MASTER IN ADVANCED ENGINEERING MANAGEMENT

CAPACITY CONSTRAINED MATERIALS PLANNING AND SCHEDULING IN A PLASTIC MANUFACTURING COMPANY

by

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ABSTRACT

The competition is strong between firms in Bangladesh, manufacturing plastic items, especially in the areas of bottling of water and other juices. A large number of companies grew over the few years, thereby creating intense competition in the market. The problems for a company are manifolds: i) there is generally a huge amount of stock, ii) they don't know how to load and release orders when there are multiple simultaneous orders from many customers, etc. Additionally, their capacity is limited, and thus, are always overloaded. Therefore, if they want o prosper further, the company needs to prepare a good materials planning system, which would minimize average flow time, the most common measure of scheduling.

Though MRPII is a system for materials planning as well, it cannot handle and schedule orders as per capacity, and prepare an optimal plan. Thus, it is required that an optimal planning algorithm would be used for scheduling orders, and then preparing a backward scheduling plan to find out materials purchasing timings.

This study uses Heuristic Algorithm for desired performance measure (alternatives are, number of tardy jobs, minimizing flow time, minimizing average lateness, etc.) for parallel identical machines.

CHAPTER 1
INTRODUCTION

1.1 Background and Present State of the Problem

Materials management is a part of production planning and control, and business logistics systems. It can be defined as a function responsible for the coordination of planning, sourcing, purchasing, transporting, storing and distributing materials in a manner so as to provide a pre-decide service to the customer at a minimum possible cost.

The importance of material management (MM) lies in the fact that any significant contribution made by the MM function in reducing materials cost will go a long way in improving the profitability and the rate of return on investment.

1.1.1 Problem Statement

The competition is strong between firms in Bangladesh, manufacturing plastic (PET) items, especially in the areas of bottling of water and other juices. A large number of companies grew over the few years, thereby creating intense competition in the market.
The problems for a company are manifolds: i) there is generally a huge amount of stock, ii) they don't know how to load and release orders when there are multiple simultaneous orders from many customers, etc. Additionally, their capacity is limited, and thus, are always overloaded. Therefore, if they want to prosper further, the company needs to prepare a good materials planning system, which would minimize average flow time, the most common measure of scheduling.

Though MRPII is a system for materials planning as well, it cannot handle and schedule orders as per capacity, and prepare an optimal plan. Thus, it is required that an optimal planning algorithm would be used for scheduling orders, and then preparing a backward scheduling plan to find out materials purchasing timings.

This study uses Heuristic Algorithm for desired performance measure (alternatives are: number of tardy hobs, minimizing flow time, minimizing average lateness, etc.) for parallel identical machines [Baker 1974].

1.2 Objectives of the Study

This study is concentrated around Materials Management activities. The study is designed to meet the following objectives:

1. To investigate performance measures related to capacity constrained order scheduling and purchasing for *m*-jobs-at-a-time and one-job-at-a-time.
2. To prepare a schedule as per heuristic rule.
3. To prepare a schedule of materials plan, both aggregated and disaggregated, based on the best schedule.

1.3 Scopes and Limitations

From definition of materials management, it is clear that the scope of materials management (MM) is vast. Because of time limitation, the study would concentrate on the issues of only scheduling and materials procurement planning.

The study would not cover storage planning, sourcing, distribution requirements planning, etc. of the vast area of knowledge on materials management.

1.4 Methodology

1. The industry would be visited for detailed data collection.
2. The appropriate performance measure would be selected based on 'Materials Management' characteristics.
3. A schedule of multiple jobs on parallel identical machines would be prepared using a heuristics rule.
4. Based on this schedule, a detailed procurement order release dates would be found using backward scheduling technique.

CHAPTER TWO
LITERATURE REVIEW

2.1 Scheduling in Constrained Environment

The term, scheduling is used to refer to the setting of operations, their due dates, release dates and delivery times for manufacturing orders. In an MRP environment, the scheduling algorithm that is usually included in the production control module is not enough to satisfy minimum level of optimality. This is because of backward scheduling algorithm, which cannot satisfy optimality.

