DESIGN AND IMPLEMENTATION OF A PRIORITISED KANBAN AND FINITE SCHEDULING SYSTEM TO SUPPORT THE JIT PHILOSOPHY IN A MEDIUM SIZED ELECTRIC MOTOR MANUFACTURER

Martin John Horn

A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering

Johannesburg, 1989

DECLARATION

I declare that this project report is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Martin Horn

MARTIN HORN

19th day of JULY 1989

ABSTRACT

This report describes the development and implementation of an extremely low cost manufacturing planning and control (MPC) system in a medium sized electric motor manufacturing plant attempting to implement the JIT philosophy.

A novel three bin kanban system with colour coded priorities controls material flows without paperwork or clerical effort. Fully levelled schedules and quick setups are not required, but use of the smallest practically possible lot sizes is ensured. The system significantly improves workforce motivation and is also used as a productivity improvement tool.

A simple microcomputer based master schedule, concentrating on a bottleneck operation, allows sales managers to load and drive the factory according to their customers' priorities. Within capacity constraints, the schedule provides for almost any required mix of products to be manufactured in a fixed, optimal sequence inside each of a series of 10 day time buckets.

Sales to net inventory and delivery performance both improved by 50% within 3 months.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

APICS	American Production and Inventory Control Society
C-Kanban	Conveyance Kanban
CNC	Computer Numerical Controlled (Machine)
CRP	Capacity Requirements Planning
EAD	Estimated Annual Demand
EI	Employee Involvement
EOQ	Economic Order Quantity
FAS	Final Assembly Schedule
GT	Group Technology
JIT	Just In Time
MPC	Manufacturing Planning and Control
MPS	Master Production Schedule
MRP	Material Requirements Planning
MRP II	Manufacturing Resource Planning
OPT	Optimised Production Technology
P-Kanban	Production Kanban
ROP	Reorder Point
SAPICS	South African Production and Inventory Control Society
SBU	Strategic Business Unit
SMED	Single Minute Exchange of Dies
TPM	Total Preventive Maintenance
TPS	Toyota Production System
TQC	Total Quality Control
WCM	World Class Manufacturing
WIP	Work In Progress

1.0 INTRODUCTION

1.1 GEC Small Machines Company

The company unde discussion in this project is GEC Small Machines; a South African manufacturer of small and medium sized electric motors. It is a division of the GEC Electric Motor Manufacturers Co. (Pty) Limited, which in turn is a wholly owned subsidiary of GEC S.A. (Pty) Limited. These relationships are shown in Figure 1, as are the 'sister' companies within the Motor Manufacturers group; some of whom are very important vendors to Small Machines.

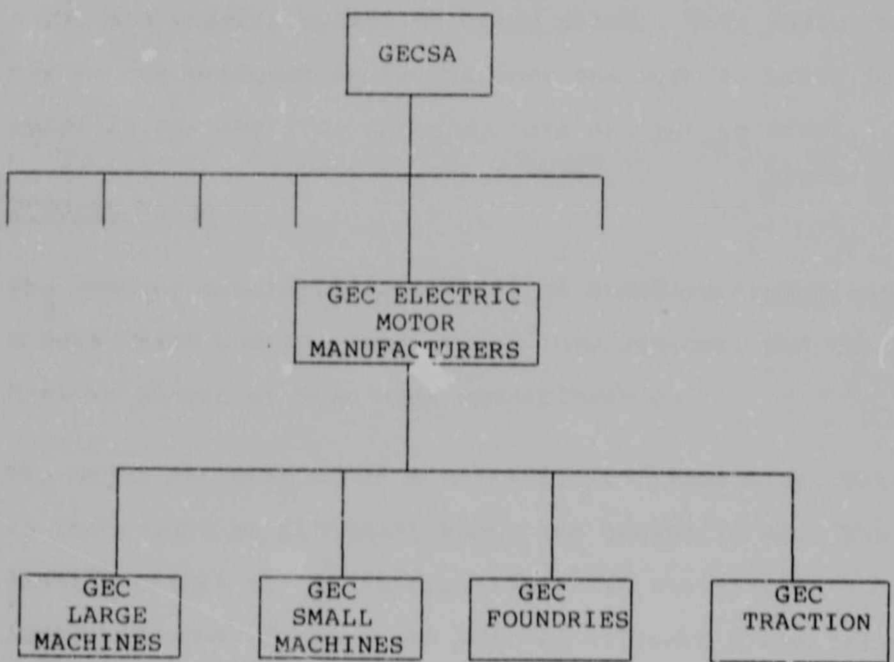

Figure 1.1: GEC Small Machines Company - Corporate Relationships

The management philosophy of GECSA involves decentralisation into Strategic Business Units (SBU), of which the Small Machines Company is one of some 27 in South Africa. Each SBU is treated as an autonomous profit centre and is expected to optimise its profits and to grow by means of the facilities, resources, and support provided by GECSA.

