 1.2 Rules and policies for A1 product lines.

8. Implementing Methodologies and policies for A2 Category Parts.

An A2 category part remains the most crucial and contributes most to the aggregate of methodology in terms of both, value and volume. These are *high volume* and *medium value* product lines.

Processing of A2 category product lines are defined on top level in our methodology of processing parts through manufacturing system. The second tier of rules and policies to facilitate the overall understanding of this methodology particularly in respect to A2 category production criteria is summarised in the headings below;

Forecast schedule: For customer schedule entry rules on Sage system, please refer to document 1.2.

Production schedule/plan: A2 category parts will have a fixed production quantity and fixed production slot.

- Fixed Production Quantity: This refers to production planning that 3 months customer forecast to be considered to evaluate a fixed batch quantity. This fixed batch quantity will be total quantity required by the customer divided by number of slots. For example; if the customer forecast for a product line for next three months is 600 units and dedicated production slot is *weekly* then fixed production quantity will be 50 units (600/12 weeks). If production slot is *fortnightly* then fixed production quantity will be 100 units (600/6).
- Fixed Production Slot: This will be determined by the planner. The criteria for fixed production slots will be based on factors like; work-centre capacity, holding cost, machine set-up cost stillages availability and other physical constraints known to the planner.
- In situation where fixed production quantity is less than quantity required/forecasted by customer than increase production quantity for that production slot to match customer requirement.

Works Order: Raised for next 3 months on fixed batch quantity and frequency of production in accordance to dedicated production slots.

Stock: Stock to be analysed every month. At the end of every month, if inventory for any product line in this category is more than demand for products up to and including next production slot, then do not produce parts at the next production slot.

Material Replenishment: Based on production schedule. Order material quantities to match multiple of production batch quantity i.e. if production batch quantity is 100, then order 100 or 200 sheets. Aim for smaller and frequent batches.

	Week - 0	Week -1	Week -2	Week -3	Week -4
Production Slot (units)		100		100	
Material in stores (units)	100		100		

The possible benefits that could be achieved by implementing the methodology and above policies include;

- Production will be controlled from front end (stores).
- This will prevent planning department from scheduling and rescheduling customer schedules and then works order on a regular and continuous basis, when there is a change in customer order.
- Production will have a standard working plan isolated from regular changes from planning which effectively is caused by frequent changes from customer.
- Reduction in everyday disruption from planning due to customer schedule change.
- This will standardise the production system and reduce firefighting.

The role of departments with implementing policies and methodologies is further explained in the flowchart 1.4.

