CHAPTER ONE

INTRODUCTION

1.1 Background of the study

In the past twenty (20) years, technological advancements, international competitions and market dynamics have brought a major impact to the textile manufacturing industry. Intense competition encourages management to develop new production and supply methodologies in order to remain competitive (Abernathy, 1995). One key issue involves the allocation of scarce production resources over competing demands, which is a typical problem in dealing with many complex man-made systems (Cassandras, 1993).

Many manufacturing facilities generate and update production schedules, which are plans that state when certain controllable activities (e.g., processing of jobs by resources) should take place. Production scheduling can be difficult and time-consuming. In dynamic, stochastic manufacturing environments, managers, production planners, and supervisors must not only generate high-quality schedules but also react quickly to unexpected events and revise schedules in a cost-effective manner. These events, generally difficult to take into consideration while generating a schedule, disturb the system, generating considerable differences between the predetermined schedule and its actual realization on the shop floor. Rescheduling is then practically mandatory in order to minimize the effect of such disturbances in the performance of the system. Production scheduling activities are common but complex. There exist many different views and perspectives of production scheduling. Each perspective has a particular scope and its own set of assumptions. Different perspectives lead naturally to different approaches to improving production scheduling. The three important perspectives are;

Problem-solving: Finding Optimal Schedules

When viewed from the problem-solving perspective, production scheduling is a fascinating puzzle to be solved by moving tasks around a Gantt chart, searching for the optimal solution. MacNiece (1951) gives a beautiful example of using a Gantt chart to solve a scheduling problem. The problem is to determine if an order for an assembly can be completed in 20 weeks. The Gantt chart has a row for each machine group and bars representing already planned work to which he adds the operations needed to complete the order. He argues that using a Gantt chart is a much quicker way to answer the question. More generally, the ability to formulate the problem rigorously and to analyze it to find properties of optimal solutions has attracted a great deal of research effort. In addition to exact techniques, there are a variety of heuristics and search algorithms used to find near-optimal solutions to these problems (Brucker and Peter, 2004). Although there exist a significant gap between scheduling theory and practice, some researchers have improved real-world production scheduling through better problem-solving (Dawande et al., 2004).

The optimization approach relies upon the ability to formulate the problem. Its feasibility depends upon the ability to collect the data needed to specify the problem instance. More importantly, its relevance depends upon whether or not someone will use the schedule that is generated. The relevance problem is not new and predates the academic research on scheduling. Reacting to situations that he observed ninety years ago, Gantt (1973) warned that the most elegant schedules created by planning offices are useless if they are ignored.

Decision-making

Decision-making is a slightly broader perspective on production scheduling. Decision-making is, in general, a process of gathering information, evaluating alternatives, selecting one, and implementing it. Schedulers must perform a variety of tasks and use both formal and informal information to make scheduling decisions. McKay and Wiers (2004) provide an excellent discussion of the decision-making perspective, starting with the tasks that schedulers perform each day:

- Situation assessment: what is where;
- Crisis identification: what needs immediate attention;
- Immediate resequencing and task reallocation: reactive decisions;
- Complete scenario update: remapping the future;
- Future problem identification: what problems can be foreseen;
- Constraint relaxation and future problem resolution: discounting future problems; and
- Scheduling by rote: dealing with the rest of the problem.

Two important points should be highlighted. One, in this perspective, the production scheduling objective is "to see to it that future troubles are discounted" (Coburn, 1981). There are many types of disturbances that can upset a production schedule, including machine failures, processing time delays, rush orders, quality problems, and unavailable material. Problems can be caused by sources outside the shop floor, including labor agreements and the weather. It is unlikely that such a wide variety of possible problems can ever be considered automatically, implying that computers will never completely replace human schedulers. Moreover, improving production scheduling requires that the schedulers manage bottleneck resources effectively, understand the problems that occur (whether caused by others or by themselves), and take steps to handle future uncertainty (McKay and Wiers, 2004).

Scheduling decision support systems can be useful as well. As suggested by McKay and Wiers (2006) and Wiers (1997), the design of a scheduling decision support tool should be guided by the following concepts:

(i) The ability of the scheduler to directly control the schedule (called "transparency"),

(ii) The amount of uncertainty in the manufacturing system,

(iii) The complexity of the scheduling decision, and how well-defined the scheduling decision is. (An ill-defined scheduling decision is characterized by incompleteness, ambiguity, errors, inaccuracy, and possibly missing information.

The second point is that there is a place for problem-solving. The scheduling by rote task requires creating a schedule for the work that is not in process, assigning work to resources, and sequencing the operations subject to the constraints that the scheduler imposes to avoid future problems. Schedule generation algorithms can be useful in this step to reduce the workload of the scheduler and find solutions that are better than those a human can find (due to the size or complexity of the problem).

The Organizational Perspective: Sharing Information

The organizational perspective, which is the most complete, views production scheduling as a system of decision-makers that transforms information about the manufacturing system into a plan (the production schedule) (Herrmann, 2004).

In a manufacturing facility, the production scheduling system is a dynamic network of persons who share information about the manufacturing facility and collaborate to make decisions about which jobs should be done when. The information shared includes the status of jobs (also known as work orders), manufacturing resources (people, equipment, and production lines), inventory (raw materials and work-in-process), tooling, and many other concerns. The persons in the production scheduling system may be managers, production planners, supervisors, operators, engineers, and sales personnel. They will use a variety of forms, reports, databases, and software to gather and distribute information, and they will use tacit knowledge that is stored in their memory. The following are among the key decisions in a production scheduling system:

- releasing jobs for production,
- prioritizing jobs that require the same resources,
- assigning resources (people, equipment, or production lines) to jobs,
- reassigning resources from one job to another,
- determining when jobs should be started, and,
- interrupting jobs that should be halted.

The production scheduling system is a control system that is part of a larger, more complex manufacturing planning and control system. The production scheduling system includes but is more than a schedule generation process (be it manual or automated). The production scheduling system is not a database or a piece of software. The production scheduling system interacts with but is not the system that collects data about the status of open work orders (often called a manufacturing execution system). The production scheduling system is not an optimization procedure. The production scheduling system provides information that other managers need for other planning and supervisory functions.

Representing decision-making systems is a difficult task. Herrmann and Schmidt (2002) describe decision-making systems in product development. The most typical representation is an organization chart, which lists the employees of a firm, their positions, and the reporting relationships. However, this chart does not explicitly describe the decisions that these persons are making or the information that they are sharing. Another representation is a flowchart that describes the lifecycle of an entity by diagramming how some information (such as a customer order, for example) is transformed via a sequence of activities into some other information or entity (such as a shipment of finished goods). Swim lanes are a special type of flowchart that adds more detail about who does which activities, a key component of a decision-making system (Sharp and McDermott, 2001). Herrmann (2004) uses swim lanes to represent a production scheduling system since the swim lanes model yields a structured model that describes the decision-making and information flow most efficiently and clearly shows the actions and decisions that each participant performs. One limitation is that the model does not show the structure of the organization. Also, representing a larger, more complex system would require swim lanes models at different levels of abstraction to avoid confusion. Swim lanes are not the only possibility. Work by Guinery and MacCarthy (2005) on improving production scheduling systems used modified GRAI modelling techniques for representing decision centres. A scheduler is only one node in the production scheduling system network. The scheduler's tasks describe the activity within that node. The information that the scheduler needs arrives from other nodes, and the schedules that are created go to other nodes in the network.

The production planning and production scheduling interface

Production planning is the function of establishing an overall level of output, called the production plan. The process also includes any other activities needed to satisfy current planed levels of sales, while meeting the firm's general objectives regarding profit, productivity, lead times and customer satisfaction, as expressed in the overall business plan. A primary purpose of the production plan is to establish production rate that will achieve management objective of satisfying customer demands. Demand satisfaction could be accomplished through the maintaining, raising or lowering of inventories or backlogs (WIP), while keeping the workforce relatively stable.

The production schedule is derived from the production plan; it is a plan that authorized the operations function to produce certain quantity of item within a specified time frame.

Production scheduling has three primary goals or objectives. The first involves due dates and avoiding late completion of jobs. The second goal involves throughput times; the system, from the opening of a job order until it is completed. The third goal concerns the utilization of work centers (Hurtubise et al, 2004)

According to Kriepl and Pinedo (2004), planning models differ from scheduling models in a number of ways. First, planning models often cover multiple stages and optimize over medium term horizon, whereas scheduling models are usually designed for a single stage (facility) and optimize over a short term horizon. Secondly, planning models uses more aggregate information, whereas scheduling models use more detailed information. Thirdly, the objective to be minimized in a planning model is typically a total cost objective and the unit in which this is measured is a monetary unit; the objective to be minimized in a schedule model is typical a function of the completion times of the jobs and the unit in which this measured is often or time unit. Nevertheless even though there are fundamental differences between these two types of models, they often have to be incorporated into a single frame work, share information, and interact extensively with one another.

Computer-based production scheduling

Advances in information technology have made computer-based scheduling systems feasible for firms of all sizes. Wight (1984) lists three key factors that led to the successful use of computers in manufacturing:

- ❖ IBM developed the Production Information and Control System starting in 1965.
- ❖ The implementation of this and similar systems led to practical

knowledge about using computers.

- Researchers systematically compared these experiences and developed new ideas on production management.

Early computer-based production scheduling systems used input terminals, centralized computers (such as an IBM 1401), magnetic tape units, disk storage units, and remote printers (O'Brien, 1969). Input terminals read punch cards that provided data about the completion of operations or material movement. Based on this status information, the scheduling computer updated its information, including records for each machine and employee, shop order master lists, and workstation queues. From this data, the scheduling computer created, for each workstation, a dispatch list (or "task-to-be-assigned list") with the jobs that were waiting for processing at that workstation. To create the dispatch list, the system used a rule that considered one or more factors, including processing time, due date, slack, number of remaining operations. The dispatcher used these lists to determine what each workstation should do and communicate each list to the appropriate personnel.

Interactive, computer-based scheduling eventually emerged from various research projects to commercial systems. Godin (1978) describes many prototype systems. An early interactive computer-based scheduling program designed for assembly line production planning could output graphs of monthly production and inventory levels on a computer terminal to help the scheduling personnel make their decisions (Duersch and Wheeler, 1981). The software used standard strategies to generate candidate schedules that the scheduling personnel modified as needed. The software's key benefit was to reduce the time needed to develop a schedule. Adelsberger and Kanet (1991) use the term *lei stand* to describe an interactive production scheduling decision support system with a graphical display, a database, a schedule generation routine, a schedule editor, and a schedule evaluation routine. The Logistics Management System (LMS) was an innovative scheduling system developed by IBM for its semiconductor manufacturing facilities. LMS began around 1980 as a tool for modeling manufacturing resources. Computer-based scheduling systems are now moving towards an approach that combines dispatching rules with finite-capacity production schedules that are created periodically and used to guide the dispatching decisions that must be made in real time.

Material Requirements Planning (MRP) translates demand for end items into a time-phased schedule to release purchase orders and shop orders for the needed components. MRP affected production scheduling by creating a new method that not only affected the release of orders to the shop floor but also gave schedulers the ability to see future orders, including their production quantities and release dates (Wight, 1984). MRP, in turn, led to the rise of Manufacturing Resources Planning (MRP II), Manufacturing Execution Systems (MES), and now Enterprise Resource Planning (ERP) systems.

Modem computer-based scheduling systems offer numerous features for creating, evaluating, and manipulating production schedules (Seyed, 1995, provides a discussion on how to choose a system.) The three primary components of a scheduling system are the database, the scheduling engine, and the user interface (Yen and Pinedo, 1994). The scheduling system may share a database with other manufacturing planning and control systems such as MRP or may have its own database, which may be automatically updated from other systems such as the manufacturing execution system. The user interface typically offers numerous ways to view schedules, including Gantt charts, dispatch lists, charts of resource utilization, and load profiles. The scheduling engine generates schedules and may use heuristics, a rule-based approach, optimization, or simulation. Based on their survey of hundreds of manufacturing facilities, LaForge and Craighead (1998) conclude that computer-based scheduling can be successful if it uses finite scheduling techniques and if it is integrated with the other manufacturing planning systems. Computer-based scheduling can help manufacturers improve on-time delivery, respond quickly to customer orders, and create realistic schedules. Finite scheduling means using actual shop floor conditions, including capacity constraints and the requirements of orders that have already been released. Information technology has had a tremendous impact on how production scheduling is done. Among the many benefits of information technology is the ability to execute complex algorithms automatically. The development of better algorithms for creating schedules is thus an important part of the history of production scheduling.

Algorithms used in production scheduling

Linear programming was developed in the 1940s and applied to production planning problems (though not directly to production scheduling). George Dantzig invented the simplex method, an extremely powerful and general technique for solving linear programming problems, in 1947.

In the 1950s, research into sequencing problems motivated by production scheduling problems led to the creation of some important algorithms, including Johnson's rule for the two-machine flowshop, the Earliest Due Date (EDD) rule for minimizing maximum lateness, and the Shortest Processing Time (SPT) rule for minimizing average flow time (and the ratio variant for minimizing weighted flow time). Solving more difficult problems required a different approach. Branchand-bound techniques appeared around 1960. These algorithms implicitly enumerated all the possible solutions and found an optimal solution.