Scheduling and Sequencing problems are of many types. These range from parallel machine mathematical programming models to heuristic algorithms, depending upon complexity of materials flow, process layout, and constraints. These also include parallel identical machines, where similar machines are engaged on producing the same products. In case, many work centers are involved with many constraints, mathematical programming needs many variables. and thus, even for a computer program, it takes too long time for a feasible solution, which is classically known as np-hardness [baker 1974, French 1982].

In majority of the cases. jobs are processes under several constraints, leading to several assumptions. The assumptions ultimately create sub-optimality in schedule. In such a case, heuristics algorithms satisfy the minimum requirements [Bitran 1997, Dogramaci 1981, Karmarkar 1985, Kep et al. 1998, Trigeiro 1989]

2.2 Materials Management

In any production environment, materials. also known as current asset, constitute a major part of company's over-all assets. This needs minimization in order to reduce costs and remain competitive.

Materials management has been defined by many persons in many ways, though the main theme says that coordination in planning, sourcing, purchasing, moving, storing, distribution, relocating and controlling of materials in an optimum manner, so as to provide a pre-decide service to the customer at a minimum possible cost, is the essence of materials management.

As an area of knowledge and practice, the scope of materials management (MM) is vast. It encompasses almost all the stages of supply chain. or production-distribution chain. It covers the functions ranging from purchasing to shipping. MM can broadly identify the following functions, which is in turn include some more sub-functions:

1. Materials planning (include production planning, forecasting, Master Production Scheduling, detailed materials planning, capacity planning etc.),
2. Materials control (includes production activity control, real-time scheduling. quality control of materials etc.),
3. Purchasing (includes vendor scheduling, transportation, price negotiation etc.),
4. Sales (includes distribution planning. sales planning. shipping, order reception etc.),
5. Stores and inventory control (includes stores layout planning, lot size determination, replenishment, inventory valuation, physical inventory control etc.).

The whole chain can be divided into three parts: i) company's internal activities. such as storage. retrieval, materials planning, production planning and control. materials processing, managing WIP, at sending back to storage as finished good; ii) the Backward Channel, which includes procurement. sourcing. supplier relations, transportation, etc ; iii) the Forward Channel, which includes distribution channel members (Figure 2.1). Many activities in Figure 2.1 are Materials Management (MM) activities. Each element in this system acts as a 'supplier' to the next as a 'customer' to the previous one, or both. Customer satisfaction has to be the primary goal of each supplier, irrespective of his place in the system.

The intense competition in the market has led companies to optimize each point/stage in the supply chain. Several mathematical tools are used for such a purpose, such as Analytic Hierarchy Process (AHP), Readiness Assessment Methods, Mathematical

Programming, Heuristics, etc. In this view, if a company wants to survive, any company offering goods or services is faced with the need to act quickly to changing customer demands, to improve continuously the quality of products and their delivery and to reduce costs. Controlling costs means controlling quality, time limits and quantities.

The performance of a materials plan can be judged using performance indicators, which may include total costs of purchasing, ordering, holding, shortage, excess, etc. The plan with minimum cost may be selected for execution. Performance Indicators (PIs) are a means to this end. They provide management with a tool to compare actual results with a pre-set target, and to measure the extent of any deviation. A Performance Indicator is a variable indicating the effectiveness and/or efficiency of a part or whole of the process or system against a given norm/target or plan. Several other indicators in scheduling are minimum flow time, average lateness, etc. To determine these things, priority rules also come into action.

Quick response to market needs is another important factor to competitiveness. Doing better and remaining ahead of the competition is the overall goal. For that, average flow time must be minimized such that production process also can contribute to quick response to market. The theme of modern quality management, to reduce waste is another competitiveness factor, which says, 'Do it right the first time' that is the all-inspiring adage, so that the product not only appears quickly in the market but proves to be reliable as well

The following figure outlines the production, distribution and forward, backward chain system in a supply chain. Though all these stages need to be optimized with a kind of tool this study concentrates only on internal scheduling and associated materials planning, with a measure of performance, which is minimization of total inventory costs.