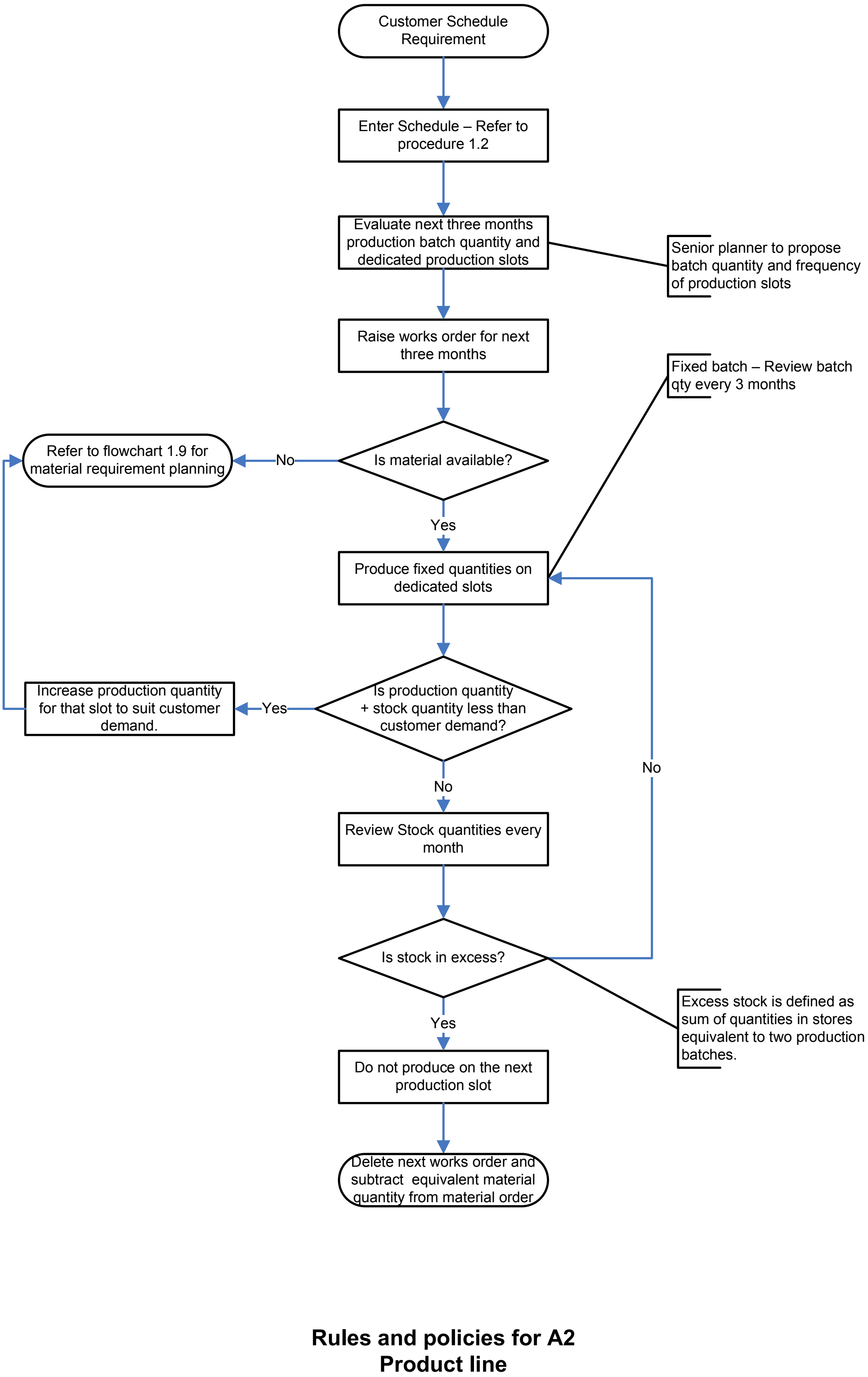


Figure 1.3 Rules and policies for A2 product lines.

9. Implementing Methodologies and policies for A3 Category Parts.

As we all understand **A3** category parts are low cost high volume parts. In the original ABC analysis the ratio of product value to product volume for this category is 1:3.6 (i.e. 18.2% total volume accounts for 5% of total value of products sold). This suggests that these product lines need simplest control with minimal ratio of resource allocation at all stages of production and planning.

In our methodology we have defined rules for processing of these parts through our manufacturing system. In order to further implement the rule we could introduce some simple and logical policies to compliment and anticipate the capability of our methodology. These policies are reflected in the headings below;

Schedules: The schedule horizon should be fixed to minimum, i.e. the schedules on the system should be **order-based** for next two orders or less.

Production: Produce in fixed batch quantities and this quantity could be reviewed every 3-6 months.

Works Order: Works orders only appear on the system once triggered by min level in stores and conveyed by store person to planning

Stock: Allocate a dedicated location for storing these product lines in stores. These parts preferably stored in totes or stackable plastic bins instead of cardboard boxes.

Replenishment: Based on min level. Once the level reaches **min**, the store-person could inform planning to raise works order for production.