About 430 people are employed by this SBU and manufacturing takes place at the Small Machines' factory in Benoni, Transvaal. Stocking and selling outlets exist throughout the country. Some are controlled by the company, whilst others are independant agents. The company also manufactures motors for other major motor manufacturers, large industrial customers (e.g. pump and lawnmower manufacturers) and under proprietary brand names. This means that all motors produced in the factory are made to order for specific customers or sales outlets and not to stock.

1.2 Product Range

The company manufactures a range of standard dimensioned motors which comply with various International and South African Bureau of Standards specifications.

The major designation of a motor is its frame size, which is the height of its shaft above the ground in mm. The Small Machines range includes ten frame sizes, from 71 to 225mm and some of these are offered as short frame (s), medium frame (m) or long frame (l); for example 132s and 132m.

There are two popular types of enclosures: "Totally Enclosed Fan Cooled", designated a D frame; and "Drip Proof", a C frame. The D frames and their matching end-shields are offered in aluminium, with the option of steel for smaller motors and cast iron for larger motors.

Within these frame sizes and types, a range of windings and pole configurations are offered. This gives a choice of kilowatt outputs, voltages and speeds in three phase. For smaller motors single phase is also an option. Most motors can be foot, flange or pad mounted.

The above variations give a total number of some 900 models on GEC's standard price list. However, motors closely related to the standard range, but with variations according to the customer's requirements, are also offered. In theory the maximum number or individual types of motors could be in excess of 3000, of which about 1000 are currently manufactured.

Variations can be simply of a cosmetic nature, such as different paint finishes, or of a mechanical or elecrical nature. Mechanical features include:

- improved enclosures for spark, dust ignition, hose or carbon black proofing.
- non standard shaft materials (or extensions)
- special mountings
- special flange endshields (e.g. for gear box manufacturers)

- special cable or terminal boxes
- heaters fitted
- burn out protected

Electrical variations include:

- high starting torgue
- slow speed
- multi speed motors
- different insulation class

1.3 The Need for Just In Time Manufacturing

In the early 1980's the company's performance with regard to quality, cost and delivery/service was going from bad to worse. Manufacturing layouts, methods and systems had not changed appreciably for at least 15 years and management, although aware of various symptoms, was unable to pinpoint the root causes of their problems.

By 1984 these problems had become chronic, especially in the mini-motors range (71, 80 and 90 frame sizes) where final test rejects were of the order of 40%, of which at least 20% needed complete rewinding. Output was running at about 40% of budget. Due to these factors, as well as increasing competition, the company was considering withdrawing from the mini-motors market.

In mid 1984 several of the company's managers attended the South African Production and Inventory Control Society (SAPICS) conference in Swaziland where they viewed the Hewlett Packard video on Just In Time (JIT).

The JIT philosophy was regarded by these managers as the possible saviour of the mini-motors division. In October 1984 the GECSA board gave the go ahead to use the mini-motors division of GEC Small Machines as a pilot in the implementation of JIT.

1.4 The Just In Time Philosophy

Japan's overcrowding and lack of natural resources led to the development of the essentially frugal philosophy of Just In Time manufacturing. This approach is highly applicable to the South African situation. As Schonberger [1] observes:

"Perhaps lack of capital to squander actually gives developing countries an extra advantage: an inclination for simple, low cost solutions."

Just In Time is also referred to as Stockless Production or Zero Inventories, but all three of these are unfortunate terms, because they fail to convey the breadth of concepts involved. They tend to imply a narrow focus on stock reduction when what is in fact envisaged is a new philosophy for running a manufacturing business, which emphasises co-ordination, integration and simplicity. JIT is not a project or a program. It is an ongoing search for more and more highly rationalised systems of managing the productive resources of people, money, materials, space, machines, tools and information.

Schonberger [2] uses the term 'World Class Manufacturing' (WCM) which includes the five major tools of 'just-in-time (JIT) production, total quality control (TQC), total preventive maintenance (TPM), employee involvement (EI) and simplicity."

The term WCM implies the ability to provide products with the consistent high quality, low cost and level of fast dependable service equal to that of the world's best. In order to do this it is considered essential to employ the above five tools. The term JIT is used throughout this report in its broadest sense as a management philosophy leading to WCM.

JIT production involves the use of smaller lots and smaller inventories. Schonberger [3] points out the important benefits of this that are not included in economic order quantity (EOQ) calculations:

"Better quality, less waste and rework, more awareness of sources of delay and error, higher levels of worker motivation, and greater process yield and productivity. You don't have to achieve one-at-a-time production to gain some of these JIT benefits; any move <u>towards</u> smaller lots will help."