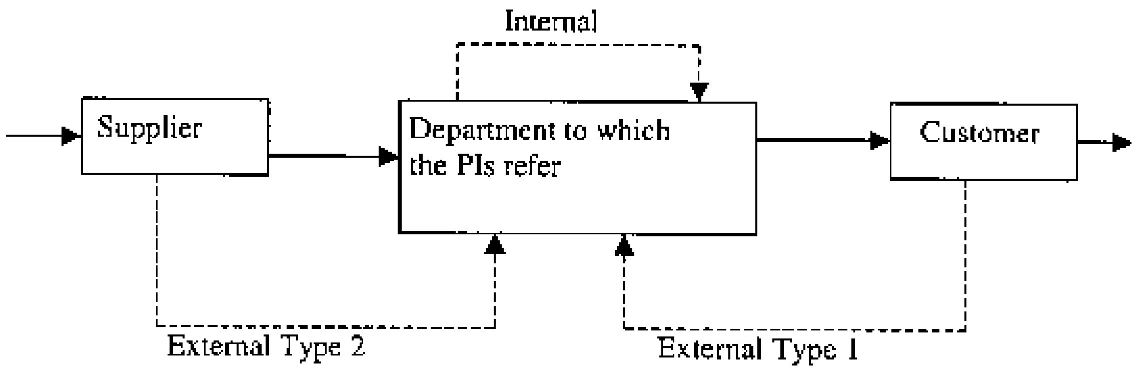


Figure 2.1 External and Internal Performance Indicators

Though the study concentrates on only a few internal performance indicators, there are a lot of indicators, which may be:

- Type 1 (Backward Channel), indicating how the suppliers are performing in supplying materials and services required for smooth running of production schedule For example, the speed with which a customer order is executed, the quality of a product - as experienced by the customer.

- Type 2 (Forward Channel), indicating how efficiently the products are distributed throughout the target market, how channel members are performing, necessity of more channel routes, etc. For example, the number of times the department wants to modify an outstanding error, the speed with which the department pays its bills.

Internal aspects of performance of MM functions also include: turnover per employee and the percentage of actual development times that do not exceed the agreed development times. Good performance basically means the efficient usage of internal resources. External and internal aspects are not independent, poor internal performance is likely to cause a poor external performance. In order to achieve overall benefits, optimization at a single stage of the complete supply chain may not offer desired benefits. All the stages are individually optimized with a suitable tool, both in terms of technical ability, level of optimality and time required for arriving at a solution.

In many cases, it has been seen that a good optimal solution is achieved, though not tested, takes such a long time that it ultimately discourages industries to use the algorithm or tool. The feasibility of a tool always means the degree of optimality compromised with an acceptable time limit for computation. The interval of validity of this target should also be mentioned.

Several algorithms may be available to arrive at a solution. Performance Indicators, such as mean flow time, may be used to select the better one. Heuristics are there in place, for research and industrial application for a feasible time limit. PIs have to be used in concert. If a department is aiming at short throughput times and cost sources such as stock levels, personnel and machine are not considered, it is not so hard to achieve set targets. But this is one-dimensional management and it moves problems around rather than solving them. Customer satisfaction will not be realized. The problem is to balance the conflicting objectives, and to minimize the total of all the costs involved and maximize customer service consistent with the goals of the whole organization.

Not only the mathematical tools play role in this aspect. Many companies cannot make profit despite improved productivity, because of variation in production-distribution strategies. Customer demand for new and better products and their demand rates change frequently. Under these circumstances, the rapid response to changes in product design and volume is any manufacturer's major concern for survival in the ever-growing competition. The 'productivity paradox' of Skinner indicates that the productivity and profits do not always go hand in hand. This occurs when the increase products due to improved productivity are not sold because of poor quality of products and the flexibility of manufacturing system to customer expectations. As productivity is the measure of the efficiency of converting tangible inputs into outputs, it does not consider whether the produced item generate profits through sales. So this productivity paradox can be cured only through evaluation of a performance measure, integrated manufacturing performance (IMP), which is a ratio of total output to sum of productivity cost, quality cost, and flexibility cost. We have to simultaneously consider performance indicator to solve the multi-objectives decision-making (MODM).