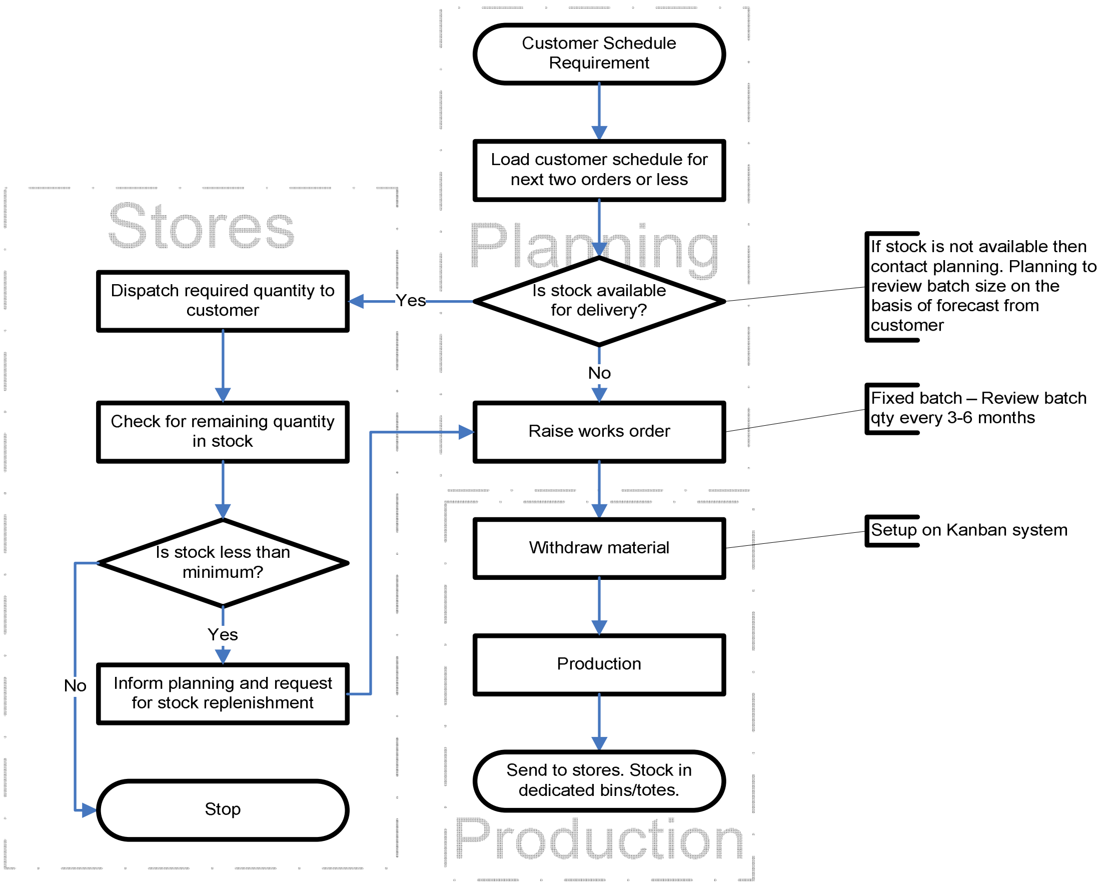
The above policies are more visual and could be implied within factory without overly distracting the production system.

The possible benefits that could be achieved by implementing the methodology and above policies include;

- This will prevent planning from scheduling and rescheduling customer schedules and then works order, beyond fixed schedule horizon (two or less orders), when there is a change in customer order. Reduction in data entry (schedule and reschedule customer orders for months ahead) on the system will save time and resources at planning.
- Production will have real requirement from internal customer (stores) and will be isolated from everyday disruption from planning due to customer schedule change.
- The visual system of dedicated area for A3 product lines working on min/max level could improve the layout, performance and management of stores.
- Material requirement could be based on 'Kanban' system. Every production run will ideally be more than one month's requirement (low value, high volume). This will possibly match supplier lead time (4-6 weeks). Once the material is consumed from stores another lot could be ordered and this could form a sustainable 'Kanban' system.
- This will result in improvement of production plans in terms of accuracy.

A visual system in stores and improved planning and production system will improve customer service and streamline the flow of production for, in this case, A3 category parts.

The role of departments with implementing policies and methodologies is further explained in the flowchart below.