Since decision-makers generally need solutions in a reasonable amount of time, search algorithms that could find near-optimal solutions became more important, especially in the 1980s and 1990s. These included local search algorithms such as hillclimbing, simulated annealing, and tabu search. Other innovations included genetic algorithms, ant colony optimization, and other evolutionary computation techniques.

Benefits of production scheduling

Production scheduling helps manufacturers create the most optimal schedules, while meeting a number of important priorities:

- Increased production efficiency. Run like products together to reduce mild changes and clean-out time.
- Process change-over reduction.
- Inventory reduction. Less inventory is needed to fill time sensitive orders when capacity can be accurately predicted.
- Accurate delivery date quotes. This creates customer loyalty and satisfaction.
- Supply chain optimization.
- Material Requirements Plan (MRP) to ensure the necessary materials for order is on hand or ordered on time.
- Reduce scheduling effort by arranging an optimal schedule per the constraints.
- Labor load levelling. Reduce labor spikes and declines by projecting schedule into the future.
- Real time information. View the jobs that are currently running, allow customer services to see the capacity available.
- Identify and reduce bottlenecks.

Factors affecting scheduling processes

Factors which directly have impact on the scheduling process includes the type of job to be processed and the different resources needed for each process routings, processing times, setup times, changeover times, number of shifts, downtimes and planned maintenance.

Random demand makes the scheduling of labor extremely difficult, since customers don't like to wait, labor must be scheduled so that customers wait is minimized. This sometime requires the use of queuing theory or waiting line theory.

1.2 Statement of the problem

Planning and scheduling are decision-making processes that are used on a regular basis in many manufacturing and service industries. These forms of decision-making play an important role in procurement and production, in transportation and distribution, and in information processing and communication. The planning and scheduling functions in a company rely on mathematical techniques and heuristic methods to allocate limited resources to the activities that have to be done. This allocation of resources has to be done in such a way that the company optimizes its objectives and achieves its goals. Objectives can take many different forms, such as minimizing the time to complete all activities, minimizing the number of activities that are completed after the committed due dates, and so on.

Orders that are released in a manufacturing setting have to be translated into jobs with associated due dates. These jobs often have to be processed on the machines in a workcenter in a given order or sequence. The processing of jobs may sometimes be delayed if certain machines are busy. Pre-emption's may occur when high priority jobs are released which have to be processed at once. Unexpected events on the shopfloor, such as machine breakdowns or longer-than-expected processing times, also have to be taken into account, since they may have a major impact on the schedules. Developing, in such an environment, a detailed schedule of the tasks to be performed helps maintain efficiency and control of operations. The shopfloor is not the only part of the organization that impacts the scheduling process. The scheduling process also interacts with the production planning process, which handles medium- to long-term planning for the entire organization. This process intends to optimize the firm's overall product mix and long-term resource allocation based on inventory levels, demand forecasts and resource requirements.

Production scheduling has three primary goals or objectives. The first involves due dates and avoiding late completion of jobs. The second goal involves throughput times; the firm wants to minimize the time a job spends in the system, from the opening of a shop order until it is closed or completed. The third goal concerns the utilization of work centers. Firms usually want to fully utilize costly equipment and personnel.

Often, there is conflict among the three objectives. Excess capacity makes for better due-date performance and reduces throughput time but wreaks havoc on utilization. Releasing extra jobs to the shop can increase the utilization rate and perhaps improve due-date performance but tends to increase throughput time.

A feasible schedule satisfies demands. An optimal schedule minimizes total production cost while satisfying demands. The problem that most manufacturing firms face is how to establish an efficient production schedule that minimizes both total production and inventory (storage) cost while satisfying customer demands.

1.3 Objectives of the study

The objective of this study is to establish an efficient production schedule that will minimize total production cost and increase efficiency at TexStyle Ghana Limited. The study will also attempt to:

- Determine the level of supply at each source;
- Determine the level of demand at each destination;

1.4 Justification of the study

This study focuses on production, equipment and inventory scheduling problem in the textile manufacturing industry. It will help to optimize the organisations product-mix and long-term resources allocation based on inventory levels, demand forecast and resource requirement. In view of the benefits of production scheduling, this study will help reduce scheduling effort in the Tex Styles Ghana Limited (TSGL) by arranging an optimal schedule per the constraints. It will also provide real time information in view of the WIP's and capacity available.

1.5 Research Methodology

Several papers place production problems into conventional linear programming frameworks. This study models the production problem as a balanced transportation problem (related type of linear programming problem) which can easily be solved using the transportation model, a special streamlined version of the simplex method for efficiently solving transportation problems.

A transportation problem is the problem of finding the minimum-cost distribution of a given commodity from a group of supply centers (sources) i=1,…,m to a group of receiving centers (destinations) j=1,…,n. Each source has a certain supply (s_i) and each destination has a certain demand (d_j). The cost of shipping from a source to a destination is directly proportional to the number of units shipped. However, its important applications (e.g., production scheduling) actually have nothing to do with transportation.

A transportation problem will have feasible solutions if and only if

$$\sum_{i=1}^{m} s_i = \sum_{j=1}^{n} d_j \qquad \text{(A balanced transportation problem)}$$

An Initial Basic Feasible Solution (IBFS) can be found using several alternative methods but this study will consider the Vogel's Approximation Method (VAM).

To obtain optimality, the Modified Distribution Method (MODI) will be used to improve on the basic feasible solution.

A twelve month data on TSGL production capacities and expected demands (in units) for the period will be collected for the study. Regular and overtime production cost (in GHc) including inventory at the beginning of the year will also be gathered for this study.

Data will be formulated and analysed using Excel Solver.

1.6 Brief History of Tex Styles Ghana Limited (TSGL)

The history of TSGL, for the purpose of this study will be grouped into three (3) phases, namely;

i) **Incorporation** - establishment/construction

ii) **Takeover** - mismanagement/run down

iii) **Reinvestment** – mergers/acquisition

The **first phase** involved the construction of the Tex Styles factory in Ghana which started in **March 1963**, followed by its incorporation in **January 1966** as Ghana Textiles Printing Company for the production of African prints. This was inspired by the post-independence government's industrialisation initiative to reduce economic dependence by producing items that were previously imported. Management had been in the hands of **Unilever/Anglo Dutch African Textiles Investigation Group** (ADATIG) with the government of Ghana assuming majority shareholding up to the end of December 1981.

The **second phase** was between **1982-1993** during which the workers mobilised themselves and took over the management of the factory and ejected its management (Unilever) by disenfranchising offshore shareholders, therefore there was no new investment and production machinery was left to decay. This labour insurgence discouraged foreign investments thereby bringing production to a complete halt.

The **third phase** (1994 to date) involved Unilever resuming full management control after twelve years of expropriation. In 1996 Gamma Holding, represented by Vlisco B.V. assumed majority shareholding and management control, and in 1998, Unilever divested its minority shares to Gamma Holding. The current shareholding structure is as follows: VLISCO 71%, GHANA GOVT 16% and TRUEBROOK 13%.

TSGL is a subsidiary of Vlisco BV, Holland, which is also a subsidiary of Gamma Holdings NV. Gamma Holdings develops, manufactures and sells innovative, high quality industrial and consumer related textile products throughout the world. The Company was founded in **1846** and is head quartered in Helmond, the Netherlands. Its subsidiaries in Africa manufacture and distribute dyed and printed ethnic fabrics under the brand names, Vlisco, GTP, Uniwax and Woodin (Vlisco News Bulletin)

Vlisco Ghana Group (VGG) until 2005, comprised of a group of three (3) companies (i.e. which were vertically integrated) Juapong Textiles Limited (JTL), Tex Styles Ghana (TSG) and Premium African Textiles Company Limited (PATCO).

Juapong Textiles Limited (JTL): This used to be the spinning and weaving factory which produced the raw material (Grey baft) for the printing of different brands of textiles. In **2005** due to competition from Asia, obsolete technology and managerial inefficiency leading to high cost of production, the management of Vlisco divested sixty-three percent (63%) of its shares to the government of Ghana.

Tex Styles Ghana Limited (TSGL) [formerly Ghana Textiles Printing- GTP]: This is the printing factory of the group which produces GTP wax prints (core product), Woodin fancies (which are premium fancy brands retailed in up market boutiques), as well as Diva (a mass market fancy brand).

Premium African Textiles Company Limited (PATCO): This is the distribution company of the group with Gamma (represented by Vlisco BV) holding 100% shares.

It operates thirteen (13) distribution outlets nationwide wholesaling products from TSGL. It also redistributes imports from Holland (Vlisco wax) to its distributors. PATCO also supervises four (4) Woodin boutiques attached to its distribution outlets where retailing of the Woodin products is done.

The two subsidiary companies are managed by a Managing Director (MD) who is also the Chairman of both boards of directors. The MD is assisted by the Management Committees of the respective companies appointed by the MD. The two management committees comprise cross functional teams which are the policy-making body of the group.

Tex Styles Ghana Limited is the market leader in African prints manufacturing in Ghana with annual sales close to twenty-five million euros (€25m) and over nineteen million (19m) yards in volume giving it a market share of 40% (VGG Annual Report 2008)

PATCO is the sales and distribution arm of VGG and is strategically located in thirteen (13) regional capitals nationwide. It distributes the company's brands through two hundred & twenty (220) distributors of PATCO.

CORPORATE VISION

'To be a global, innovative, value-creating group of companies with a leading niche market position in African prints.'

It aims to give all Ghanaians wherever they live, a sense of pride in wearing its brands on all occasions with a goal to make Accra the fashion capital of West Africa by 2010.

It hopes to achieve this through superior quality and fashionable brands, which take account of the trends in clothing, age group, urbanization and cultural development of the various population groups in Africa.'

CORPORATE MISSION

We aim to build the strongest African textiles group in African prints with premium brands, excellent distribution and committed employees in a socially responsible environment. We do this by providing a professional and inspiring working environment for employees where an entrepreneurial spirit is essential for creating value and solutions for our customers' continuous improvement and profitable growth.

1.7 Limitations of the study

The following limitation was encountered during the study:

- Reluctance to disclose actual production cost incurred by the company.

1.8 Organisation of the study

This thesis consist of five chapters, the first chapter covers the introduction of the study. Chapter two gives the literature review essential to this study. The third chapter discusses the methodology and the proposed model. Chapter four, deals with the data collection and analysis. Chapter five, the final chapter, gives account of the summary, conclusion and recommendations.

1.9 Summary

This chapter looked at the background of the study, stated the problem of the study and defined the objectives as well as the justification of the study. It also discussed briefly the method to be used and finally, how the work is organised. The next chapter looks at the relevant literature in the area of production scheduling.

CHAPTER TWO

LITERATURE REVIEW

2.0 Chapter overview

This chapter will focus on studies carried out by renowned researchers on production scheduling in industrial practice.

2.1 Introduction

There are many excellent reviews of scheduling theory: a review of single machine research can be found in Gupta & Kyparisis (1987); a review of dynamic scheduling research can be found in Ramasesh (1990); multi constrained job shops are reviewed in Gargeya & Deane (1996); the job shop scheduling problem is reviewed by Blazewicz et al. (1996); and heuristic scheduling systems are treated in Morton & Pentico (1993).

Scheduling theory was written by Conway et al., (1967) and Baker (1974). Since then, operations research has produced over twenty thousand (20,000) publications about the scheduling problem (Dessouky et al., 1995). In operations research, scheduling is usually defined as allocating a set of resources to perform a set of tasks. In production systems, this typically concerns allocating a set of machines to perform a set of jobs within a certain time period. The result of scheduling is a schedule, which can be defined as: a plan with reference to the sequence of and time allocated for each item or operation necessary to its completion (Vollmann et al., 1988).

Early works on production scheduling focused on developing methods and algorithms for identifying the optimal sequence of the required tasks considering either only one processor (machine) or multiple processors (machines)(Baker,1974). In each of these scheduling methods, the optimal schedule is achieved based on a certain desired goal such as to minimize the total make-span to complete all the selected tasks, or to minimize the mean flow of these selected tasks.

In manufacturing facilities, production schedules state when certain controllable activities (e.g., processing of jobs by resources) should take place. Production schedules coordinate activities to increase productivity and minimize operating costs. Using production schedules, managers can identify resource conflicts, control the release of jobs to the shop, ensure that required raw materials are ordered in time, determine whether delivery promises can be met, and identify time periods available for preventive maintenance.

The two key problems in production scheduling are "priorities" and "capacity"(Wight, 1984). In other words, "What should be done first?" and "Who should do it?" These questions are answered by "the actual assignment of starting and/or completion dates to operations or groups of operations to show when these must be done if the manufacturing order is to be completed on time" (Cox *et al.*, 1992). This is also known as *detailed scheduling*, *operations scheduling*, *order scheduling*, and *shop scheduling*.

Unfortunately, many manufacturers have ineffective production scheduling systems. They produce goods and ship them to their customers, but they use a broken collection of independent plans that are frequently ignored, periodic meetings where unreliable information is shared, expediters who run from one crisis to another, and ad-hoc decisions made by persons who cannot see the entire system. Production scheduling systems rely on human decision-makers, and many of them need help dealing with the swampy complexities of real-world scheduling (McKay and Wiers, 2004).