The performance of a production system may be judged in terms of performance of production plan as well, and vice versa. The following figure shows two such examples, where, trend in performance in production schedule and capacity availability are shown.

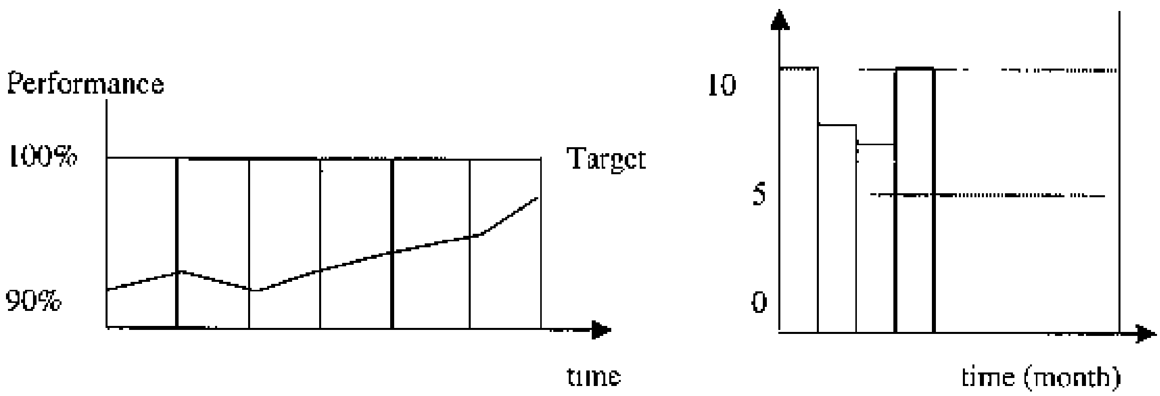


Figure 2.2 Example of Presentation of PI

The list examples of PIs that can be encountered within industrial companies is shown in table 2.1.

Table 2.1 Widely Used Selection of PIs for Industrial Companies.

Activity	Performance Indicator
Market research	- 'image' of the company - Brand name - accuracy of forecasts
Products development	- speed with which new technology is applied - number of technical changes after commercial releases of a product
Manufacturing	- Mean flow time - scrap - throughput time
Logistics	- delivery ratio (volume) - delivery ratio (# of orders) - stock ratio - delivery reliability - inventory level
Sales	- delivery time - quality of directions for use
Service after sales	- call rate - response time of technicians - compliance with appointments
Administration	- timeliness of financial reports - accuracy of financial reports
Internal services	- timeliness of travel documents - throughput time of typing work
Management	- percentage of executed decisions - execution speed of decisions
Implementation of Performance Indicator	- number of deadliness reached in time

2.3 Scheduling Rules: Mathematical models

Several researchers used various mathematical models to analyze various scheduling environments.

2.3.1 Overview of the Scheduling Theories

Each of the scheduling theories has constraint(s) as outlined below.