Rules and policies for A3 Product line

Figure 1.4 Rules and policies for A3 product lines.

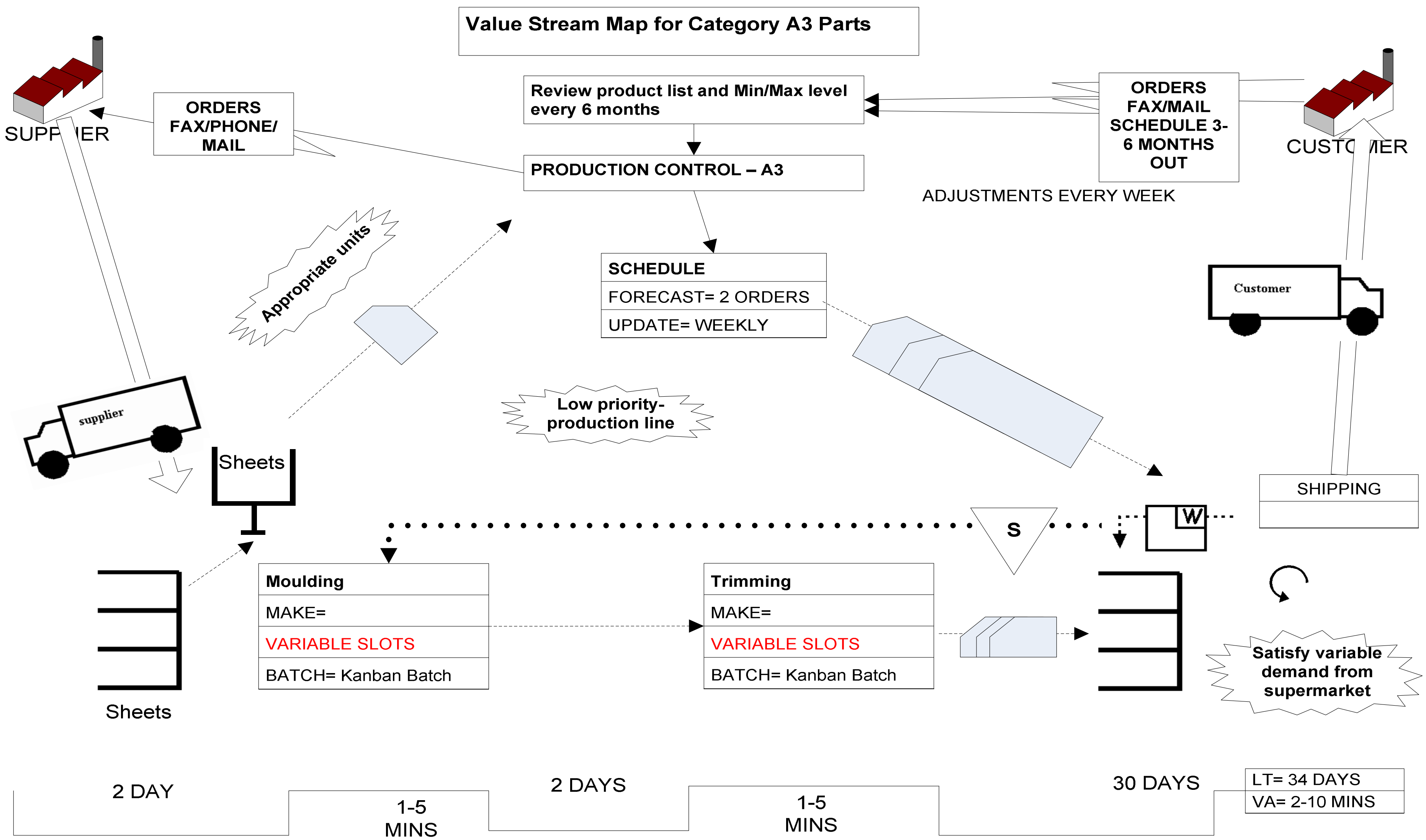


Figure 1.5 Value stream map for A3 product category.