Shingo [4], one of the pioneers of JIT in Japan, writes:

"JIT involves the meaning that each process must be supplied with the required items, at the required time, and in the required quantity."

This statement embodies the basis of JIT material flows on the shop floor. If all materials arrive from suppliers or from upstream processes exactly as required, there will be virtually no work in process (WIP) in the system. This implies no queues and therefore minimum lead times. Indeed, one of the main aims of JIT is to reduce lead times until they approach the sum of the actual processing times. Fast lead times give huge competitive advantages, but there are numerous other benefits. The JIT philosophy and many of its specific techniques originated at Toyota in Japan as part of the Toyota production system (TPS). Taiichi Ohno, the so called 'father' of TPS, says [5]:

"There is not a single factor which commends a lengthy lead time."

Some of the benefits are perhaps even more important than the direct cuts in inventory investment which many Westerners have focused on in justifying their adoption of JIT. As companies shrink lead times and reduce their stockholdings of raw materials, WIP and finished goods, they find that they hardly need any warehouses, factory stores or storage space between machines. Along with these space savings; out go racks, conveyors, forklifts and other materials handling equipment. In some cases entire automated storage and retrieval systems have been mothballed, and in others, plans to build such systems have been shelved.

Apart from these physical gains, the very fast throughput times and very low inventory levels allow much simpler production and inventory control systems to be used. This means that the need for expensive computer hardware, software and supporting personnel is greatly reduced; as is the need for production planners, clerks, storekeepers, material controllers, expediters, accountants and inventory managers. Ohno [6] concludes:

"If the meaning of production control is truly understood, inventory control is unnecessary."

Many 'traditionally' trained and experienced managers believe that JIT won't work for them and that they have valid reasons for holding stocks at all stages of their manufacturing operations. This is because some suppliers deliver late, some suppliers give poor quality, some machines are likely to break down, some processes are unreliable and need 100% inspection, the company's lead time is longer than the customer's expected order to delivery time, the machine changeover time is so long that a large batch must be run to 'improve the economics', etc... The list of excuses appears endless, and JIT seems impossible; but only because its most basic aim has been overlooked. Ohno [7] reminds us:

"The most important aim of the Toyota system is the thorough elimination of waste."

Thus, none of the above are valid reasons for holding stocks in the long run. Each is an indication of waste in the total system and these wastes must be eliminated.

Toyota defines seven categories of wastes [8] arising from:

- overproducing
- time on hand (waiting)
- transporting
- the processing itself
- unnecessary stock on hand
- unnecessary motion
- producing defective goods

It is not deemed necessary to explain or give examples of these wastes as they are each extensive and are well covered in the existing literature. It was mentioned earlier that one of the main aims of JIT is to reduce lead times until they approach the sum of the actual processing times. However, the processing itself often contains wastes, including wasted time, and therefore throughput times can be cut still further.

A useful concept when attempting to eliminate waste is that of adding value, which implies moving closer to the final, saleable product. Each activity performed or resource utilised, must be critically examined to see whether it adds value or not. All non-value adding steps or resources are, in fact, cost-adding because they consume time, energy, capital, etc; and so they are wastes that must be eliminated. It is obvious that machining a shaft adds value to a steel billet, whereas moving it to a store and booking it in does not. However, it is not always as simple as this. For example, a grinding operaration may appear to add value until we examine and improve an upstream process so that grinding is no longer necessary.

It is clear that, traditionally, companies have held buffer stocks to insulate themselves from the many unsolved problems and wastes in their production systems. The JIT philosophy challenges the assumption that these buffers stocks <u>must</u> be there and encourages their removal on the basis that they not only insulate us from problems, but actually hide the problems, or wastes. The removal of these buffer stocks forces line stoppages and exposes the hidden problems such as machine breakdowns, substandard quality, scheduling errors, wasted floor area, excessive labour, excessive changeover times, unnecessary machine time, poor stock distribution, unreliable suppliers, etc. The challenge is then to attack the root cause of each problem so that it does not recur. Thus, the production system runs more efficiently and productively than before, with more consistent quality and also without the buffer stocks. Schonberger [9] summarises this approach:

"The improvement journey requires clearing away obstacles so that production can be simplified."

One of the JIT pioneers at Kawasaki USA, Dennis Butt, tried to rationalise and articulate the overall JIT effort by saying [10]:

"I envision the entire plant as a series of stations on the assembly line, whether physically there or not."

This statement sums up JIT material flows and production rather well, but the suppliers and the customers should be seen as stations on the assembly line too, in order to appreciate the concept of an advanced JIT production facility. Such a facility would have a very quick throughput time and would be very efficient, but the lead time as perceived by the customer would not necessarily be short. This could arise through paperwork and system delays in processing the customer's order from the salesman through credit control, design engineering, etc., to the production facility.