To improve production scheduling, organizations have adopted many decision support tools, from Gantt charts to computer-based scheduling systems (Herrmann, 2005, 2006a).

Computer software can be useful. For example, in the 1980s, IBM developed the Logistics Management System (Fordyce *et al*., 1992), an innovative scheduling system for semiconductor manufacturing facilities that was eventually used at six IBM facilities and by some customers (Fordyce, 2005). Pinedo (1995) and McKay and Wiers (2006) discuss the design of scheduling decision support systems, and McKay and Wiers (2004) provide practical guidelines on selecting and implementing scheduling software.

However, information technology is not necessarily the answer. Based on their survey of hundreds of manufacturing facilities, LaForge and Craighead (1998) conclude that computer-based scheduling can help manufacturers improve on-time delivery, respond quickly to customer orders, and create realistic schedules, but success requires using finite scheduling techniques and integrating them with other manufacturing planning systems. Finite scheduling uses actual shop floor conditions, including capacity constraints and the requirements of orders that have already been released.

Academic research on scheduling problems has produced countless papers on the topic. Pinedo (1995) lists a number of important surveys on production scheduling. Vieira *et al*. (2003) present a framework for rescheduling, and Leung (2004) covers both the fundamentals and the most recent advances in a wide variety of scheduling research topics. However, there are many difficulties in applying these results because real-world situations often do not match the assumptions made by scheduling researchers (Dudek *et al*., 1992).
Studies of production scheduling in industrial practice have also led to the development of a business process perspective that considers the knowledge management and organizational aspects of production scheduling (MacCarthy, 2006).

Frederick W. Taylor’s most important contribution to production scheduling was his creation of the planning office (described in Taylor, 1911). His separation of planning from execution justified the use of formal scheduling methods, which became critical as manufacturing organizations grew in complexity. It established the view that production scheduling is a distinct decision-making process in which individuals share information, make plans, and react to unexpected events. An interesting feature of the planning office was the bulletin board. There was one in the planning office, and another on the shop floor (Thompson, 1917). The bulletin board had space for every workstation in the shop. The board showed, for each workstation, the operation that the workstation was currently performing, the orders currently waiting for processing there, and future orders that would eventually need processing there. Thus, it was an important resource for sharing information about scheduling decisions to many people. Many firms implemented versions of Taylor’s production planning office, which performed routing, dispatching (issuing shop orders) and scheduling, “the timing of all operations with a view to insuring their completion when required” (Mitchell, 1939). The widespread adoption of Taylor’s approach reflects the importance of the organizational perspective of scheduling, a system-level view that scheduling is part of the complex flow of information and decision-making that forms the manufacturing planning and control system (McKay *et al.*, 1995; Herrmann, 2004; MacCarthy, 2006). The rise of information technology did not eliminate the planning functions defined by Taylor; it simply automated them using ever more complex software that is typically divided into modules that perform the different functions more quickly and accurately than Taylor’s clerks could (see Vollmann *et al.*, 1997).

The man most commonly identified with production scheduling is Henry L. Gantt, who not only worked with Taylor at Midvale Steel Company, Simonds Rolling Machine Company, and Bethlehem Steel but also served as a consultant to many other firms and government agencies (Alford, 1934). To improve managerial decision-making, Gantt created innovative charts for visualizing planned and actual production. A *Gantt chart* is “the earliest and best known type of control chart especially designed to show graphically the relationship between planned performance and actual performance” (Cox *et al*., 1992).

Gantt designed his charts so that foremen and other supervisors not in the planning office could quickly know whether production was on schedule, ahead of schedule, or behind schedule. His charts were improvements to the forms that Taylor developed for the planning office. Notably, he created charts for the personal use of supervisors in a format that they could carry with them at all times (unlike Taylor’s bulletin board, which was useful only when one was near it). Although they were part of Taylor’s broader manufacturing planning system, Gantt charts were meant to help individual managers make better decisions (Wilson, 2003). Gantt gave two principles for his charts: one, measure activities by the amount of time needed to complete them; two, use the space on the chart to represent the amount of the activity that should have been done in that time.

Gantt’s work on charts to help supervisors reflects the view that scheduling is a decision-making process in which schedulers perform a variety of tasks and use both formal and informal information to accomplish these. We call this view the decision making perspective. To perform this process well, schedulers must address uncertainty, manage bottlenecks, and anticipate the problems that people cause (McKay and Wiers, 2004).

Johnson analyzed the properties of an optimal solution and presented an elegant algorithm that constructs an optimal solution. The published paper (Johnson, 1954) not only analyzed the two-stage flow shop scheduling problem (a basic result in the theory of production scheduling) but also considered problems with three or more stages and identified a special case for the three-stage problem.

Jackson (1956) generalized Johnson's results for a two-machine job shop scheduling problem. Smith (1956) considered some single-machine scheduling problems with due dates. Both of these early, notable works cited Johnson's paper and used the same type of analysis. Bellman and Gross (1954) addressed a slightly simplified version with a different approach while employing Johnson's results. Conway *et al.* (1967) describe Johnson's paper as an important influence, as it was "perhaps the most frequently cited paper in the field of scheduling." In particular they noted the importance of its proof that the solution algorithm was optimal. Johnson's paper "set a wave of research in motion" (Dudek *et al.*, 1992).

Johnson's paper epitomizes the problem-solving perspective, in which scheduling is an optimization problem that must be solved. A great deal of research effort has been spent developing methods to generate optimal production schedules, and countless papers discussing this topic have appeared in scholarly journals.

Although there exists a significant gap between scheduling theory and practice (as discussed by Dudek *et al.*, 1992; Portougal and Robb, 2000; and others), researchers have used better problem-solving to improve real-world production scheduling in some settings (see, for instance, Zweben and Fox, 1994; Dawande *et al.*, 2004; Bixby *et al.*, 2006; Newman *et al.*, 2006). It may be that the results of production scheduling theory are applicable in some, but not all, production environments (Portougal and Robb, 2000).

Artificial intelligence (AI) appeared to provide a better basis for modeling and solving the scheduling problem: artificial intelligence research had already achieved significant successes in solving complex problems in a number of scientific fields. In particular, artificial intelligence was expected to be capable of capturing formerly intangible human decision behavior in scheduling.

In Grant (1986), the potential use of artificial intelligence in scheduling is advocated by comparing operations research and artificial intelligence methods in the context of developing a scheduling system for repair job scheduling. Artificial intelligence techniques, by modeling human expertise, turn out to be useful to develop more efficient search strategies than would have been possible with operations research techniques. The applicability of expert systems to job shop scheduling is also investigated by Randhawa & McDowell (1990). The problem of job shop scheduling is described from two perspectives: industry and academia. Industry has generally focused on pragmatic approaches to job shop scheduling, such as Just.In.Time (JIT), Manufacturing Resource Planning (MRP), and Optimized Production Technology (OPT). Academia has attempted to solve the job shop scheduling problem by mathematical approaches or to predict system performance by using simulation. Randhawa and McDowell state that these efforts from academia show that mathematical techniques are not suited for solving real.world problems. They also discuss the potential benefits of artificial intelligence techniques because of the limited applicability of operations research techniques in job shop scheduling. However, from other reports on the applicability of artificial intelligence in scheduling in practice, it can be concluded that the same problems that hampered the implementation of scheduling techniques from operations research in practice, also arise in the application of artificial intelligence to production scheduling. Kathawala & Allen (1993) list a number of existing expert systems for scheduling and mention some issues that should be taken into account when developing expert systems for job shop scheduling. The problem solving domain should be well understood, stable, and not subject to negotiation. Furthermore, human experts should be available and willing to cooperate; they could fear losing their jobs and therefore obstruct expert systems

development. Also, the costs of expert systems, which can become very high, should be carefully evaluated against the potential profits. In Kanet & Adelsberger (1987), the applicability of expert systems to production scheduling is discussed. A state of the art review is given, along with the remark that the area of expert systems in production scheduling is still in its infancy. They indicate that in order to encompass sole mimicking of human scheduling behavior, successful scheduling systems of the future should be able to enumerate more alternatives than a human scheduler can, and be able to learn from experience. This leads to the observation that artificial intelligence not only inherited problems of operations research, but that some additional pitfalls were introduced as well. This is illustrated in the work of Randhawa & McDowell (1990), who indicate that a prerequisite for developing an expert system for production scheduling is the availability of expert knowledge. Unfortunately, this knowledge is dispersed among operators, foremen, supervisors, schedulers, and so on (Patten, 1968). They envisage tackling this problem by simulating the job shop and training experts through simulations.

Research on intelligent scheduling for solving production problems considering real world constraints was initiated by Fox, 1983. In this research, constraints were used for guiding the direction of search to identify the feasible and the optimal schedules. Since then, many researches on constraint-based scheduling have been carried out (Zweben, 1994). The methodologies of intelligent scheduling are classified into two categories: constructive approach and repair approach. The constructive approach achieves a complete schedule gradually from a partial schedule using constraints as guidance (Fox et al, 1989). The repair-based method, on the other hand, starts with a complete schedule and modifies it through iterations towards the optimal solution (Morris, 1990) and (Zweben et al, 1992). Both approaches aim at identifying the optimal schedule considering the demanding constraints through iterative search process. Many advanced computing techniques, including genetic algorithm (Goldberg, 1989), tabu-search (Glover, 1989), etc. can also be employed to improve the efficiency of scheduling, while maintaining the quality of the created schedule.

Hoogeveen et al., (1997) and Lawler et al., (1993) present a review of the main contributions to the area of deterministic scheduling problems, with emphasis on the classical models. Most of the references are on theoretical work, and with respect to setup times, the only references are on sequence-independent batch setup times for the single-machine scheduling problem.

For the single-machine scheduling problems with sequence-independent batch setup times several works have been published where different performance measures are considered.

Bruno and Downey (1978), Monma and Potts (1989), Zdrzalka (1992), Williams and Wirth (1996), Mason and Anderson (1991) and Gupta (1988) discussed single-machine problems. Kim and Bobrowski (1994) present a computer simulation model for a limited machine jobshop scheduling problem with sequence-dependent setup times. They study the influence of setup times and due date's information in priority rules performance for job-shop problem with setup times. Ovacik and Uzsoy (1994) present a family of rolling horizon heuristics to minimize the maximum lateness on a single machine in the presence of sequence-dependent setup times. They also present a survey on the work done on this scheduling problem. Laguna (1997) presents a heuristic procedure to a realistic production and inventory control problem with sequence-dependent setup times. The heuristic is based on a simple short-term tabu search coordinated with a linear programming and traveling salesperson solvers to guide the search. Ríos-Mercado and Bard (1997) present a branch-and-bound enumeration method scheme for the makespan minimization of the flow-shop scheduling problem with sequence-dependent setup times.

Production planning and scheduling for the two-stage parallel flow shop problem is a complicated procedure. Caie et al., (1980) modeled an injection molding production planning problem as a mixed binary integer programming problem, with the objective function defined as the sum of setup costs, holding costs and overtime costs over the planning horizon.

Van Wassenhove and De Bodt (1983) described a case study of injection molding. Using machine mold compatibility, the problem domain is decomposed into five subproblems. Each subproblem is then considered as a single machine problem, which is solved by heuristic procedures of Lambrecht and Vandervcken (1979), and Dixon and Silver (1980), both of which are modified versions of a heuristic proposed by Eisenhut (1975). They all did not consider any shortage or backorder costs. He and Kusiak (1992) discussed three industrial scheduling problems in manufacturing systems. The first problem is the single machine scheduling problem with sequence-dependent setup times and precedence constraints. A mixed integer formulation was proposed. The second problem is a machine cell scheduling problem. A new dispatching rule was developed to minimize the total tool setup time. The third problem is concerned with scheduling laser cutting operations. An integer programming formulation was proposed. Nam and Logendran (1995) analyzed some switching rules for aggregate production planning problems. Based on the net amount of a product to be produced, the rules specify whether the production rate should be high, normal, or medium. The rules give some simple, practical approaches to the managers for decision making, but they are applicable only to single-product problems. Kalpic et al., (1995) described a multi-period, multi-criteria production planning problem in a thermoplastic factory. Two objectives, financial contribution and duration of the longest resource engagement were considered. The model was formulated and solved as a linear programming problem, with proper weights given to the objectives. A goal programming variation was also applied and the two methods were compared. Nagarur et al., (1997) proposed a production planning and scheduling model for injection molding of PVC pipe fittings. The objective is to minimize the total costs of production, inventory, and shortages. A goal programming method is used to generate the solution. Golovin (1997) proposed a linear programming based production scheduling model with an objective function of minimizing the total cost, including cost of setups, holding cost of inventory, production cost and cost of additional resources (overtime). Westenberger and Kallrath (1994) in a cooperational work of Bayer AG and BASF Aktiengesellschaft formulated a typical but generic scheduling problem with the objective to push the development of algorithms for scheduling problems in process industry. Their proposal to establish a working group to develop standardized benchmark problems for planning and scheduling in the chemical industry initiated many research projects and activities. The *Westenberger-Kallrath problem* has been understood as a typical scheduling problem occurring in process industry including the major characteristics of a real batch production process (involving multi-product facilities, multi-stage production, combined divergent and convergent product flows, variable batch sizes, non-preemptive processes, shared intermediates, alternative recipes, flexible proportions of output products, blending processes, sequence and usage dependent cleaning operations ,finite intermediate storage, cyclic material flows, re-usage of carrier substances, and no-wait production for certain types of products) so as to encourage researchers and engineers to test their algorithms and software tools by applying them to this test case.