10. Implementing Methodologies and policies for B1 Category Parts.

In our methodology 'B' category parts are approximately 80% product lines and they account for 22% of volume and 38% value. These are low volume category parts.

Although low volume, there is a large variation in standard cost for these product lines. Processing of these products through the manufacturing system will require greater understand of production constraints and customer schedule forecast.

Processing of B1 category product lines are defined on top level in our methodology of processing parts through manufacturing system. The second tier of rules and policies to facilitate the overall understanding of this methodology is summarised in the headings below;

Forecast schedule: For customer schedule entry rules on Sage system, please refer to document 1.2.

Production schedule/plan: B1 category parts will have a variable production quantity and fixed production slot.

- Variable Production Quantity: This refers to production planning that these product lines will be produced in a variable production batch quantity or the production quantity will be based on restrictions and constraints of Shop floor.
- Variable Production Slot: This will be determined by the planner. The criteria for production slots will be based on factors like; work-centre capacity, holding cost, machine set-up cost stillages availability and other physical constraints more understood by the planner.

Works Order: At the beginning of the month calculate demand for next period. Initially works orders will be setup for next 1 period. The quantity to manufacture can be amended as a result of change in customer demand.

Stock: Stock will be monitored on a monthly basis and works orders could be adjusted to reflect current stock.

Material Replenishment: Based on production schedule. Order material quantities to match works order requirement. Aim for smaller and frequent batches.