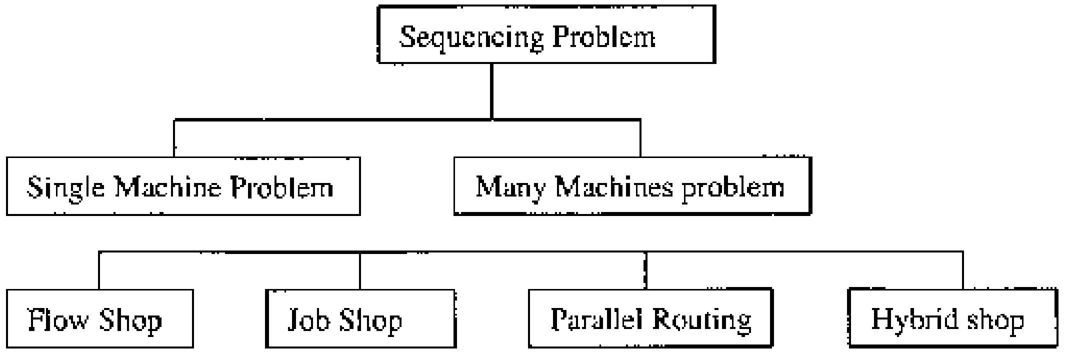


Figure 2.3: Classification of sequencing problems

1. Single Machine

The simplest pure sequencing problem is one in which there is a single resource: or where there is a scheduling model involving only one process [R. Gary Parker]. As simple as it is, however, the single machine case is still very important for several reasons. One of the reasons is that, in the learning process, he single machine problem can illustrate a variety of scheduling topics in a tractable model.

2. Parallel Machine

A simple context by investigating the effects of parallel resources is the problem of single stage sequencing with several machines.

As in the basic model, suppose there *are n* single-operation jobs simultaneously available at time *zero*. Also suppose that there are *m* identical machines available for processing, and that a job can be processed by at most one machine at a time. Once again it is possible to deal with the fundamental performance measures, only these time scheduling decisions will reflect resource parallelism [Baker. 1974].

3. Flow Shop Scheduling

This model contains multiple processors in parallel. It is only natural to examine models with multiple processors in series. However, it is not appropriate to think in terms of serial configurations unless jobs are multi-stage in nature. That means that it is essential to distinguish between jobs and. each of the processing operations that is a part of it.

The shop contains *m* different machines, and each job consists of *m* operations. each of which requires a different machine. The flow shop is characterized by a flow of work that is unidirectional [Baker, 1 974]

4. Job Shop Scheduling

Job shop scheduling problem differs from the flow shop problem in one important aspect that is the flow of work in job shop scheduling is not unidirectional. The elements of a problem are a set of machines and a collection of jobs to be scheduled. Each job consists of several operations with the same linear precedence structure as in the flow shop model. Although it is possible to allow any number of operations in a given job, the most common formulation of the job shop problem specifies that each job has exactly m operations one on each machine [Baker. 1974].

5. Hybrid Flow Shop

A hybrid flow shop may be generally defined as a system characterized by a mixture of different types of production process in which materials flow in one direction. This kind of production system evident in many industries, especially in those which process steel, chemical products. and paper [Gupta. 19911].

2.3.2 Research on Production Scheduling

The issues concerning the planning arid controlling of PCB assembly operations have been addressed by various researchers for the last 10 years. A general report of the literature in the field, followed by a specific coverage of the earlier work on sequencing, is presented.

Randhawa *et al* (1985) has considered an Integer Programming (LP) application to solve the sequencer mix problems, using a method similar to branch and bound. Cunningham and Browne (1986) have used a LISP-base heuristic to solve the problem of scheduling the PCBs for assembly in automatic insertion machines. They have shown that algorithmic solutions are often not appropriate for scheduling problems and that these problems are more amenable to heuristic solution techniques. Fathi and Taheri (19891 proposed methods for loading the sequencers in printed circuit pack environment. John 1990) proposed a heuristic for loading new work on printed circuit pack assembly lines. Rockwell and Wilhelm (1990) addressed the problems of alternative cell designs for smooth material flow, managing buffer capacities, effects of material management policies and those, which determine the duration between arrival of jobs Taylor and Graves (1990) examined the effects of introducing new processing flexibility in PCB assembly. They demonstrated the variation in times spent on set-up, machine utilization and WIP as batch sizes are varied. Ben Arieh and Maimon (1992) used 3imulated Annealing to sequencing jobs in printed circuit pack sequencers. Minimization of set-up tiny and maximization of workload balance were considered by Luzzatto and Perona (1993). A heuristic with four nested loops has been proposed for the formation of cells, taking care of both the objectives. Sadiq et al. (1993) proposed the intelligent slot assignment algorithm for minimizing total set-up time in Surface Mount technology (SMT) type placement machines. They have described the importance and need for the reduction of set-Lip times In PCB assembly, and have proposed a heuristic to assign components into different feeder slots in the feeder assembly. Askiti et al. (1994) have done an extensive study of the literature and proposed methods for PCB family grouping and component allocation for a multi-machine, open-shop assembly cell, with the objective of minimizing the makespan. They have proposed three procedures: the first for grouping, the second for scheduling sub-family using SPT rule, and the third for forming board sub-families based on similarity.