Integrated vehicle and crew scheduling is an active research area in transportation systems. Cordeau et al., (2001) propose a Benders decomposition scheme to solve aircraft routing and crew scheduling problems. They use a set partitioning formulation for both the aircraft routing and the crew scheduling. In the first scheme, the primal sub problem involves only crew scheduling variables and the master problem involves only aircraft routing variables. Both the primal sub problem and master problem relaxation are solved by column generation. Integer solutions are found by a three-phase method, adding progressively the integrity constraints. More recently, Mercier et al., (2005) have improved the robustness of the proposed model. Their method reverses the Benders decomposition proposed in (2001) by considering the crew scheduling problem as the master problem. Haase and Fridberg (1999) propose a method to solve bus and driver scheduling problems. The problem is formulated as a set partitioning problem with additional constraints in which a column represents either a schedule for a crew or for a vehicle. The additional constraints are introduced to connect both schedule types. A branch-and-price-and-cut algorithm is proposed in which column generation is performed to generate both vehicle and crew schedules. The method is improved in (2001) with a set partitioning formulation only for the driver scheduling problem that incorporates side constraints for the bus itineraries. These side constraints guarantee that a feasible vehicle schedule can be derived afterwards in polynomial time. Furthermore, the inclusion of vehicle costs in this extended crew scheduling formulation ensures the overall optimality of the proposed two phase crew-first, vehicle-second approach. Freling et al., (2003) propose a method to solve bus and driver scheduling problems on individual bus lines. They propose a formulation that mixes the set partitioning formulation for crew scheduling and the assignment formulation for the vehicle scheduling problem. They compute lower bound and feasible solutions by combining Lagrangian relaxation and column generation. Columns correspond to crew scheduling variables. The constraints involving the current columns are relaxed in a Lagrangian way. The obtained Lagrangian dual problem is a single-depot vehicle scheduling problem (SDVSP). Once the Lagrangian relaxation is solved a new set of columns with negative reduced costs is generated. The method is iterated until the gap between the so-computed lower bound and an estimated lower bound is small enough. Feasible solutions are generated from the last feasible SDVSP and the current set of columns.

Specific employee scheduling problems involved in production scheduling are often tackled considering the job schedule is fixed. As a representative work in this area, Valls et al., (1996) consider a fixed schedule in a multi-machine environment and consider the problem of finding the minimal number of workers. The problem is formulated as a restricted vertex coloring problem and a branch and bound algorithm is presented. A large part of work involving both job scheduling and employee timetabling aims at keeping the number of required employees at each time period under a threshold, without considering the regulation constraints of employee schedules nor the individual preferences and skills of employees. Daniels and Mazzola (1994) consider a flow-shop problem in which the duration of an operation depends on the selected mode to process an operation. Each mode defines a number of resources (workers) needed during the processing of the operation. The scheduling horizon is discretized in periods and at each time period; the number of workers cannot exceed a fixed number. Optimal and heuristics approaches are proposed.

Daniels et al., (1996) propose the same approach in a parallel machine context. Baileyet al., (1995) and Alfares and Bailey (1997) propose an integrated model and a heuristic for project task and manpower scheduling where the objective is to find a trade-off between labor cost and daily overhead project cost. The labor cost depends on the number of employed workers at each time period. The daily overhead cost depends on the project duration. There are no machine constraints and the labor restrictions consist in setting a maximal number of workers per period. Faaland and Schmitt (1993) consider an assembly shop with multiple workstations. Each task must be performed on a given workstation by a worker. There are production and late-delivery costs on one hand and labor cost linked to the total number of employees on the other hand. The authors study the benefits of cross-training which allows employees to have requisite skills for several work-centers. A heuristic based on a priority rule and on the shifting bottleneck procedure is proposed.

A more general problem is studied by Daniels et al., (2004). They extend the model proposed in (1994) to an individual representation of employees in a flow-shop environment. Each employee has the requisite skills for only a subset of machines and can be assigned to a single machine at each time period. The duration of a job operation depends on the number of employees assigned to its machine during its processing. The employees assigned to an operation are required during all its processing time. No schedule regulations are considered except unavailability periods. A branch and bound method is developed and the benefit of the level of worker flexibility for makespan minimization is studied.

In (2005), Ha¨ıt et al. propose a general model for integrating production scheduling and employee timetabling, based on the concepts of load center, configuration, employee assignment and sequence. This model allows one to represent the simultaneous work of an employee on several machines. However, the computation method of the job durations performed simultaneously by the same operator is not provided. The authors provide two examples of integrated resolution in a flow-shop context. In the first example, they propose a dynamic programming algorithm to find a feasible path in the configuration graph with a fixed number of equivalent operators and a fixed sequence of jobs. In the second example they propose a heuristic and a lower bound of the makespan in a flow-shop where the timetabling problem is reduced to the assignment of an employee to each machine, the duration of the jobs depending of the employee performance.

Drezet and Billaut (2005) consider a project scheduling problem with human resources and time-dependent activities requirements. Furthermore, employees have different skills and the main legal constraints dictated by the workforce legislation have to be respected. The model is quite general. However, only human resources are considered since the considered context is not a production scheduling problem where machines are critical resources. A tabu search method is proposed as well as proactive scheduling techniques to deal with the uncertainty of the problem.

The economic lot scheduling problem (ELSP) has been extensively studied over 40 years, and more than 100 papers have been published in a variety of journals. The earliest contributions to this problem include Eilon(1957), Rogers (1958) and Hanssmann (1962). A lower bound on the minimum average cost can be easily obtained by taking each product in isolation and calculating economic production quantities, and this approach is known as the independent solution (IS) since it ignores the capacity issue of the sharing of the machine by several products. A tight lower bound has been implicitly suggested by Bomberger (1966), and rediscovered in several different ways by several researchers (Dobson 1987, Gallego and Moon, 1992). The idea is to compute economic production quantities under a constraint on the capacity of a machine. The capacity constraint is that enough time must be made available for set-ups. The problem can be formulated as a non-linear program and easily solved via a line search algorithm. However, the synchronization constraint, stating that no two items can be scheduled to produce at the same time, is ignored. Thus, the value of the non-linear program results in a lower bound on the minimum average cost.

Research on economic lot scheduling problem (ELSP) has focused on cyclic schedules. Moreover, almost all researchers have restricted their attention to cyclic schedules that satisfy the zero switch rule (ZSR). This rule states that a production run for any particular product can be started only if its physical inventory is zero. Counterexamples to the optimality of this rule have been found but are rare (Maxwell 1964, Delporte and Thomas (1978)). If we restrict ourselves to the case that the cycle times for all products must be the same, the problem is a simpler version of the ELSP and known as the common cycle approach. The objective value obtained from this approach serves as the upper bound on the general ELSP. Jones and Inman (1989) and Gallego (1990) showed that this approach works well under certain situations. There are two other approaches for heuristics for the ELSP: the basic period approach and the time-varying lot sizes approach. The basic period approach requires, in addition to the ZSR, that every item must be produced at equally spaced intervals that are multiples of a basic period (this together with the ZSR implies that each item is produced in equal lot sizes). Most of the heuristic algorithms that follow this approach first select the frequency (i.e. number of production runs per cycle) with which each product is to be produced, and then search for a feasible schedule that implements these frequencies (Doll and Wybark 1973). The time-varying lot sizes approach, which relaxes the restriction of equally spaced production runs, was initiated by Maxwell (1964) and Delporte and Thomas (1978). Dobson (1987) showed that any production sequence (i.e. the order in which the products are produced in a cycle) can be converted into a feasible production schedule in which the quantities and timing of production lots are not necessarily equal provided that, beyond the time needed for production, there is sometime available for setups. Dobson also developed a heuristic to generate production frequencies and a sensible production sequence. Near optimal schedules can be obtained by combining Dobson's heuristic with Zipkin's (1991) algorithm which finds the production run times and machine idle times for each product for a given production sequence. Gallego and Roundy (1992) extended the time-varying lot sizes approach to the ELSP which allows backorders. Dobson (1992) extended his earlier work (1987) allowing the set-up time to be sequence dependent. Gallego and Shaw (1997) showed that the ELSP is strongly NP-hard under the time-varying lot sizes approach with or without the ZSR restriction, giving theoretical justification to the development of heuristics.

As pointed out by Silver (1993) in his review, if quantitative models are to be more useful as aids for managerial decision-making, they must represent more realistic problem formulations, particularly permitting some of the usual *givens* to be treated as decision variables. Givens can be defined as the parameters which have been treated as fixed or given, for example, setup time, setup cost, production rate, defective rate, etc. Silver (1993) listed a wide variety of possible improvements to undertake (equivalently, usual givens to change) in manufacturing operations, such as set-up time/cost reduction, higher quality level, controllable production rates, lead time reduction, etc. There is a rapidly growing literature on modelling the effects of changing the givens in manufacturing decisions. In the realm of changing the givens, a variety of modifications on the ELSP have been developed (Silver *et al*., 1998).

Allen (1990) modified the ELSP to allow production rates to be decision variables. He then developed a graphical method for the rates and cycle times for a two-product problem. Silver (1990), Moon *et al*., (1991), Gallego (1993), Khouza (1997), and Moon and Christy (1998) showed that production rate reduction was more profitable for underutilized facilities. Silver (1995) and Viswanathan and Goyal (1997) considered the situation in which a family of products follows a cyclic schedule, but there is a limit on shelf life. The cycle length and production rate are adjusted to ensure a feasible schedule.

Gallego and Moon (1992) examined a multiple product factory that employs a cyclic schedule to minimize holding and set-up costs. When set-up times can be reduced, at the expense of set-up costs, by externalizing internal set-up operations, they showed that dramatic savings are possible for highly utilized facilities. Gallego and Moon (1995) developed an ELSP with the assumptions that set-up times can be reduced by a one-time investment. Hwang *et al*., (1993) and Moon (1994) developed an ELSP in which both set-up reduction and quality improvement can be achieved through investment. More recently, Moon *et al*., (1998) applied the stabilization period concept, in which yield rates gradually increase during the period, to the ELSP.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

The problem of balancing costs of regular and/or overtime production and inventory storage to minimize the total cost of meeting given sales requirements can be set up as a transportation problem. The transportation problem received this name because many of its applications involve determining how to optimally transport goods. However, some of its important applications such as production scheduling/problems actually have nothing to do with transportation. This chapter will focus on the development of an algorithm for solving production problems that has been modelled as a transportation problem.

The production problem involves the manufacturing of a single product, which can either be stored or shipped. The cost of production and the storage cost of each unit of the products are known. Total cost is made up of total production cost plus total storage cost (as total shipping cost is presumed fixed or constant).

Holding cost is the cost of carrying one unit of inventory for one time period. The holding cost usually includes storage cost, insurance cost, taxes on inventory, and a cost due to the possibility of spoilage, theft or obsolescence. The most significant component of the holding is the opportunity cost incurred by tying up capital with inventory.

3.1 Modelling the Problem

The production problem may be modelled as a balanced transportation problem by considering the time periods during which production takes place at sources $S_1, S_2, \ldots, S_m$ and the time periods in which units will be shipped to destinations. The production capacities at source S are taking to be the supplies $a_1, a_2 \ldots a_m$ in a given period i and the demands at the warehouse W_j is d_j.

Let C_{ij} be the production costs per unit during time period i plus the storage cost per unit from time period i until time period j. The problem is to find a production schedule, which will meet all demands at minimum total cost, while satisfying all constraints of productive capacity and demands.

To solve it, let X_{ij} denote the number of units to be produced during time period i from S_i for shipment during time period j to W_j, $i = 1,2 \ldots, n$. Then $X_{ij} \geq 0$ for all i and j.

For each i, the total amount of commodity produced at S_i is $\sum_{j=1}^{n} x_{ij}$.

We consider a set of m supply points from which a unit of the product is produced. But since supply point i can supply at most a_i, units in any given period,

we have $\sum_{j=1}^{n} x_{ij} \leq a_i \qquad i = 1,2, \ldots, m$ (Supply constraints).

We also consider a set of n demand points to which the products is shipped. Since demand point's j must receive at least d_j units of the shipped products.

We have $\sum_{i=1}^{m} x_{ij} \leq d_j \qquad j = 1,2, \ldots, n$ (Demand constraints)

Since units produced cannot be shipped prior to being produced, C_{ij} is prohibitively large for $i>j$ to force the corresponding X_{ij} to be zero, or if shipment is impossible between a given source and destination, a large cost of M is entered.