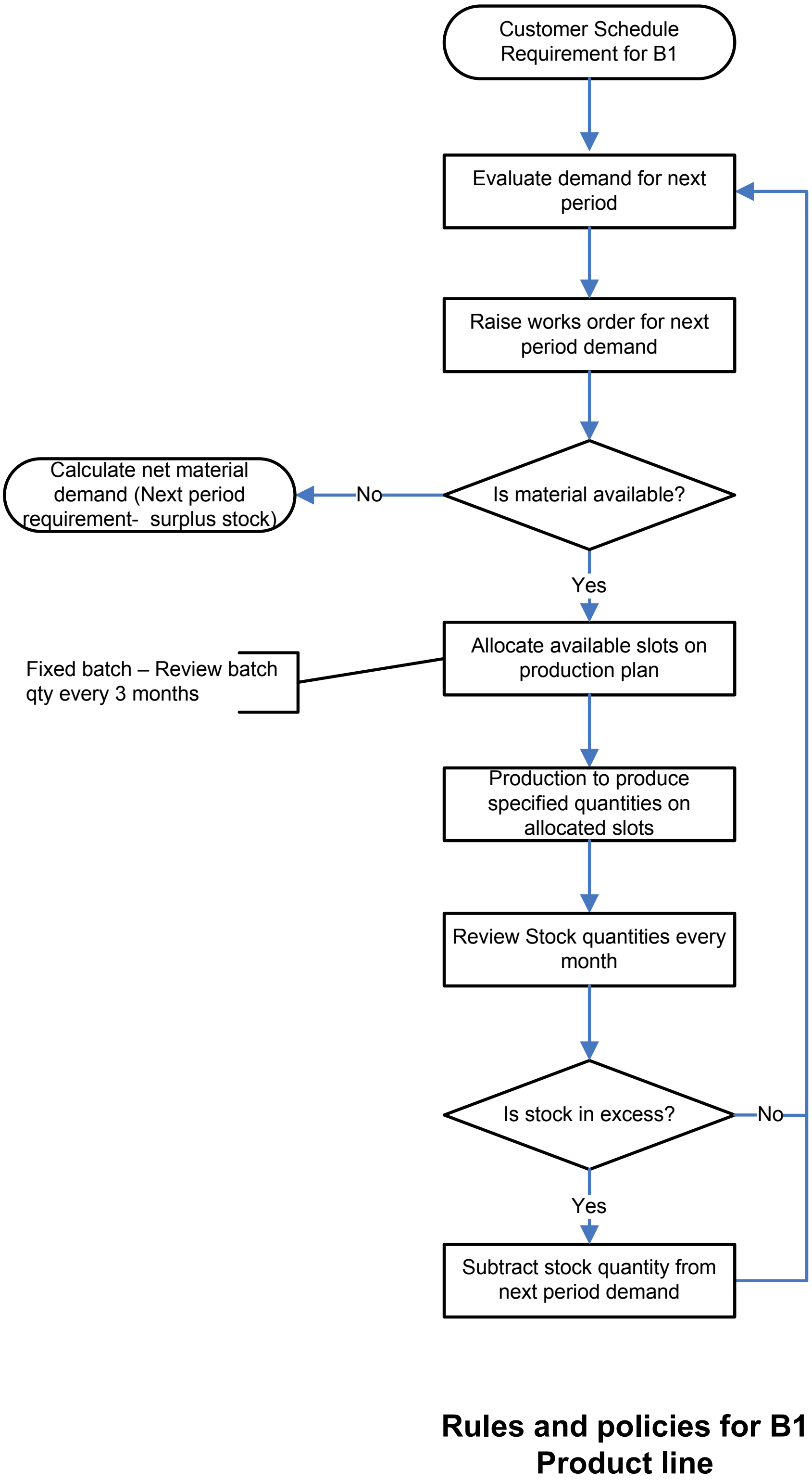


Figure 1.6 Rules and policies for B1 product lines.

11. Implementing Methodologies and policies for B2 Category Parts.

In our methodology 'B' category parts are approximately 80% product lines and they account for 22% of volume and 38% value. These are low volume category parts.

B2 category product lines are low value and low volume product lines. Since these product lines are low value it would be necessary to manufacture suitable batch quantity to justify internal costs (setup costs and holding costs) which contradicts the fact that these product lines are also low volume product lines, therefore it will be necessary that manufacturing of these product lines do not supersedes profits in producing those product lines.

Processing rules for B2 category product lines are defined on top level in our methodology of processing parts through manufacturing system. For practical implications these rules are simplified as policies and procedures and are further summarised in the headings below;

Forecast schedule: For customer schedule entry rules on Sage system, please refer to document 1.2.

Production schedule/plan: B2 category parts will have a variable production quantity and fixed production slot.

- Variable Production Quantity: This refers to production planning that these product lines will be produced in a variable production batch quantity. Production quantity to be justified/negotiated with customer.
- Variable Production Slot: This will be determined by the planner. The criteria for production slots will be based on factors like; work-centre capacity, holding cost, machine set-up cost stillages availability and other physical constraints more understood by the planner.

Works Order: At the beginning of the month calculate demand for next 3 periods. Setup works order to reflect demand for 3 periods. The quantity to manufacture can be amended as a result of change in customer demand.

Stock: Stock will be monitored on a 6 months basis and works orders could be adjusted to reflect current stock.

Material Replenishment: Based on production schedule. Order material quantities to match works order requirement. Aim for smaller and frequent batches. Justify material order quantity.