The advantages of high quality and, to some extent, low costs can be achieved by applying the JIT philosophy to only the production facility, but the potential improvements in customer service will probably not materialise. It is essential to see JIT as a management philosophy to be applied to the whole organisation. Lead times must be reduced by eliminating waste in the office as well as on the shop floor and all departments must be geared to exploit the competitive advantage of having a JIT production facility. Clearly, the concept of EI must be extended beyond the shop floor to all the company's employees. It is only in this manner that high quality, low cost and excellent customer service can become a reality. Perhaps, Butt's statement should be altered by substituting the word "organisation" for "plant" to yield a vision of a true JIT company.

In summary, "JIT is a whole company operating philosophy for long term growth, survival and excellence in the face of worldwide competition." [11]. It incorporates perpetual efforts to eliminate waste, cut lead times and increase flexibility through the total involvement of all employees and the use of the simplest, most practical methods and systems.

In spite of whatever implementation difficulties are encountered, the decision by GEC Small Machines to embrace the JIT philosophy should never be viewed as a mistake. As Schonberger [12] points out:

"Today there is wide agreement ...... that continued improvement in quality, cost, lead time and customer service is possible, realistic and necessary."

To discuss the full range of specific techniques of JIT, TQC, TPM and EI in this report would be of little value as such techniques are extensively covered in the literature. Instead, the discussion is largely confined to those techniques which were considered or used by GEC Small Machines during the course of this project and to certain practical issues involved in their implementation. Although this discussion and its conclusions will relate specifically to control systems for the GEC Small Machines environment, it is expected that certain fairly general principles will emerge which may be of use to other companies implementing JIT-based systems.

The report begins with a description of the need for an effective manufacturing planning and control system at the company. The existing situation is described in terms of the manufacturing process, the early JIT efforts, and the production systems in use. This leads on to a definition of the problem in terms of requirements, constraints and criteria.

The problem is examined in two parts: the need for a suitable master production schedule, and the need for a system to provide the raw materials and components to execute such a schedule. Available techniques are discussed in relation to each part of the problem and a theoretical model solution is developed in each case.

The detailed development and implementation of these solutions is then described in two separate chapters, together with the results achieved. The interrelationship between these two systems and their advantages and disadvantages, are also discussed.

Finally, certain conclusions are drawn and recommendations of both a specific and a general nature are given.

2.0 THE NEED FOR AN EFFECTIVE MANUFACTURING PLANNING AND CONTROL SYSTEM

2.1 The Existing Situation

When the author joined GEC Small Machines in March 1986, certain improvements had already been achieved by applications of the JIT philosophy. Most of the effort had been concentrated on the mini-motors product line as the pilot project. A certain degree of lot size reduction had been undertaken, with a drop in WIP from an initial 30 days to about 5 days. Vastly improved layouts had been implemented and various TQC techniques had been utilised. Quality improvements included the reduction of rejects from 40% to about 10% and complete rewinds from 20% to about 3%. A full discussion of the mini-motor pilot project and its results is given by Carstens [13].

However, the mini-motors manufacturing facility was really a self-contained focused factory within a factory and dependant only on the in-house aluminium die cast shop for frames and endshields. All other component manufacture in the plant did not supply the mini-motor line. Also, mini-motors accounted for less than 20% of the company's sales and thus an urgent need existed to improve the operations in the remainder of the plant.

2.1.1 The Manufacturing Process

Briefly, the manufacturing process for the larger motors (known as industrial motors) entails the following:

1. A stator core is built up and welded to the required length from a number of steel laminations selected from a standard range. These lamination are supplied by punch presses at the GEC Large Machines Company, which is on the same site.

2. Various gauges of copper wire are wound in coils, to specification, by special purpose machines or by hand and then inserted into the stator core, together with insulating materials. The insertion process is performed by a machine or by hand and is known as "shooting" of the coils.

3. Various wiring connections are then made and the wound stator core is tested on an in-line test bench before being permitted to proceed to a resin dip and baking oven.

4. This resin dipped stator is then pressed into a frame which has been machined in-house, but still requires a spigotting operation which must be performed after inserting the stator core. The raw iron castings are supplied by the GEC Foundry Company in Springs and the aluminium ones by the in-house die casting facility.

5. A matching rotor core is built up to specification in the aluminium die cast shop using steel laminations produced by the GEC Large Machines Company. The core then has a shaft pressed into it; which has been machined in-house from raw steel billet. This rotor unit is subsequently balanced on a special purpose machine.

6. The stator core in its frame and the rotor unit then proceed to the final assembly line, where the many other small components are added. Some of these, such as endshields and certain terminal boxes, lids and feet, have been machined in-house from castings. These castings originate from the same sources as frame castings. The other parts for final assembly such as capacitors, bearings, fans and cowls are bought out.