The total cost of production is given as $\sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$

The general formulation of a production problem is:

Minimize $\sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$

Subject to $\sum_{j=1}^{n} x_{ij} \leq a_i$ $\quad i = 1, 2, \ldots, m$ (Supply constraints)

$\sum_{i=1}^{m} x_{ij} \leq d_j$ $\quad j = 1, 2, \ldots, n$ (Demand constraints)

$X_{ij} \geq 0,$ $\quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$

Since the production problem is a linear programming problem, it can be solved by simplex methods but because of its special nature, it can be solved more easily by special forms of the simplex methods, which are more efficient for the production problem than the main simplex methods.

3.2 The Balanced Problem

From the supply and demand constraints, If $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} d_j$, then total supply equals total demand and the problem is said to be a balanced production problem.

If $\sum_{i=1}^{m} a_i \geq \sum_{j=1}^{n} d_j$, then the problem is said to be an unbalanced production problem.

As stated earlier, the special algorithm works well for the balanced problem. Therefore, the unbalanced problem can always be modelled as an equivalent balanced problem to which the special method can be applied.

In a balanced production problem, all the constraints must be binding. If any supply constraints were not binding, then the remaining available products would not be sufficient to meet all demands. Hence, the balanced production problem may be written as:

Minimize $\sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$

Subject to $\sum_{j=1}^{n} x_{ij} = a_i$ $\quad i = 1, 2, \ldots, m$ (Supply constraints)

$\sum_{i=1}^{m} x_{ij} = d_j$ $\quad j = 1, 2, \ldots, n$ (Demand constraints)

$X_{ij} \geq 0,$ $\quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$

It is relatively simple to find a basic feasible solution from a balanced production problem. Also, simplex pivots for these problems do not involve multiplication, but reduced to additions and subtraction. For these reasons, it is desirable to formulate a production problem as a balanced production problem. The balanced production problem is specified by the supply, demand and production cost, so the relevant data can be represented in a parameter table in the format of Table 3.1. Since this is a minimization problem, the numbers in the upper right corners in each cell is the unit cost, not revenue. The quantities produced are shown on the right rows whiles demand is shown along the columns.

Table 3.1 :

			Destination			
Source	W_1	W_2		. . .	W_n	Supply
S_1	C_{11} X_{11}	C_{12} X_{12}	C_{13} X_{13}	. . .	C_{1n} X_{1n}	a_1
S_2	C_{21} X_{21}	C_{22} X_{22}	C_{23} X_{23}	. . .	C_{2n} X_{2n}	a_2
S_3	C_{31} X_{31}	C_{32} X_{32}	C_{33} X_{33}	. . .	C_{3n} X_{3n}	a_3
. . .						. . .
S_m	C_{m1} X_{m1}	C_{m2} X_{m2}	C_{m3} X_{m3}	. . .	C_{mn} X_{mn}	a_m
Demand	d_1	d_2			d_n	

(a) It is observed that:

(i) The coefficient of each variable X_{ij} in each constraint is either 1or 0

(ii) The constant on the right hand side of each constraint is an integer

(iii) The coefficient matrix A has a certain pattern of 1's and 0's

It can be shown that any linear programming problem with these properties above satisfies the following: thus, if the problem has a feasible solution, then there exist feasible solutions in which all the variables are integers. It is this property on which the modification of the simplex method that provides efficient solution algorithms is based.

(b) The (m+n) conditions;

$$\sum_{j=1}^{n} x_{ij} = a_i \qquad i=1,2, \ldots,m$$

$$\sum_{i=1}^{m} x_{ij} = d_j \qquad j=1,2, \ldots, n$$

are dependent since $\sum_{i=1}^{m} a_i = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} = \sum_{j=1}^{n} d_j$

Thus the effective number of constraints on the balanced production problem is (m+n-1). We therefore expect a basic feasible solution of the balanced production problem to have (m+n-1) non- negative entries.

3.3 The Unbalanced Problem

Considering the following production problem:

Minimize $\sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$

Subject to

$$\sum_{j=1}^{n} x_{ij} \leq a_i \qquad i=1,2,\ldots, m \quad \text{(Supply constraints)}$$

$$\sum_{i=1}^{m} x_{ij} \leq d_j \qquad j=1,2, \ldots, n \quad \text{(Demand constraints)}$$

$$X_{ij} \geq 0, \qquad i=1,2,\ldots, m \text{ and } j=1,2,\ldots,n$$

The unbalanced problem occurs when $\sum_{i=1}^{m} a_i \neq \sum_{j=1}^{n} d_j$.

3.3.1 Balancing a Production Problem If Total Supply Exceeds Total Demand

If total supply exceeds total demand, we can balance a production problem by creating a dummy demand point W_F that has a demand equal to the amount of excess supply. Since unit cost of each source or shipments to the dummy demand point are not real shipments, they are assigned a cost of zero. Shipments to the dummy demand point indicate an unused supply capacity. This is illustrated in the table below.

Table 3.2

Source	W_1	W_2		W_n	Dummy W_F	Supply
S_1	C_{11}	C_{12}	. . .	C_{1n}	0	a_1
S_2	C_{21}	C_{22}	. . .	C_{2n}	0	a_2
.						.
.						.
S_m	C_{m1}	C_{m2}	. . .	C_{mn}	0	a_m
Demand	d_1	d_2	. . .		d_n	

3.3.2 Balancing a Production Problem If Total Supply Is Less than Total Demand

If total supply is less than total demand, we balance the production problem by creating a factious source S_F whose capacity is strictly the excess of demand over supply and that the unit cost from source to every warehouse is zero. This is illustrated in the table below:

Table 3.3 Destination

Source	W_1	W_2	. . .	W_F	Supply
S_1	C_{11}	C_{12}	. . .	C_{1n}	a_1
S_2	C_{21}	C_{22}	. . .	C_{2n}	a_2
.					.
.					.
S_m	C_{m1}	C_{m2}	. . .	C_{mn}	a_m
S_F	0	0	. . .	0	
Demand	d_1	d_2	. . .	d_n	

3.4 Finding an Initial Basic Feasible Solution

Three methods can be used to find the initial basic feasible solution for a balanced transportation problem. These are;

1. Northwest Corner Methods.
2. Minimum or Least Cost Methods.
3. Vogel's Approximation Methods.

The solution obtained under each of the three methods is not optimal.

3.4.1 The North West Corner Rule for finding an initial basic feasible solution

In this method, we choose the entry in the upper left hand corner (Northwest corner) of the transportation tableaus, i.e the shipment from source 1 to warehouse 1. Use this to supply as much of the demand at W_1 as possible. Record the shipment with a circled number in the cell.

If the supply at S_1 is not used up by the allocation use the remaining supply to fill the remaining demands at W_2, W_3,.... In that order until supply at S_1 is used up, record all shipments in circles in appropriate cells. When one supply is used up, go to the next supply and start filling the demands beginning with the first warehouse in that row, where there is still a demand unfilled, recording in circled numbers all allocations.

In certain cases, a degenerate situation arises and the solution is not a BFS because it has fewer than (m+n-1) cells in the solution. This occurs because at some point during the allocation when a supply is used up, there is no cell with unfulfilled demand in the column. In the non-degenerate case, until the end, whenever a supply is used up, there is always an unfulfilled demand in the column.

The northwest corner method still yields a BFS even in the case of degeneracy, if it is modified as follows: having obtained a solution which is not basic, choose some empty cells and add the solution with circled zeros in them to produce a BFS, i.e,

(i) The total number of cells with allocations should be (m+n-1)

(ii) There should be no circuits among the cells of the solution.

3.4.2 Least Cost Method

The Northwest Corner method does not utilize production cost per unit, so it can yield an initial basic feasible solution that has a very high production cost. Then determining an optimal solution may require several pivots or iterations. The minimum cost method uses the production costs in an effort to produce a basic feasible solution that has a lower total cost. Fewer pivots or iterations will then be required to find the problem's optimal solution.

Under the Minimum Cost Method, we find the variable with the smallest or least unit cost (call it X_{ij}). Then assign X_{ij} the largest possible value, min (a_i d_j). Cross out row i and column j and reduce the supply or demand of the non-crossed out row or column by the value of X_{ij}. We then choose from the cells that do not lie in a crossed-out row or column, the cell with the next minimum unit cost and repeat the procedure, without violating any of the supply and demand constraints.

We continue until there is only one cell that can be chosen. In this case, cross out both cell's row and column. With the exception of the last variable, if a variable satisfies both a supply and demand constraints, only cross out a row or a column, not both.

Since the Minimum Cost Method chooses variables with small costs to be basic variables, it does not always yield a basic feasible solution with a relatively low total production cost. In certain cases the Minimum Cost Method compels one to choose a basic variable with relatively high shipping cost. Thus the Minimum Cost Method would yield a costly basic feasible solution. Vogel's Approximation Method for finding a basic feasible solution usually avoids extremely high shipping cost.

3.4.3 Vogel's Approximation Method

Begins by computing for each row and column, a "penalty" equal to the difference between the smallest costs in the row and column and the second smallest. Row penalties are shown along the right of each row and column penalties are shown below each column. Next we find the row or column with the largest penalty. The method is a variant of the least cost method and based on the idea that if for some reason, the allocation cannot be made to the least unit cost cell via row or column then, it is made to the next least cost cell in that row or column and the appropriate penalty paid for not being able to make the best allocation.

We choose the cell with the greatest row and column penalties. Allocate as much to this cell as the row supply or column demand will allow. This means either a supply is exhausted or a demand is satisfied. In either case, delete the row of the exhausted supply or the column of the satisfied demand. We re-compute new penalties (using only cells that do not lie in a crossed-out row or column), and repeat the procedure until only one uncrossed cell remains. We set this variable equal to the supply or demand associated with the variable, and cross out the variable's row and column, A BFS has now been obtained.

NB, The Vogel's Approximation Method provides a BFS which is close to optimal or is optimal and thus performs better than the Northwest Corner or the Minimum Cost Method.

Unlike the Northwest Corner Method, Vogel's Approximation Method may lead to an allocation with fewer than (m+n-1) non-empty cells even in the non-degenerate case. To obtain the right number of cells in the solution, we add enough zero entries to empty cells, avoiding the generation of circuits among the cells in the solution.

Of the three methods discussed, the Northwest Corner method requires the least effort and Vogel's method requires the most effort. Extensive research (Glover et al, 1974) has shown that when Vogel's method is used to find an initial basic feasible solution, it usually takes substantially fewer pivots or iterations than the other two methods. For this reason, the Northwest Corner and the Minimum or Least Cost methods are rarely used to find a basic feasible solution to a large production problem.

3.5 Improving solution to optimality

The solutions obtained under the three methods are feasible, but not optimal. To obtain optimality, we improve on these solutions using two methods. These are:

(i) The Steppingstone Method

(ii) The Modified Distribution Method (MODI)

3.5.1 The Steppingstone Method

Suppose that we have a basic feasible solution, consisting of non-negative allocations in (m+n-1) cells, we call the cells which are not in the basic feasible solution unoccupied cells. Then for each unoccupied cell, a unique circuit begins and ends the cell, consisting of that unoccupied cell and other cells all of which are occupied such that each row or column in the tableau either contains two or none of the cells of the circuit.

3.5.1.1 Test for optimality

To test the current basic feasible solution for optimality, we take each of the unoccupied cells in turns and place one unit allocation in it. This is indicated by just the sign "-" and "+". Following the unique circuit containing this cell as described above place alternately the signs "-" and "+" until all the cells of the circuit are covered. Knowing the unit cost of each cell, we compute the total change in cost produced by allocation of one unit in the empty cell and the corresponding placements in the other cells of the circuit.

This change in cost is called improvement index of the unoccupied cell. If the improvement index of each unoccupied cell in the given basic feasible solution is nonnegative then the current basic feasible solution is optimal since every reallocation increases the cost. If there is at least one unoccupied cell with a negative improvement index then a reallocation to produce a new basic feasible solution with a lower cost is possible and so the current basic feasible solution is not optimal. Thus the current basic feasible solution with a lower cost is possible and so the current basic feasible solution is not optimal. Thus the current basic feasible solution is optimal if and only each unoccupied cell has a non-negative improvement index.

3.5.1.2 Improvement to optimality

If there exist at least one unoccupied cell in a given basic feasible solution which has a negative improvement index, then, the basic feasible solution is not optimal.

To improve on this solution, we find the unoccupied cell with the most negative improvement index of say N using the circuit that was used in the calculation of its improvement index, find the smallest allocation in the cells of the circuit with sign " - ". Call this smallest allocation k. Subtract k from the allocations in all the cells in the circuit with the sign "-" and add it to all the allocations in the cells in the circuit with the sign "+". This has the effect of satisfying the constraints on demand and supply in the transportation tableau. Since the cell which carried the allocation k now has a zero allocation, it is deleted from the solution and is replaced by the cell in the circuit which was originally unoccupied and now has an allocation k. The result of each reallocation is new basic feasible solution. The cost of this new basic feasible solution in

N is less than the cost of the previous basic feasible solution. This new basic feasible solution is tested for optimality and the whole procedure repeated until an optimal solution is attained.