Gupta (1998) and Tune (1991) presented approximate algorithms that minimize the makespan in a two-Stage hybrid flow shop when the second stage consists of identical machines. Narasimhan and Manngiameli (1987) proposed a generalized cumulative deviation rule in the hybrid flow shop with multiple machines at the first stage. They compared this rule under various operation conditions with three other sequencing rules: shortest processing time, longest processing time and minimum deviation; where the minimum deviation rule attempts to balance the loads among machines at the second stage. Wittrock (1988) proposed an algorithm that minimizes the makespan at one machine in each of several banks of machines. Brah and Hunsucker (1991) presented a branch and bound algorithm for optimizing the maximum completion time in a flow shop with multiple processors at each stage.

Brown Randall and Ceyhun Qzgur (1997) presented a new scheduling framework (Priority Class Scheduling) which reduces the conflict in the manufacturing marketing interface. Priority class scheduling rewards manufacturers in many ways. First, it makes small improvement in production deficiency. Second, it enables marketing department to involve in the setting of production priorities. Third, it improves customer services by putting in place the realistic production timetable. Fourth, it allow~ manufacturers to concentrate on improving both quality and efficiency. Finally, it improves both he communication and the co-operation between the shop floor, the production scheduler, the marketing section, and the customer service section Within a production period, all jobs are classified into priority classes based on both their due dates and importance.

Production is scheduled within each production period to maximize throughput subject to the priority class constraints. If any job in priority class *i* is started in the production period, then all jobs in the priority class *i-1* must be completed within the production period.

C. Chu, J.M.Proth and C. Wang (1098) presented a solution for job-shop scheduling problems. The criterion to be minimized is the makespan. To reach this goal, authors proposed a heuristic algorithm that gradually improves a given schedule by reversing the order in which some tasks are performed on machines. The job-shop scheduling problem is being modeled as a disjunctive graph, reversing the order of two consecutive tasks which are performed on a given machine; is equivalent to reversing the direction of a critical disjunctive arc. The important fact is that, due to the results proposed in this paper; the author was able to choose the critical disjunctive arc to be reversed such that the makespan decreases at each iteration if the critical path is unique. Otherwise, at least as many iterations as the numbers of critical paths are needed. This approach is, therefore, simple and easy to implement.

Yang Byung Park, C. Dennis Pegden and E. Emory Enscore (1984) provided a survey and evaluation of static flowshop scheduling rules. A total of sixteen scheduling heuristics, including several revisions and combinations of previously reported methods, are summarized. These scheduling rules are evaluated using a discrete event simulation model. The results for the simulation model are analyzed using both statistical and non-statistical methods. The results from the study suggest which of the popular scheduling rules holds promise for the application to practical flowshop problems.

Anderson et al. (1990) presented two new dispatching rules for minimizing tardiness in a job shop. Both rules are closely related to the modified operation due date (MOD) rule. The first is a combination of the shortest processing time (SPT) rule and the critical ratio (CR) rule, and the second is an combination of the SPT rule and the slack per remaining work (S/RPT) rule. The two new rules are simple to implement and can easily be adapted to minimize weighted tardiness. Moreover, they do not require any parameter estimation for their implementation, which is a notable disadvantage of some earlier rules such as COVERT. Simulation results show that the performance of the two new rules is better than that of other rules that have been developed to minimize total weighted and unweighted tardiness. This holds true across a range of shop conditions. Furthermore, the rules are effective in minimizing the number of tardy jobs.