7. The assembled motor is finally tested on an in-line test bench before being spray painted, receiving a rating plate and, in some cases, being boxed for delivery.

2.1.2 The Move Towards Cellular Manufacturing

The JIT effort for industrial motors began by moving machines into group technology (GT) machining cells, each producing a specified range of components for final assembly. These moves were in progress at the time the author joined the company. There were also plans to form cells in the stator winding area, as well as in final assembly.

The author believed that this was a good first step in the introduction of JIT and indeed some benefits were quickly apparent. Some of the handling steps which had existed under the old job shop layout were no longer required. Also, WIP buffers between machines disappeared once three or four machines were tightly grouped into a cell, but the larger buffer stocks before and after cells remained.

A very important advantage of the move to GT cells was that routings were now defined and fixed, so that each part had a clear path through production. This is an essential prerequisite to the introduction of kanban systems, discussed later.

2.1.3 The Production System

The methods in use for planning and scheduling customer orders and their required components could hardly be termed a "production system." In fact, methods were more haphazard than systematic. The ordinary rule was that all batch sizes, from raw material ordering to finished motors, would consist of at least 5 weeks requirements as determined by the estimated annual demands (EADs). However, these batch sizes were usually modified to allow for rejects, long lead times for some items, lack of confidence in supplier's delivery promises and other inefficiencies. Excessive clerical work and paper was involved in the issuing of works orders, stores requisitions, drawings, and in some cases CNC programs, for every component required by assembly.

To make matters worse, there was no formal system for order promising or determining priorities. While salesmen went out quoting blanket lead times, often without any liaison with the factory (who in any case were hardly in a position to give accurate delivery dates), overdues were the order of the day. As Vollmann et al [14] observe:

"Many make to order firms have a simple policy of six weeks (or some other such period) delivery for every order. If this were correct on the average, it means that in 50% of the cases delivery could have been sooner, and in 50% of the cases delivery will be late."

GEC Small Machines was using such a system without even knowing what the correct average delivery period should be! In such a situation, the only apparent way to customer service levels was by continuous and chaotic expediting efforts. Priorities were continually changing and were established by various factors; such as the status of the company officer chasing the overdue, the power or perceived importance of the customer, the convenience of the factory or, often, the availability of parts.

The factory planning department, in reacting to this situation, tried to keep large quantities of components in WIP stores. These could then be drawn out and matched with whichever order was currently required. This might just have been chased through winding or retrieved from the dusty piles of wound stator WIP which lay, frequently risking damage, on the floor in the assembly area. Unfortunately, due to the inaccurate Kardex systems in use in the disorganised raw materials and WIP stores, the required components were often not available; in spite of the high overall stock levels.

This simply compounded the problems of the machine shop foremen, who were often asked to break down their long batch runs and set-up to make a few parts for the latest crisis order. These foremen normally had to do their own machine scheduling since piles of paper orders for component machining were issued to them with no regard for their current workload, nor any attempt at capacity planning. Orders were simply to be completed as soon as possible, with perhaps 30% of them bearing an "urgent" stamp. There were no staff attempts at back scheduling to try to match component production with the expected needs of the assembly line. Thus a foreman could easily be running a large batch of parts, of which very few were immediately needed, whilst holding up parts which would soon be urgently required in assembly.

The introduction of cellular manufacturing had eased the foremen's load to some extent. They now only had to worry about what to run in each cell instead of on each machine as previously. However, planning methods as described above had not changed at all and hence the overall improvement due to the use of GT cells was slight.

Lockyer [15] points out the inadequancies of production control at GEC Small Machines when he defines two basic and apparently simple questions that such a department should be able to answer at all times:

"1. Can a particular task be undertaken, and if so, when?

2. How far have the tasks in hand proceeded?"

Clearly the company's production control department was unable to answer either of these questions accurately. Vollmann, et al [16] note that:

"The firm with poor systems has extra inventories, extra lead times, extra capacity, extra personnel, excessive overtime, long delivery times and other kinds of slack built into its operations."

Some of the other symptoms that they don't mention include order backlogs, unclear delivery dates, inflexibility and, very obviously in this case, nervousness (i.e. frequent changes and crises). Lockyer [17] observes that many such "weaknesses of industrial units .... can be directly attributed to inferior or non-existent production control, while really effective production control can achieve increases in output far more spectacular and at far lower cost than any other management tool."

It was becoming increasingly apparent to the management of GEC Small Machines that their production system was out of control and that in such a situation, any other JIT benefits would be difficult to achieve.

Hence, the author was given the urgent task of designing and implementing a new production and inventory control system as the next step in the company's JIT improvement drive.

2.2 Problem Definition

2.2.1 Problem Statement

The design and implementation of a complete manufacturing planning and control (MPC) system at GEC Small Machines was required to support and facilitate the introduction of the JIT manufacturing philosophy.