3.5.2 The Modified Distribution Method (MODI)

Consider the balanced production problem below:

Table 3.5

	Warehouse				
Source	W_1	W_2		W_n	Supply
S_1	C_{11} X_{11}	C_{12} X_{12}	. . .	C_{1n} X_{1n}	a_1
S_2	C_{21} X_{21}	C_{22} X_{22}	. . .	C_{2n} X_{2n}	a_2
S_3	C_{31} X_{31}	C_{32} X_{32}	. . .	C_{3n} X_{3n}	a_3
.	.	.		.	
.	.	.	. . .	.	
.					
S_m	C_{m1} X_{m1}	C_{m2} X_{m2}	. . .	C_{mn} X_{mn}	a_m
Demand	d_1	d_2	. . .	d_n	

Assuming an initial basic feasible solution is obtained. Then (m+n-1) cells are occupied.

3.5.2.1 Test for optimality

For each occupied cell (i,j) of the transportation tableau, compute a row index u, and column index V_j such that $C_{ij}=U_i-V_j$. Since there are (m+n-1) occupied cells, it follows that there are m+n-1 of these equations. Since there are (m+n) row and column indices altogether, it follows that by prescribing any arbitrary value for one of them, say U = 0, we then solve the equations for the remaining (m+n-1) unknowns U_i, V_j. With all the U_i, V_j known, we compute for each unoccupied cell such that the evaluation factor $e_{st} = C_{st} - u_s - v_t$

It can be shown that the evaluation factors are the relative cost factors corresponding to the non-basic variables when the simplex method is applied to the transportation problem. Hence the current basic feasible solution is optimal if and only if $e_{st} \geq 0$ for all unoccupied cells (s,t), since the production problem is a minimization problem. If there are unoccupied cells with negative evaluation factors, then current basic feasible solution is not optimal and needs to be improved.

3.5.2.2 Improvement to optimality

To improve the current non-optimal basic feasible solution we find the unoccupied cell with the most negative evaluation factor, construct its circuit and adjust the values of the allocation in the cells of the circuit in exactly the same way as was done in the steppingstone method. This yields a new basic feasible solution. With a new basic feasible solution available, the whole process is repeated until optimality is attained.

3.5.2.3 Remark

The fact that the circuit is not constructed for every unoccupied cell makes the Modified distribution Method (MODI) more efficient than the Steppingstone Method. In fact the Modified Distribution Method (MODI) is currently the most efficient method of solving the production problem.

3.6 Summary

In this chapter, we considered the modelling of the production problem into transportation problem for easy computation. The next chapter will focus on analyzing the expected demands, inventory and regular production and overtime capacities for the year. Here, an excel solver will then be used to find the optimal production schedule.

CHAPTER FOUR

DATA COLLECTION AND ANALYSIS

4.0 INTRODUCTION

Tex Styles Ghana Limited develops, manufactures and sells innovative, high quality industrial and consumer related textile products throughout the world. It produces African wax prints based on orders from its registered customers. Orders that are released into production have to be translated into jobs with associated due dates. These jobs often have to be processed on the machines in a workcenter in a given order or sequence. The processing of jobs may sometimes be delayed if certain machines are busy. Pre-emption's may occur when high priority jobs are released which have to be processed at once. Unexpected events on the shopfloor, such as machine breakdowns or longer-than-expected processing times, also have to be taken into account, since they may have a major impact on the schedules. Developing, in such an environment, a detailed schedule of the tasks to be performed helps maintain efficiency and control of operations.

This chapter will focus on computational procedure, data analysis and finding of an optimal schedule.

4.1 Computational Procedure and Data Analysis

Table 4.1 shows the company's production capacities (regular and overtime) and expected demands (in yards) for wax prints from January – December 2009.

Table 4.1: Expected demand and capacity data for TexStyle Ghana Ltd - 2009

Month	Wax Demand(yd)	Regular Capacity(yd)	Overtime Capacity(yd)
January	1495611	1683184	504955
February	1230950	1208030	362409
March	1345640	1087640	326292
April	1068151	1160600	348180
May	1254992	1249488	374846
June	658903	630000	189000
July	1462292	1555854	915756
August	1341200	1522600	456780
September	1316404	1560869	468261
October	1476694	1216158	364847
November	1483179	1533468	460040
December	1209576	1342158	402647

Inventory/Work In Progress (WIP) at the beginning of January 2009 = 155439 yards

The production manager decides on how much should be produced based on the demands taking into consideration the plant capacities. Production is carried out throughout the day (24 hours) in three (3) shifts made up of eight (8) hours per shift. Goods produced cannot be allocated prior to being produced and also, goods produced in a particular month are allocated to the demands in the month ahead. Regular production cost per yard is GH₵ 2.1 and the overtime cost per yard is GH₵ 2.5.

Units produced on regular shifts are not available for shipments during production; they are generally sold during the next month. Unit produced during overtime shifts must be used to meet demands in the same month as produced.

Production takes place at both regular and overtime shifts for each of the twelve months. Each of these months is a source. A thirteenth source is added, i.e. the WIP, since it can also be used to satisfy demand.

Any unused capacity will be shipped to the dummy demand point. Dummy demands are only created to balance the production problem and so all their allocations do not count. To ensure that no goods are used to meet demand during a month prior to their production, a prohibitively large cost (say GH₵ 10,000) is assigned to any cell that corresponds to using a regular production to meet demand for a current or an earlier (or previous) month. In the same way, since units produced during overtime must be used to meet demands in the same month as produced, a prohibitively large cost is also assigned to a cell that corresponds to using overtime production to meet next month's demand.

It was noticed that the company incurred a regular production cost of GH₵31,150,000 and an overtime cost of GH₵13,350,000 giving a total production cost of GH₵ 44,500,000 for producing 15,343,592 yards of wax prints for the period. In view of the huge cost incurred by the company, the production tableau was modelled as a transportation problem in order to minimize the total cost of production whilst satisfying demand.

Scheduling formulation

The formulation takes into account the unit cost of production, C_{ij}, the supply at a_i at source S_i and the demand d_j at destination for $i \in$ (1,2, …,25) and $j \in$ (1,2, … 12). The problem is:

Minimize $\sum_{i=1}^{25} \sum_{j=1}^{12} c_{ij} x_{ij}$

Subject to: $\sum_{j=1}^{12} x_{ij} \leq a_i$ i = 1, 2… 25 (Supply constraints)

$\sum_{i=1}^{25} x_{ij} \leq d_j$ j = 1, 2… 12 (Demand constraints)

The objective is to determine the amount of x_{ij} allocated from source i to a destination j such that the total production cost $\sum_{i=1}^{25}\sum_{j=1}^{12} c_{ij}x_{ij}$ is minimized.

Thus, we minimize:

$$Z = \sum_{i=1}^{25}\sum_{j=1}^{12} c_{ij}x_{ij}$$

Subject to the following supply constraints (regular and overtime capacity):

$$x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} + x_{18} + x_{19} + x_{1,10} + x_{1,11} + x_{1,12} \le 155439$$

$$x_{21} + x_{22} + x_{23} + x_{24} + x_{25} + x_{26} + x_{27} + x_{28} + x_{29} + x_{2,10} + x_{2,11} + x_{2,12} \le 1683184$$

$$x_{31} + x_{32} + x_{33} + x_{34} + x_{35} + x_{36} + x_{37} + x_{38} + x_{39} + x_{3,10} + x_{3,11} + x_{3,12} \le 1208030$$

$$x_{41} + x_{42} + x_{43} + x_{44} + x_{45} + x_{46} + x_{47} + x_{48} + x_{49} + x_{4,10} + x_{4,11} + x_{4,12} \le 1087640$$

$$x_{51} + x_{52} + x_{53} + x_{54} + x_{55} + x_{56} + x_{57} + x_{58} + x_{59} + x_{5,10} + x_{5,11} + x_{5,12} \le 1160600$$

$$x_{61} + x_{62} + x_{63} + x_{64} + x_{65} + x_{66} + x_{67} + x_{68} + x_{69} + x_{6,10} + x_{6,11} + x_{6,12} \le 1249488$$

$$x_{71} + x_{72} + x_{73} + x_{74} + x_{75} + x_{76} + x_{77} + x_{78} + x_{79} + x_{7,10} + x_{7,11} + x_{7,12} \le 630000$$

$$x_{81} + x_{82} + x_{83} + x_{84} + x_{85} + x_{86} + x_{87} + x_{88} + x_{89} + x_{8,10} + x_{8,11} + x_{8,12} \le 1555854$$

$$x_{91} + x_{92} + x_{93} + x_{94} + x_{95} + x_{96} + x_{97} + x_{98} + x_{99} + x_{9,10} + x_{9,11} + x_{9,12} \le 1522600$$

$$x_{10,1} + x_{10,2} + x_{10,3} + x_{10,4} + x_{10,5} + x_{10,6} + x_{10,7} + x_{10,8} + x_{10,9} + x_{10,10} + x_{10,11} + x_{10,12} \le 1560869$$

$$x_{11,1} + x_{11,2} + x_{11,3} + x_{11,4} + x_{11,5} + x_{11,6} + x_{11,7} + x_{11,8} + x_{11,9} + x_{11,10} + x_{11,11} + x_{11,12} \le 1216158$$

$$x_{12,1} + x_{12,2} + x_{12,3} + x_{12,4} + x_{12,5} + x_{12,6} + x_{12,7} + x_{12,8} + x_{12,9} + x_{12,10} + x_{12,11} + x_{12,12} \le 1533468$$

$$x_{13,1} + x_{13,2} + x_{13,3} + x_{13,4} + x_{13,5} + x_{13,6} + x_{13,7} + x_{13,8} + x_{13,9} + x_{13,10} + x_{13,11} + x_{13,12} \le 1342158$$

$$x_{14,1} + x_{14,2} + x_{14,3} + x_{14,4} + x_{14,5} + x_{14,6} + x_{14,7} + x_{14,8} + x_{14,9} + x_{14,10} + x_{14,11} + x_{14,12} \le 504955$$

$$x_{15,1} + x_{15,2} + x_{15,3} + x_{15,4} + x_{15,5} + x_{15,6} + x_{15,7} + x_{15,8} + x_{15,9} + x_{15,10} + x_{15,11} + x_{15,12} \le 362409$$

$$x_{16,1} + x_{16,2} + x_{16,3} + x_{16,4} + x_{16,5} + x_{16,6} + x_{16,7} + x_{16,8} + x_{16,9} + x_{16,10} + x_{16,11} + x_{16,12} \leq 326292$$

$$x_{17,1} + x_{17,2} + x_{17,3} + x_{17,4} + x_{17,5} + x_{17,6} + x_{17,7} + x_{17,8} + x_{17,9} + x_{17,10} + x_{17,11} + x_{17,12} \leq 348180$$

$$x_{18,1} + x_{18,2} + x_{18,3} + x_{18,4} + x_{18,5} + x_{18,6} + x_{18,7} + x_{18,8} + x_{18,9} + x_{18,10} + x_{18,11} + x_{18,12} \leq 374846$$

$$x_{19,1} + x_{19,2} + x_{19,3} + x_{19,4} + x_{19,5} + x_{19,6} + x_{19,7} + x_{19,8} + x_{19,9} + x_{19,10} + x_{19,11} + x_{19,12} \leq 189000$$

$$x_{20,1} + x_{20,2} + x_{20,3} + x_{20,4} + x_{20,5} + x_{20,6} + x_{20,7} + x_{20,8} + x_{20,9} + x_{20,10} + x_{20,11} + x_{20,12} \leq 915756$$

$$x_{21,1} + x_{21,2} + x_{21,3} + x_{21,4} + x_{21,5} + x_{21,6} + x_{21,7} + x_{21,8} + x_{21,9} + x_{21,10} + x_{21,11} + x_{21,12} \leq 456780$$

$$x_{22,1} + x_{22,2} + x_{22,3} + x_{22,4} + x_{22,5} + x_{22,6} + x_{22,7} + x_{22,8} + x_{22,9} + x_{22,10} + x_{22,11} + x_{22,12} \leq 468261$$

$$x_{23,1} + x_{23,2} + x_{23,3} + x_{23,4} + x_{23,5} + x_{23,6} + x_{23,7} + x_{23,8} + x_{23,9} + x_{23,10} + x_{23,11} + x_{23,12} \leq 364847$$

$$x_{24,1} + x_{24,2} + x_{24,3} + x_{24,4} + x_{24,5} + x_{24,6} + x_{24,7} + x_{24,8} + x_{24,9} + x_{24,10} + x_{24,11} + x_{24,12} \leq 460040$$

$$x_{25,1} + x_{25,2} + x_{25,3} + x_{25,4} + x_{25,5} + x_{25,6} + x_{25,7} + x_{25,8} + x_{25,9} + x_{25,10} + x_{25,11} + x_{25,12} \leq 402647$$

And the following demand constraints:

$$x_{11} + x_{21} + x_{31} + x_{41} + x_{51} + x_{61} + x_{71} + x_{81} + x_{91} + x_{10,1} + x_{11,1} + x_{12,1} \leq 1495611$$

$$x_{12} + x_{22} + x_{32} + x_{42} + x_{52} + x_{62} + x_{72} + x_{82} + x_{92} + x_{10,2} + x_{11,2} + x_{12,2} \leq 1230950$$

$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} + x_{63} + x_{73} + x_{83} + x_{93} + x_{10,3} + x_{11,3} + x_{12,3} \leq 1345640$$