R. Moras, M. L. Smith, K. S. Kumrar and M. A. Azim (1997) presented the antithetic properties of flowshop sequences which are investigated to improve the classical Monte

Carlo method for solving the n-job, m-machine problem with minimization of makespan. Alidaee, B (1990) established a negative correlation of the makespan values of forward and reverse sequences. Ashour, S. (1980) developed the Antithetical Monte Carlo (AMC) method, which can be used to quickly estimate the mean of the makespan distribution by exploiting the antithetic property or sequences. Bahouth, S. B. and Foote. B.I. (1994) used AMC to find low makespan values.

Baker, K. R. (1974) determined a threshold value of makespan beyond which it would be likely to find an optimal or near optimal makespan when reversing a sequence. Statistical tests indicate that the performance of AMC is superior to that of the classical Monte Carlo method. Possible applications of this concept are discussed including extensions to other mathematical problems with antithetic properties.

Kun-Hyung Kim and Pius J. Egbelu (1998) presented a mixed integer programming model which is formulated for scheduling a set of jobs through a shop when each job is supplied or provided with multiple process plans or process routings. Simultaneous selection of a process plan for each job and the sequencing of the jobs through the machines *n* the shop based on the set of selected process plans is addressed. The procedure developed seeks to integrate the selection of machines for each job and the sequencing of jobs on each machine based on the objective of minimizing production makespan. The application of the procedure is demonstrated with an example problem. The following conclusions were drawn as a result of the research. Bhaskaran, K (1990) concluded that the procedure produces optimal or near optimal solution. Chang, T., C., and Wysk, R. A. (1995) concluded that the benefit from the developed approach is that it allows a shop to adaptively select process plans for jobs to optimize on production makespan. By combining solution quality with scheduling flexibility and efficiency, the productivity of a shop can be greatly enhanced.

Marcos Singer and Michael Pinedo (1998) presented and compared a number of branches and bound algorithms for minimizing the total weighted tardiness in job shops. There are basically two types of branching schemes. The first one inserts operation in a partial schedule, while the second one fixes arc in the disjunctive graph formulation of the problem. The bounding schemes are based on the analysis of precedence constraints and on the solution of non-preemptive single machine sub-problems that are subject to so-called delayed precedence constraints.

Z. Xu and S. Randhawa (1998) presented scheduling strategies for a dynamic job shop in a tool-shared, flexible-manufacturing environment. A two-phase approach is issued to examine the impact of job scheduling rules and tool selection policies. For a dynamic job-shop system *n*, a tool shared flexible manufacturing environment. The first phase develops a generalized simulation model and analyses 'simple' job scheduling rules and tool selection policies under various operating scenarios. The results from this investigation are then used to develop and analyze various bi-criteria rules in the second phase of this study. The results show that the scheduling rules have the most significant impact on system performance, particularly at high shop load levels. Tool selection policies affect some of the performance measures, most notably proportion of tardy jobs, to a lesser degree Higher machine utilization can be obtained at higher tool duplication levels but at the expense of increased tooling costs and lower tool utilization. The results also show that using different processing time distributions may have a significant impact on shop performance.

P. R. McMullen (1998) presented a heuristic for sequencing mixed-model production schedules for assembly lines when JIT production is an objective, and setup requirements are presented. The heuristic examines a sequence and determines an objective function value based upon the parts usage rate (Miltenburg, 1989) and the number of setups involved. This technique is applied to several problems, and the resulting sequences are simulated to determine production performance measures of production makespan, system time and average WIP inventory level. The experiment shows that the multiple objectives of minimizing both parts usage rate and required setups can be addressed provided management has an understanding of the relative importance of usage rate and setups for their specific application.

2.4 Scheduling Using Expert Systems

Expert systems have been used in research and applications in scheduling operations, specifically when the use of mathematical tools become complex and time consuming

SINHA et al. (1989) represent an expert system for inventory management. The focus is on the development of a simple, user friendly tool that can be used by managers to increase the effectiveness of their inventory control system. The expert system is capable of deriving input parameters by performing necessary analysis on databases, implementing a set of rules for the selection of inventory models.

Description of the expert system: the following three functions have been identified and are critical to the successful implementation of an expert system for inventory management

The ability to select an appropriate inventory model.