2.2.2 Requirements

The minimum requirements for the system were defined as:

i) The system must be capable of controlling the entire manufacturing process from the procurement of raw materials to the shipping of finished products.

ii) The system must allow for the production of motors in line with the volume and mix specified by the current EADs and must be capable of adapting, along with the factory, to future EADs.

iii) The system must order the production of motors according to actual customer requirements and not to stock.

iv) The system must ensure the supply of the required materials at the required time to allow the completion of customer orders by the promised date.

v) The system must be capable at all times of providing accurate information concerning what orders can be produced when (order promising) and how far existing orders have already progressed.

vi) The transmission of information by the system must be fast enough to permit useful action to be taken.

2.2.3 Constraints

Factors constraining the choice of solutions were:

i) The system must be designed to support the JIT philosophy of manufacturing. It must allow and even encourage continuous improvement towards WCM.

ii) The system must be simple enough to be understood by everyone down to at least the line supervisor level. It must thereby inspire enough confidence for people to believe that they will get the best results by working with the system and not around it. All informal systems of "hot lists", "black books", etc., must be completely eliminated.

iv) It was highly unlikely that any major capital expenditure would be considered by the GECSA board.

2.2.4 Criteria

The following criteria were considered desirable:

i) The system should be as cost effective as possible to implement.

ii) The system should minimise factory throughput times.

iii) The system should eliminate unnecessary inventories and improve stock turns.

iv) The system should encourage the elimination of waste.

v) The system should utilise the capacity of bottlenecks effectively.

vi) The system should encourage consistent production to specification "first time, every time."

vii) The system should allow the development of people through decision making at the lowest possible levels.

viii) The system should be flexible and responsive to varying customer demand.

In view of the many problems, outlined earlier, that were being experienced by the company, the most important initial objective of the new system was to achieve control over the factory's operations. It was apparent that this alone would automatically yield substantial improvement in many of the problem areas and that further, focused improvement efforts would then be possible within the controlled environment. Also, a controlled environment would eliminate much of the "firefighting" efforts currently being expended by management and allow them some time to concentrate of real improvements.

3.0 SURVEY OF AVAILABLE TECHNIQUES AND DEVELOPMENT OF A THEORETICAL MODEL SOLUTION

In the course of researching the problem the author consulted numerous books, journal articles and papers and found many disagreements between different authors. From a systems point of view, the options fell into one of two broad categories: traditional 'push' systems, and various 'pull' systems which mostly arose from the JIT philosophy. However, a few texts also discussed the possibility of the partial use of push systems within a manufacturing philosophy that was otherwise based on JIT.

The 'traditional' writers explained their methods logically and in detail, but for the most part were either unaware of the JIT approach or only glossed over it very briefly. At no stage did any of them compare the different approaches and attempt to justify their's as being superior. After discussing complex and expensive computer systems and the extensive audits and information integrity required for such systems to work, Vollmann et al [18] briefly mention a "Japanese approach .... called Just In Time manufacture" and observe that:

"There is so little inventory in these systems that detailed monitoring of transactions is unnecessary. At the Toyota automobile factory, for example, deliveries of parts from vendors are going out of the door as finished autos within hours. The parts <u>had</u> to arrive or the line would stop! Moreover, every worker is also a quality controller, so the parts had to be of the correct quality."

The authors appear to marvel at such a highly efficient approach, but decline to explore it any further than this. Instead, they continue to discuss the use of complex systems to control a complex organisation and fail to draw a fairly obvious conclusion. As the Ingersoll Engineers' [19] suggest, the most logical approach is to simplify, streamline and integrate the business first and then apply what little technology and computing power is really necessary. Schonberger [20] agrees:

"Simplify and reduce, simplify and integrate, simplify and expect results."

The Japanese writers on the other hand, in explaining their methods and systems, could not avoid challenging the very assumptions upon which the traditional approaches were based. However, they did not concern themselves with direct system comparisons either, but simply built their own approaches up logically from sound first principles, which they explained thoroughly.

Finally, there were texts written about Japanese systems by leading American consultants who had previously spent many years implementing traditional systems and even written books about them. These consultants (Schonberger, Hall, Hayes, Wheelright, Sandras, Wheeler, etc.) were struck by the greater efficiencies inherent in the simple logic of the Japanese methods and made many interesting comparisons with traditional approaches.

The author did not come across any book or paper which seriously challenged the JIT approach as inefficient or asserted that the traditional methods were superior. Indeed, the American experts believed in the power of the JIT philosophy and wrote at length on strategies for its implementation in Western companies.