$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} + x_{64} + x_{74} + x_{84} + x_{94} + x_{10,4} + x_{11,4} + x_{12,4} \leq 1068151$$

$$x_{15} + x_{25} + x_{35} + x_{45} + x_{55} + x_{65} + x_{75} + x_{85} + x_{95} + x_{10,5} + x_{11,5} + x_{12,5} \leq 1254992$$

$$x_{16} + x_{26} + x_{36} + x_{46} + x_{56} + x_{66} + x_{76} + x_{86} + x_{96} + x_{10,6} + x_{11,6} + x_{12,6} \leq 658903$$

$$x_{17} + x_{27} + x_{37} + x_{47} + x_{57} + x_{67} + x_{77} + x_{87} + x_{97} + x_{10,7} + x_{11,7} + x_{12,7} \leq 1462292$$

$$x_{18} + x_{28} + x_{38} + x_{48} + x_{58} + x_{68} + x_{78} + x_{88} + x_{98} + x_{10,8} + x_{11,8} + x_{12,8} \leq 1341200$$

$$x_{19} + x_{29} + x_{39} + x_{49} + x_{59} + x_{69} + x_{79} + x_{89} + x_{99} + x_{10,9} + x_{11,9} + x_{12,9} \leq 1316404$$

$$x_{1,10} + x_{2,10} + x_{3,10} + x_{4,10} + x_{5,10} + x_{6,10} + x_{7,10} + x_{8,10} + x_{9,10} + x_{10,10} + x_{11,10} + x_{12,10} \leq 1476694$$

$$x_{1,11} + x_{2,11} + x_{3,11} + x_{4,11} + x_{5,11} + x_{6,11} + x_{7,11} + x_{8,11} + x_{9,11} + x_{10,11} + x_{11,11} + x_{12,11} \leq 1483179$$

$$x_{1,12} + x_{2,12} + x_{3,12} + x_{4,12} + x_{5,12} + x_{6,12} + x_{7,12} + x_{8,12} + x_{9,12} + x_{10,12} + x_{11,12} + x_{12,12} \leq 1209576$$

Using Excel Solver to obtain the BFS and the optimal solution

Excel solver shall be used to find the solution to the scheduling formulation. Excel solver is a windows package which can be used to obtain the optimal solution to a production scheduling problem. Before using the Excel solver, an initial table is created. This is shown in Table 4.2.

Each cell in Table 4.2 contains the cost per unit of the product plus the storage cost but in this study, the storage cost is zero since production is strictly based on order from the customer. For example, in the i.e., C_{11} the cost is 2.1. A high cost of 10000 is put in cells where production is not feasible. For example, in the cellC_{21}, the cost is 10000. This is because one cannot produce in the month of February to meet a demand in January and so a high cost is allocated to that effect.

For a solution to the production problem to exist, the total demand should be equal to the total supply. The total supply according to Table 4.2 is 15905488 and the total demand is 15343592. Since the total supply is greater than the total demand, a dummy or fictitious demand of 561896 (i.e., 15905488-15343592) is created to balance the production problem with a cost per unit of zero.

The IBFS and the optimal solution to the problem are shown in Table 4.3.The IBFS gives the initial allocations of production resources necessary to meet a given demand. Each cell (usually called the occupied cell) contains the respective allocations for each of the periods during the financial year. A cell with no allocation is called an unoccupied cell or an empty cell. The optimal solution gives the allocations which will minimize the total cost of production.

4.2 Findings

All constraints and optimality conditions were satisfied and a solution was found. The following findings were observed after the analysis:

- 1,340,172 yards produced in December (regular shift) and the WIP of 155,439yards was used to satisfy the demand for January.
- The regular shift production of 1,230,950yards in January was fully used to supply the demand for February without any overtime.
- The demand for March was satisfied by the regular shift production of 1,208,030yards and overtime production of 137,610yards.
- Demand for April was met by the regular shift production of 751,541yards and overtime production of 316,610yards in March.
- 918,893yards production in regular shift and 336,099yards overtime in April was used to clear the demand for the month of May.
- In May there was no overtime production. About 57% plant capacity for the month was used for annual preventive maintenance. All 658,903yards produced was used to meet the demand for June.
- A huge overtime production of 832,292yards due to shortfall in May and a regular shift production of 630,000yards were used to offset the demand for July.
- The demand for August was met by all 1,341,200yards regular shift production.
- There were no overtime productions in August and September. All 1,316,404yards and 1,476,694yards produced in regular shift were used to satisfy the demand for September and October respectively.

- An overtime production of only 267,021yards and normal shift production of 1,216,158yards was used to satisfy the huge demand (1,483,179yards) in November.

- The demand for December was met by 971,572yards production in normal shift and 238,004yards overtime production.

- Overtime productions in February, June, August, September and October could not have been necessary to meet the demand for the year.

- The optimal solution gave the final total cost of production and is thus:

$2.1(1230950 + 1208030 + 751541 + 918893 + 658903 + 630000 + 1341200 + 1316404 + 1476694 + 1216158 + 971572 + 1340172\,) + 2.5(137610 + 316610 + 336099 + 832292 + 267021 + 238004) = 32746176$

- The company could have reduced total production cost by GH¢11,753,824.3 (26.41%) going by the model.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The application of the model showed how the monthly allocations should be done in order to reduce the cost of production. It also showed which months the stocks available should be allocated to so that they do not pile up unnecessarily.

From the findings, it's been evident that efficient scheduling could reduce production and inventory cost whilst satisfying customer demands. The demand and supply at each level were determined using the Excel Solver.

The company was able to reduce total production cost by 26.41% (GH¢11,753,824.3) resulting in the reduction of labour and raw-material cost. The due date and throughput times were achieved as unnecessary overtime and the time orders spent in the system was minimized.

Computer- based scheduling could help manufacturers to easily attend to customers' orders, improve on-time delivery and create realistic schedules. This confirms the fact that computerized scheduling tools outperform older manual scheduling tools.

The analysis also suggests that production scheduling and control can facilitate the production processes in a number of ways. Production scheduling can result in optimum utilization of capacity. Companies, with the help of production scheduling could schedule their production in a way to ensure that production capacities such as employees and machinery do not remain idle, they should be fully utilized.

Overtime production for certain periods were not necessary. The company could have achieved demands irrespective of some overtimes. This suggests that the company should not necessarily maintain a large working or labour force for its production activities. Overtime should only be carried out when it is to meet specific urgent orders. Companies pay quite higher wages to workers engaged in overtime production, therefore ensuring optimum utilization of human and plant capacities during regular production would result in a lot of savings for the company.

To a large extent, a certain level of inventory is necessary for production since that could be used to supplement some demand.

A good production scheduling ensures quality in terms of processes, products and packaging.

It can be ascertained that production scheduling and control is of immense importance to every production firm in terms of capacity utilization, inventory control and more importantly, improving the company's response to time and quality. As such, effective production scheduling and control contributes to time, quality and cost parameters of a company's success. Companies would reap a lot of savings if they could incorporate this type of scheduling in their production activities.

It is therefore recommended that companies especially, production firms should employ the usage of the transportation model to achieve optimum level production at a minimum cost.

REFERENCES

Adelsberger, H., Kanet, J., (1991). The Leitstand - a new tool for computer integrated Manufacturing, Production and Inventory Management Journal, 32(l), pp. 43-48.

Alfares, H., Bailey, J., (1997). Integrated project task and manpower scheduling. IIE Transactions, 29, pp. 711–717.

Allen, S. J., (1990). Production rate planning for two products sharing a single process facility: a Real World Case Study. Production and Inventory Management, **31**, pp. 24-29.

Amponsah, S. K., (2010). Lecture notes, Optimization Techniques I, Institute of Distance Learning, Department of Mathematics, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Amponsah, S.K., Ofosu, J.B., and Opoku-Sarkodie R.,(2011). Optimum production scheduling for a beverage firm based in Accra. Department of Mathematics Kwame Nkrumah University of Science and Technology, Kumasi Ghana. Research Journal of Applied Sciences, Engineering and Technology 3(2), pp.74-80.

Artigues, C., Gendreau, M., Rousseau, L., and Vergnaud, A., (2006). Solving an integrated employee timetabling and job-shop scheduling problem via hybrid branch-and bound.Technical Report 06700, Universit´e de Toulouse, LAAS-CNRS, Toulouse, France

Baker, K. R., (1974). Introduction to sequencing and scheduling, Wiley, New York.

Bailey, J., Alfares, H., Lin, W., (1995). Optimization and heuristic models to integrate project task and manpower scheduling. Computers and Industrial Engineerings, 29, pp. 473–476.

Baptiste, P., Pape, C. L., (1996). Disjunctive constraints for manufacturing scheduling: principles and extensions. International Journal of Computer Integrated Manufacturing, 9, pp. 306–310. Baptiste, P., Pape, C. L., Nuijten, W., (2001). Constraint-based scheduling, Kluwer, Dordrecht.

Bellman and Richard, (1956). Mathematical aspects of scheduling theory, Journal of the

Society for Industrial and Applied Mathematics, 4(3), pp. 168-205.

Bellman, Richard, and Oliver Gross, (1954). Some combinatorial problems arising in the theory of multi-stage processes," Journal of the Society for Industrial and Applied Mathematics, 2(3), pp. 175-183.

Binsse, H.L., (1887). A short way to keep time and cost, Transactions of the American Society of Mechanical Engineers, pp. 380-386.

Bodin, L., Golden, B., Assad, A., and Ball, M., (1983). Routing and scheduling of vehicles and crews the state of the art. Computers and Operations Research, 10, pp. 63–211.

Boctor, F., (1987). The G-group heuristic for single machine lot scheduling. International Journal of Production Research, **25**, pp. 363-379.

Bomberger, E., (1966). A dynamic programming approach to a lot size scheduling problem. Management Science, **12**, pp. 778-784.

Chen, Z., (2004). Simultaneous job scheduling and resource allocation on parallel machines. Annals of Operations Research, 129, pp. 135–153.

Clark, W., (1942). The Gantt chart, a working tool of management, Second Edition. Sir Isaac Pitman & Sons, Ltd., London.

Cox, J.F., Blackstone, J.H., and Spencer, M.S., (1992). APICS Dictionary, American Production and Inventory Control Society, Falls Church, Virginia.

Cordeau, J. F., Stojkovi´c, G., Soumis, F., and Desrosiers, J., (2001). Benders decomposition for simultaneous aircraft routing and crew scheduling. Transportation Science, 35, pp. 375–388.

Daniels, R. L., Hoopes, B. J., and Mazzolla, J. B., (1996). Scheduling parallel manufacturing cells with resource flexibility. Management Science, 42, pp.1260–1276.

Daniels, R. L.,and Mazzolla, J. B. (1994). Flow shop scheduling with resource flexibility. Operations Research, 42, pp. 504–522.

Daniels, R. L., Mazzolla, J. B., and Shi, D., (2004). Flow shop scheduling with partial resource flexibility. Management Science, 50, pp. 658–669.

Desaulniers, G., Desrosiers, J., Ioachim, I., Solomon, M., Soumis, F., and Villeneuve,D., (1998). A unified framework for deterministic time constrained vehicle routing and crew scheduling problems. In: Crainic, T., Laporte, G. (eds.): Fleet management and logistics, Kluwer, Dordrecht , pp. 57–93.

Delporte, C. and Thomas, L., (1978). Lot sizing and sequencing for n products on one facility. Management Science, **23**, pp. 1070-1079.

Dong, Z., (1994). Artificial intelligence in optimal design and manufacturing, Prentice Hall, Englewood Cliffs, NJ,

Dobson, G., (1987). The economic lot scheduling problem: achieving feasibility using time varying lot sizes. Operations Research, **35**, pp. 764-771.

Dobson, G., (1992). The cyclic lot scheduling problem with sequence-dependent setups. Operations Research, **40**, pp. 736-749.

Doll, L. and Whybark, C., (1973). An iterative procedure for the single machine, multiproduct lot scheduling problem. Management Science, **20**, pp. 50-55.

Drezet, L. E., Billaut, J. C., (2005). Tabu search algorithms for a predictive and a reactive project scheduling problem. In: 6th Metaheuristics International Conference,Vienna.

Duersch, R.R., and Wheeler, D.B., (1981). An interactive scheduling model for assembly-line manufacturing, International Journal of Modelling & Simulation, 1(3), pp. 241-245.

Eilon, S., (1957), Scheduling for batch production. Institute of Production Engineering Journal, **36**, pp. 549-579.

Elmaghraby, S., (1978). The Economic lot scheduling problem (elsp): review and extensions. Management Science, **24**, pp. 587-598.

Faaland, B., Schmitt, T., (1993). Cost-based scheduling of workers and equipment in a fabrication and assembly shop. Operations Research, 41, pp. 253–268.

Fordyce, K., Dunki-Jacobs, R., Gerard, B., Sell, R., and Sullivan, G., (1992). Logistics management system: An Advanced Decision Support System for the Fourth Tier Dispatch or Short-Interval Scheduling, l (l), pp. 70-86.

Fox, M. S., (1983). Constraint-directed search: a case study of job–shop scheduling, Ph.D. Thesis, CMU-RI-TR-85-7, Intelligent Systems Laboratory, the Robotics Institute, Carnegie Melon University,

Fox, M.S., Sadeh, N., and Baycan, C., (1989) Constrained heuristic search, in: proceedings of international joint conference on artificial intelligence, Menlo Park, CA, pp. 309–316.