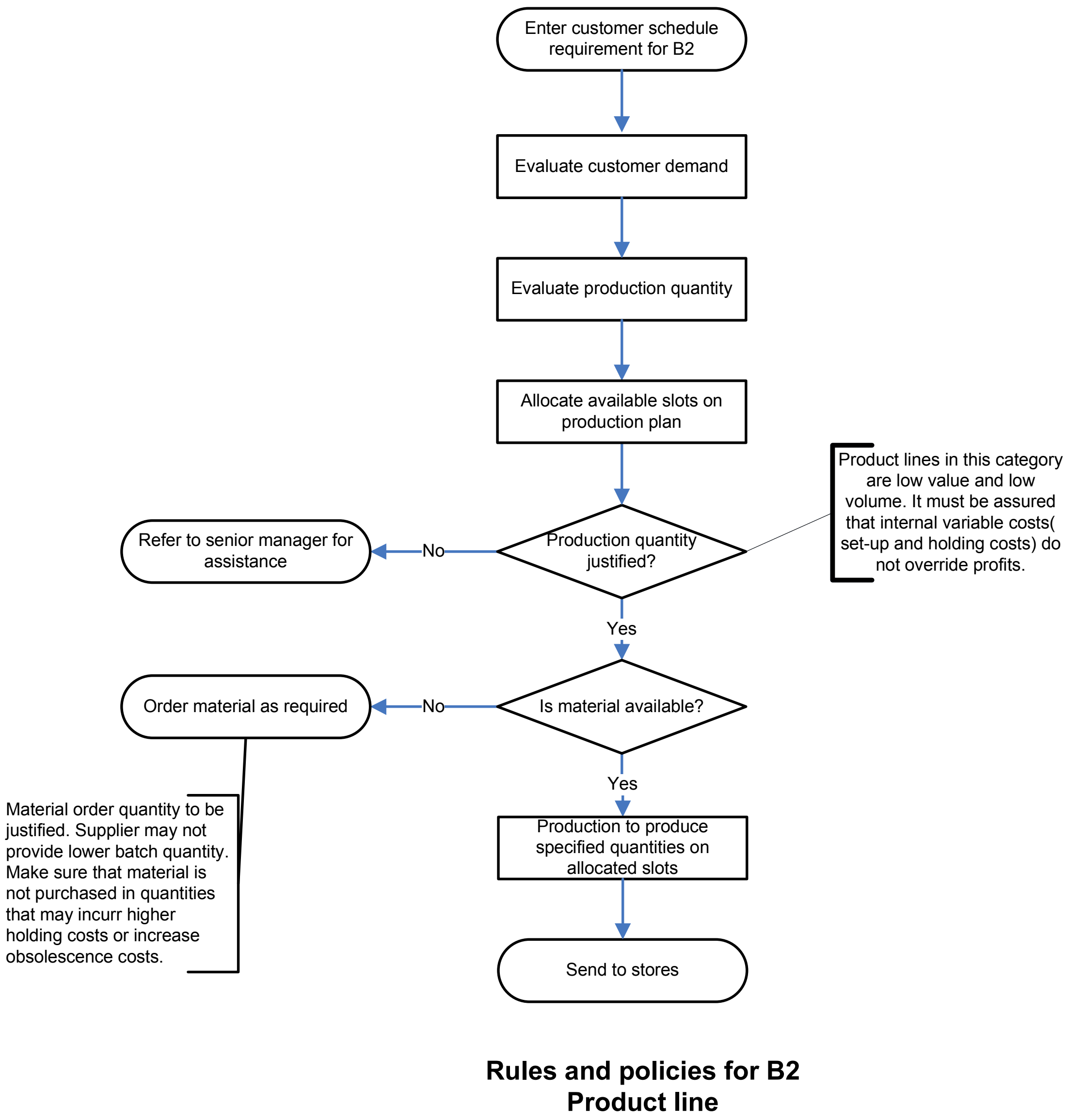


Figure 1.7 Rules and policies for B2 product lines.

12. Implementing Methodologies and policies for A1 andA2 Category Parts. (Material Management)

A1 and A2 category part remains the most crucial and contributes most to the aggregate of methodology in terms of both, value and volume.

For material management purpose A1 and A2 category is combined and together they are referred to as ‘A’category material codes.

Material management for A category parts is primarily based on fixed quantity and fixed frequency.

Material Management for A category parts include following steps;

- Planner to provide list of material that fall under A2 category.
- Check production batch quantity and frequency of production.
- Order material in multiple of production batch quantity for 1 month production schedule. Example below further explains the scenario;

	Week - 0	Week -1	Week -2	Week -3	Week -4
Production Slot (units)		100		100	
Material in stores (units)	100		100		

Material Stock Review: Review stock every month.
In situation where stock is more than required for next months production forecast then subtract appropriate material batch from next material requisition.