Many of the ideas used by the Japanese originated in the West, but were not widely used or developed there. The Japanese pieced together various techniques and developed them further into a holistic approach to efficient operations; dri[illegible] by an almost fanatical quest for continuous imp[illegible]ovement via the elimination of clearly defin[illegible]d wast[illegible]s. There is no reason why these refined ideas should not now be re-exported to the West. Certain perceptive traditional wr[illegible] have come across some universal, non-traditional truths in the course of their experience. Lockyer [21], whose book was first published in 1962, noted that:

"substantial increases in productivity are ... likely to derive from .... better scheduling, lower set-up times, improved material flow, better social relationships ...."

These ideas are generally con[illegible]idered today to have been derived from the JIT philosophy and are, of course, very important p[illegible]inciples of it; but Lockyer had [illegible]ncluded them in his text. He had further observed [22] under the heading "The Myth of Plant Utilisation":

"The effects of a utilisation at any price policy can be disastrous since excessive material and work-in-progress will result. A much more rational criterion is the velocity of material flow ...."

Lockyer saw the benefits of fast material flows only in narrow financial terms, but the potential to derive the JIT philosophy is present in the above two quotes; that is, he advocates a JIT approach without being aware of it. Thus, in the course of the readings, the author's confidence in the JIT philosophy grew, and he challenged his traditional training in the pursuit of superior solutions.

The problem is examined in two parts. Firstly, the development of a suitable master production schedule (MPS), to transform customer orders into a workload for the factory, is discussed. Secondly, the design of a system to supply the raw materials and components required to execute the MPS is considered.

3.1 Development of the Master Production Schedule

3.3.1 Finite Loading

Lockyer, [23] from his traditional viewpoint, compares finite and infinite capacity loading. He notes that loading and scheduling have to consider conflicting constraints of time and capacity.

He believes that if time is fixed by a customer's requirements it is necessary to backschedule from the due date, ignoring capacity constraints. Such an infinite capacity schedule produces rescurce demands which, he admits, often result in overloads. Thus, he says, capacity must be increased somehow or some delivery times must be relaxed, where acceptable. This approach did not seem at all appropriate for GEC Small Machines as, more often than not, capacity was not easy to increase. Overtime, the most common strategy for a short term capacity increase, was ruled out by a current union ban. Also, given the company's current due date performance record and the original system requirement of due date accuracy, it was unacceptable to choose an approach which relied on accepting customer due dates and then later going back to re-negotiate them.

Lockyer sees finite capacity forward scheduling as being possible only where time is not considered to be important and says that finite capacity scheduling effectively implies "infinite time." The author disagrees with this view and believes instead that it implies accepting reality in order to achieve a reliable low cost operation.

The reality is that if a particular customer must have his motor quickly and the plant does not have the capacity available to make it, the order cannot be accepted. If it is accepted, then that customer, or some other customer, will receive his delivery later than promised.

When such practices are ongoing, the company acquires a reputation for unreliable deliveries and many customers are, in any case, lost to the opposition. Those customers who remain will always attempt to compensate by exagerating the urgency of their order, thereby increasing the chance of receiving it by the time th really need it. This situation creates a vicious circle of poor performance by increasing the apparent pressure on factory capacity as well as the lack of trust between the factory and its customers.

A far better manufacturing strategy is to decide what volume of orders can be accepted based on current capacity and to attempt to provide those customers with reliable, excellent service. As Vollmann, et al [24] admit:

"The finite loading technique ..... more than any other capacity planning techniques, makes clear the relationship between scheduling and capacity availability."

By allocating capacity directly to customer orders it is possible to see very accurately when a particular order will be produced. The current lead time is thus determined by the existing order book. When the order book is large, those customers who genuinely cannot afford to "wait their turn" may sometimes be fitted into an earlier capacity slot where another order has been cancelled; but in general they must be turned away.

Once the company is successfully providing its existing customers with a highly reliable service, it will attract more customers. Eventually it will be aware that it is turning a large number of customers away. This will then be a clear signal that it is time to expand the business by adding extra production capacity. Thus the company can grow in a controlled, less risky manner than is possible in the 'firefighting' environment created by promising customer orders against capacity that doesn't exist; that is, an infinite capacity scheduling approach.

3.1.2 Undercapacity Scheduling

Undercapacity scheduling is a common WCM technique. By setting the daily schedule at less than the maximum daily capacity it becomes possible to attain zero deviation from schedule. This is important from the point of view of the reliable on-time deliveries discussed above. However, undercapacity scheduling is also a TQC concept since it makes it feasible to stop the line for quality and other problems. Also, as Schonberger [24] points out:

"less-than-full-capacity scheduling avoids pressuring workers and over-taxing equipment, tools and support people - and thereby avoids errors in quality that could arise from haste. Preventing errors serves to decrease the need for line stops. Equally important, error prevention smooths the output rate, which makes it more feasible to operate without large inventory buffers between successive processes: the just-in-time ideal."