Freling, R., Huisman, D., Wagelmanss, A., (2003). Models and algorithms for integration of vehicle and crew scheduling. Journal of Scheduling, 6(1), pp. 63–85.

Gallego, G., (1993). Reduced production rates in the economic lot scheduling problem. International Journal of Production Research, **31**, pp.1035-1046.

Gallego, G. and Moon, I., (1995). Strategic investment to reduce setup times in the economic lot scheduling problem. Naval Research Logistics, **42**, pp. 773-790.

Gantt, H.L., (1903). A graphical daily balance in manufacture, Transactions of The American Society of Mechanical Engineers, 24, pp. 1322-1336.

Gantt, H.L., (1916). Work, Wages, and Profits, Second Edition, Engineering Magazine Co., New York. Reprinted by Hive Publishing Company, Easton, Maryland.

Gantt, H.L., (1919). Organizing for work, Harcourt, Brace, and Howe, New York. Reprinted by Hive Publishing Company, Easton, Maryland, 1973.

Godin, V.B., (1978). Interactive scheduling: historical survey and state of the art, AIIE Transactions, 10(3), pp. 331-337.

Goldberg, D. E., (1989). Genetic algorithms in search, optimization, and machine learning, Addison-Wesley, Reading, MA.

Glover, F., (1989). Tabu-Search Part I. ORSA Journal on Computing **1** 3, pp. 190–206.

Haase, K., Desaulniers, G., Desrosiers, J., (2001). Simultaneous vehicle and crew scheduling in urban mass transit systems. Transportation Science, 35, pp. 286–303

Haase, K., Friberg, C., (1999). An exact algorithm for the vehicle and crew scheduling problem. In Wilson, N., ed.: Computer-Aided Transit Scheduling, Lecture Notes in Economics and Mathematical Systems, Vol. 471, Springer, Berlin , pp. 63–80.

Hounshell, D.A., (1984). From the American system to mass production 1800-1932, The Johns Hopkins University Press, Baltimore.

Huq, F., Cutright, K., Martin, C., (2004). Employee scheduling and make span minimization in a flow shop with multi-processor work stations: A Case Study. Omega, 32, pp. 121–129.

Hsu, W., (1983). On the general feasibility test for scheduling lot sizes for several products on one machine. Management Science, **29**, pp. 93-105.

Hwang, H., Kim, D. and Kim, Y., (1993). Multiproduct economic lot size models with investment costs for setup reduction and quality improvement. International Journal of Production Research, **31**, pp. 691-703.

Jones, C.V., (1988). The three-dimensional Gantt chart, Operations Research, 36(6), pp. 891-903.

Katok, E., and Ott, D., (2000). Using mixed-integer programming to reduce label changes in the coors aluminium can plant. Interfaces, 30(2), pp. 1-12.

Khouza, M., Michalewicz, Z. and Wilmot, M., (1998). The use of genetic algorithms to solve the economic lot size scheduling problem. European Journal of Operational Research, **110**, pp. 509-524.

Klabjan, D., Johnson, E., Nemhauser, G., (2002). Airline crew scheduling with time windows and plane count constraints. Transportation Science, 36, pp. 337–348.

Kusiak, A., (1992). Intelligent design and manufacturing, Wiley, New York. LaForge, R.L., and Craighead, C.W., (1998). Manufacturing scheduling and supply chain integration: A Survey of Current Practice, American Production and Inventory Control Society, Falls Church, Virginia.

Lenstra, J.K, (2005). Scheduling, a critical biography, presented at the second multidisciplinary international conference on scheduling: Theory and Applications, July 18-21, 2005, New York.

MacNiece, E.H., (1951). Production Forecasting, Planning, and Control, John Wiley & Sons, Inc., New York.

Maturana, F., and Norrie, D. H., (1996). Multi-agent mediator architecture for distributed manufacturing. Journal of Intelligent Manufacturing **7**, pp. 257–270.

Mallya, R., (1992), Multi-product scheduling on a single machine: a case study. Omega, **20**, pp. 529-534.

Maxwell, W., (1964). The scheduling of economic lot sizes. *Naval Research Logistics* Quarterly, **11**, pp. 89-124.

McKay, K.N., (2003). Historical survey of manufacturing control practices from a production research perspective. International Journal of Production Research, 41(3), pp. 411-426.

McKay, K.N., and Wiers, V.C.S., (2004). Practical production control: a survival guide for planners and schedulers, J. Ross Publishing, Boca Raton, Florida. Co-published with APICS.

McKay, K.N., and Wiers, V.C.S., (2005). The human factor in planning and scheduling, in Handbook of Production Scheduling, Herrmann J.W., ed., Springer, New York.

Mercier, A., Cordeau, J. F., Soumis, F., (2005). A computational study of benders decomposition for the integrated aircraft routing and crew scheduling problem. Computers and Operations Research, 32, pp. 1451–1476.

Mitchell, W.N., (1939). Organization and Management of Production, McGraw-Hill Book Company, New York.

Morris, P., (1990). Solutions without Exhaustive search: an iterative descent method for binary constraint satisfaction problem, in: Proceedings of the AAAI-90 Workshop on Constraint-Directed Reasoning, Boston, MA.

Moon, D. and Christy, D., (1998). Determination of optimal production rates on a Single facility with dependent mold lifespan. International Journal of Production Economics, **54**, pp. 29-40.

Moon, I., (1994). Multiproduct economic lot size models with investment costs for setup reduction and quality improvement: review and extensions. International Journal of Production Research, **32**, pp. 2795-2801.

Muther, R., (1944). Production-Line Technique, McGraw-Hill Book Company, New York.

Newman, A., Martinez, M., and Kuchta, M., (2005). A review of long- and short-term production scheduling at lkab's kiruna mine, in Handbook of Production Scheduling, Herrmann J.W., ed.. Springer, New York.

Numao, M., (1994). Development of a cooperative scheduling system for the steel-making process, in Intelligent Scheduling, Zweben, M., and Fox, M.S., eds., Morgan Kaufmann Publishers, San Francisco.

O'Brien, J.J., (1969). Scheduling handbook, McGraw-Hill Book Company, New York.

Ortiz, C., (1996). Implementation issues: a recipe for scheduling success, HE Solutions, March, 1996, pp. 29-32.

Parunak, H.V.D., (1996). Application of distributed artificial intelligence in industry, In: G.M.P. O'Hare, N.R. Jennings (Eds.), Foundation of Distributed Artificial Intelligence, Wiley, New York, pp. 139–164.

Pinedo, M., (2005). Planning and scheduling in manufacturing and services, Springer, New

York.

Pinedo, M. L., (2005). Planning and scheduling in manufacturing and services, Springer Series in Operations Research and Financial Engineering, Springer, Berlin.

Porter, D.B., (1968). The Gantt chart as applied to production scheduling and control, Naval Research Logistics Quarterly, 15(2), pp. 311-318.

Rondeau, P.J., and Litteral, L.A., (2001). Evolution of manufacturing planning and control systems: from reorder point to enterprise resource planning, Production and Inventory Management Journal, Second Quarter, 2001, pp. 1-7.

Roscoe, E.S., and Freark, D.G., (1971). Organization for production, fifth edition, Richard D. Irwin, Inc., Homewood, Illinois.

Rogers, J., (1958). A computational approach to the economic lot scheduling problem. Management Science, **4**, pp. 264-291.

Silver, E., (1993). Modelling in support of continuous improvements towards achieving world class operations. In Perspectives in Operations Management (Massachusetts: Kluwer), pp. 23-44.

Silver, E., (1995). Dealing with a shelf life constraint in cyclic scheduling by adjusting both cycle time and production rate. International Journal of Production Research, **33**, pp. 623-629.

Silver, E., Pyke, D. and Peterson, R., (1998). Inventory Management and Production Planning and Scheduling, 3rd edition (New York: Wiley).

Vieira, G.E., Herrmann, J.W., and Lin, E., (2003). Rescheduling manufacturing systems: a framework of strategies, policies, and methods, Journal of Scheduling, 6(l):35-58.

Viswanathan, S. and Goyal, S. K., (1997). Optimal cycle time and production rate in a family production context with shelf life considerations. International Journal of Production Research, **35**, pp. 1703-1711.

Vollmann, T.E., Berry, W.L., and Whybark, D.C., (1997). Manufacturing planning and control systems, fourth edition, Irwin/McGraw-Hill, New York.

Vos, S., Daduna, J., (2001). Computer aided scheduling of public transport, Lecture Notes in Economics and Mathematical Systems, Vol. 505, Springer, Berlin.

Wight, O.W., (1984). Production and inventory management in the computer age, Van Nostrand Reinhold Company, Inc., New York.

Wilson, J.M., (2000). History of manufacturing management, In Encyclopaedia of Production and Manufacturing Management, Paul M. Swamidass, ed., Kluwer Academic Publishers, Boston.

Xue, D., and Dong, Z., (1993). Feature modelling incorporating tolerance and production process for concurrent design. Concurrent Engineering: Research and Applications **1**, pp. 107–116.

Xue, D., and Dong, Z., (1994). Developing a quantitative intelligent system for implementing concurrent engineering design. Journal of Intelligent Manufacturing **5**, pp. 251–267

Xue, D., Rousseau, J.H., and, Dong, Z., (1996). Joint optimization of performance and costs in integrated concurrent design: Tolerance Synthesis Part. Engineering Design and Automation **2** 1, pp. 73–89.

Xue, D., (1997). A multilevel optimization approach considering product realization process alternatives and parameters for improving manufacturability. Journal of Manufacturing Systems **16** 5, pp. 337–351

Xue, D., Yadav, S., and Norrie, D. H., (1999). Knowledge base and database representation for intelligent concurrent design. Computer-Aided Design **31**, pp. 131–145.

Yen, B.P.C., and Pinedo, M., (1994). The design and development of scheduling systems, Proceedings of the Fourth International Conference on Computer Integrated Manufacturing and Automation Technology, pp. 197-204.

Zweben, M., Fox, M.S., (1994). Intelligent scheduling, Kaufmann (Morgan), Los Altos, CA.

Zweben, M., Davis, E., Daun,B., Drascher,E., Deale, M., and Eskey, M., (1992). Learning to improve constraint-based scheduling. Artificial Intelligence **58**, pp. 271–296.

APPENDIX A

COMPUTATIONAL DATA

Month(2009)	Wax Demand(yd)	Regular Capacity(yd)	Overtime Capacity(yd)
January	1,495,611	1,683,184	504,955
February	1,230,950	1,208,030	362,409
March	1,345,640	1,087,640	326,292
April	1,068,151	1,160,600	348,180
May	1,254,992	1,249,488	374,846
June	658,903	630,000	189,000
July	1,462,292	1,555,854	915,756
August	1,341,200	1,522,600	456,780
September	1,316,404	1,560,869	468,261
October	1,476,694	1,216,158	364,847
November	1,483,179	1,533,468	460,040
December	1,209,576	1,342,158	402,647

Inventory/Work in Progress (WIP) at the beginning of January 2009 = 155,439yds

APPENDIX B

SUMMARY RESULTS FROM EXCEL SOLVER

From	To	Shipment	Cost per unit	Shipment cost
Source 1	Destination 2	1230950	2.1	2584995
Source 1	Dummy	452234	0	0
Source 2	Destination 3	1208030	2.1	2536863
Source 3	Destination 4	751541	2.1	1578236
Source 3	Dummy	336099	0	0
Source 4	Destination 5	918893	2.1	1929675
Source 4	Dummy	241707	0	0
Source 5	Destination 6	658903	2.1	1383696
Source 5	Dummy	590585	0	0
Source 6	Destination 7	630000	2.1	1323000
Source 7	Destination 8	1341200	2.1	2816520
Source 7	Dummy	214654	0	0
Source 8	Destination 9	1316404	2.1	2764448
Source 8	Dummy	206196	0	0
Source 9	Destination 10	1476694	2.1	3101057
Source 9	Dummy	84175	0	0
Source 10	Destination 11	1216158	2.1	2553932
Source 11	Destination 12	971572	2.1	2040301
Source 11	Dummy	561896	0	0
Source 12	Destination 1	1340172	2.1	2814361
Source 12	Dummy	1986	0	0
Source 13	Dummy	504955	0	0

Source 14	Dummy	362409	0	0
Source 15	Destination 3	137610	2.5	344025
Source 15	Dummy	188682	0	0
Source16	Destination 4	316610	2.5	791525
Source 16	Dummy	31570	0	0
Source 17	Destination 5	336099	2.5	840247.5
Source 17	Dummy	38747	0	0
Source 18	Dummy	189000	0	0
Source 19	Destination 7	832292	2.5	2080730
Source 19	Dummy	83464	0	0
Source 20	Dummy	456780	0	0
Source 21	Dummy	468261	0	0
Source 22	Dummy	364847	0	0
Source 23	Destination 11	267021	2.5	667552.5
Source 23	Dummy	193019	0	0
Source 24	Destination12	238004	2.5	595010
Source 24	Dummy	164643	0	0
Optimal Cost				**32746176**