Wk=week	Wk-0	wk-1	wk-2	wk-3	wk-4	wk-5	wk-6	wk-7	wk-8
Material stock (units)	200								
Production Slot (units)		100		100		100		100	
Material used (units)	100		100		100		100		
Material Supplied for week	100		100						

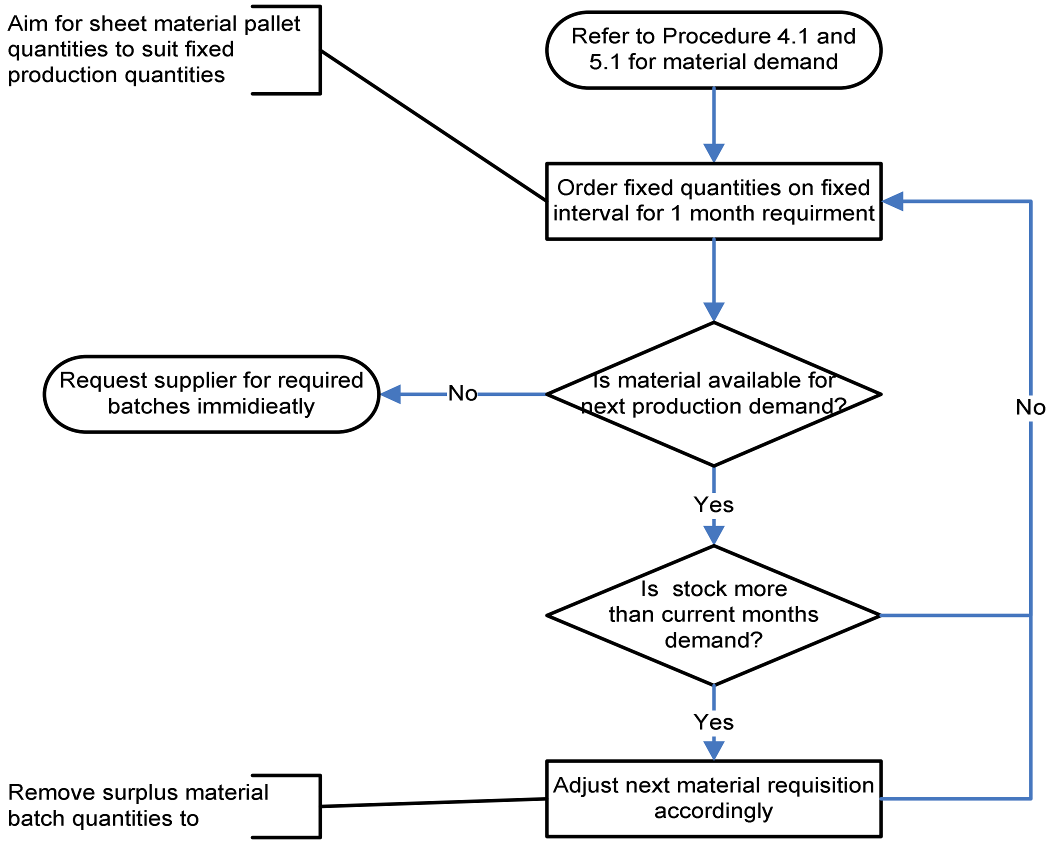
In the above example if stock in week-0 is 200 units then do not order material for wk-4 and wk-6. Material requisition to be raised in wk-4 for wk-9 and wk-11 demand.

In situation where material is not available for next production slot, request supplier for material.

Wk=week	Wk-0	wk-1	wk-2	wk-3	wk-4	wk-5	wk-6	wk-7	wk-8
Material stock (units)	0								
Production Slot (units)		100		100	100	100		100	
Material in stores (units)	100		100		100		100		

In above example an additional and abnormal demand for 100 units is required in wk-4. To satisfy the demand, order additional 100 units (1 batch quantity) of material as soon as the additional demand for product line is identified.

The role of departments with implementing policies and methodologies is further explained in the flowchart below.



Rules and policies for A1 and A2 Material Management

Figure 1.8 Rules and policies for A1 and A2 material management.