For these reasons it was decided that undercapacity scheduling should be employed at GEC Small Machines. Once the company was more advanced with JIT, there might sometimes be spare time left at the end of the day. This would then be used for information meetings, problem solving projects, training sessions, maintenance of machines, and general small group improvement activities. At the general manager's sole discretion, this spare time might occasionally be used to help out the company's most important customers by fitting in very urgent, small quantity jobs. However, this practice would be considered an absolute last resort and would generally be discouraged. The sales force would be expected to educate their customers as to the advantages of the fixed capacity schedule system and to help them to take it into account when placing orders.

3.1.3 The Function of the Schedule

Hall [25] advises:

"From the perspective of production planning, stockless production requires development of the ability to synchronise everything from the final assembly schedule. Except for final assembly, actual production is executed in response to a pull signal, not a schedule ..... The assembly schedules from which the lines really run should respond to actual demand."

Bicheno [26] concurs on the last point:

"(JIT) Scheduling aims at sending through a set of products which will meet the market demand for that time bucket, whilst not overproducing."

At GEC Small Machines, then, the schedule should relate to the exact mix of motors specified by the customers in the current finite capacity time bucket and no other schedules should be required.

A motor's specification is derived directly from the winding specification of the stator. Thus, the stator winding requirements would be identical to the "customer specified" final assembly schedule (FAS) with an appropriate throughput time offset. Given the need for a finite capacity schedule, a problem arose in considering the final assembly process because its capacity is difficult to determine. This is due in part to the number of "bolt-on" options available in final assembly, although the basic specification of the motor has been previously determined at the winding stage. Also, the assembly process is highly labour intensive and thus its capacity can be varied by moving labour into or out of the assembly section. The stator winding section on the other hand, has capacity constraints defined by the special purpose machines employed there.

Thus, the above ideas were effectively adapted to the company's particular situation by basing the scheduling system on the stator winding operation. In this manner, finite capacity scheduling was more easily utilised without losing the recommended exact correlation between the customer requirements and the FAS.

The term 'master production schedule' (MPS) is used at GEC Small Machines to denote the winding schedule. This should not be confused with the idea of an MPS under the manufacturing resource planning (MRP II) system, where the MPS can include planned orders and sometimes even subassemblies for stock. The MPS under MRP II can thus be substantially different from the FAS; whereas at GEC Small Machines the FAS is identical to the MPS except for a time offset.

3.1.4 The Optimised Production Technology (OPT)

At this point a relatively new scheduling system known as OPT was examined. This is a finite loading technique which employs certain important fundamental principles. Three of the so called "rules of OPT" are important here [27]:

"Rule 4: An hour lost at a bottleneck is an hour lost for the total system.

Rule 5: An hour saved at a non bottleneck is just a mirage.

Rule 6: Bottlenecks govern both throughput and inventories."

This means that only bottleneck resources, or operations, are of critical scheduling concern. Production output is limited by the bottleneck operations and increased throughput can only be achieved by better utilisation of the capacity of bottleneck facilities. These concepts were utilised in two ways at GEC Small Machines.

Firstly, when scheduling work for cells or calculating their capacities for system design purposes, only the bottleneck operation in each cell was considered. To load a cell with more work than its slowest operation can handle is pointless, since excess materials issued will simply manifest themselves as WIP awaiting any operation which is slower than the one preceding it. Such overproduction is contrary to the JIT philosophy and serves to obscure problems; as discussed in the previous chapter.

The second use of these ideas was in identifying complete cells which did not constitute bottlenecks in terms of the throughput of the factory as a whole. These cells, if run at full capacity, would tend to overproduce. Thus, in a situation of controlled levels of WIP with no overproduction permitted, these cells would instead stand idle for some of the time.

It was reasoned that this idle time should be used to perform extra set-ups, thereby allowing immediate lot size reductions leading to all the JIT benefits previously discussed. A procedure for calculating how small the lot sizes should become was developed for GEC Small Machines and is discussed later.

The OPT system also runs smaller batch sizes in non-bottleneck resources for the reasons just explained, but calculates these batch sizes using its computer program. The OPT system is an extensive package of proprietary software which utilizes mathematical programming, simulation, and network procedures. Its objective is to provide a general capability for modeling complex interdependant flows through a network of production processes. It thereby generates production plans and schedules which will maximise factory throughput and meet due dates by applying the sound logic contained in the OPT "rules."

Little direct information on the technical aspects of the program is available, but clearly it will consider the load on each machine in a job shop factory, decide if it constitutes a bottleneck and then schedule it accordingly. Forward finite capacity schedules are produced for bottlenecks, whilst non-bottlenecks are backward scheduled from the expected assembly schedules. Little or no consideration is given to the workloads resulting from the backward scheduling process at the non-bottlenecks since, by definition, they should have excess capacity.