The ability to derive the parameter/variable required in selecting an inventory model.

The ability to provide a solution to the inventory model once is identified.

BRUNO et al. (1986) developed an expert system for scheduling parts in a flexible machining environment. The parts are grouped into hatches, each containing 100 to 200 parts. In order to generate a release time for each batch, a dynamic priority scheme is used.

The priority is calculated as follows:

Remaining time / (due_date - release_time)

In addition to the due date, constraints related to: capacities of the queue, fixture vacancy. and machine maintenance periods are considered. The batch with the highest priority is released for machining if the above constraints are satisfied.

From the structural points of view, the scheduling systems consist of two subsystems:

Expert system for schedule generation.

Simulation system for schedule evaluation.

Because of the different data structure requirements by different modules, separate data structures are produced for the expert subsystem and the simulation subsystem.
The authors reported that the research and application show that:

Non-procedural programming increases flexibility and maintainability of planning and scheduling systems.

Heuristic knowledge can be introduced to direct decision malking

Algorithm knowledge base can be easily integrated as external routines called by OPS-5 statement.

ERSCHLER and ESQUIROL (1986) presented a job shop scheduling system, MASCOT, which uses a constraint based analysis (CBA). The system is to make resources (machines) constantly available and to finish jobs before the required due dates. The system was applied to solve a scheduling problem involving machines and operations only. Start times of operations and constraints that use common resources are considered as important aspects of the problem. The CBA approach is to generate a precedence relationship from conflicting resources. Consequently, only two types of rules were established in the knowledge base: Time updating rules, sequencing rules to generate precedence among operations.

Besides these rules, two types of facts are stored in the knowledge base such as: Invariable facts that are data that cannot be changed by the rules, variable facts that can be changed by the rules.

BENSANA et al (1986) introduced an expert scheduling system similar to the above. The job shop scheduling system, OPAL, integrates the CBA module with the rule based decision support module. The OPAL system was programmed in LISP. When operations cannot be ordered by the CBA module, and no more precedence constraints can be invented, the rules base decision support module is called to select a new pair of operations. The control strategy of the decision support module is based on the fuzzy set methodology. Each rule is assigned a static or dynamic weight index that can he viewed as a grade of membership of that rule in the fuzzy set of rules relevant to the goal. These indexes and a number of job attributes (i.e., the slack times) are used to calculate job priorities that determine the sequence of operations for the selected machine. The OPAL system is under development and only a mall number of rules in the decision support module are available.

O'CONNOR, (1984) introduced a rule-based expert scheduling system developed at Digital Co. This system is used for scheduling customer orders and it has the capability of classifying difficult orders and it has the capability of classifying difficult order into two categories; material shortage category and credit line insufficiency category. It generates a loading strategy dealing with difficult orders.

SUBRAMANYA.M and ASKIN (1986) discussed an approach for scheduling an FMS, on a daily basis for two shifts to meet the weekly production requirement. The FMS is described by three object statues such as: System status, machine status, job status.
The system and machine statues can be assigned one of the following three attribute values: heavily loaded, moderately loaded or under load. Similarly, the jobs waiting in the queues for machining can be assigned attribute values: critically late, moderately late and normal. A three level hierarchical decision structure for the expert system was developed. 'I he rules representing various object statues at different level were coded in Prolog.

DEN-ARIEH, (1986) develop an expert scheduling system, the system schedules a production cell feeding an assembly station. Production rules were coded in Prolog to represent the behavioral knowledge. The information stored in database as predicates coded in Prolog. The control strategy of the scheduler is problem independent. Rules are activated by matching mechanism available in Prolog. Triggering the set of multiple rules results in processing according to their order in the data base or in the content of the right hand side of the rule. In the level 1 subsystem, the algorithmic knowledge is represented in two ways:

Production rules written n Prolog to check conditions of calling computing routines to retrieve data and decide what need to be solved.

Computing routines written in Pascal to calculate cost charged to various candidate solutions.

The simulation subsystem written in SLAM II provides s simulated manufacturing environment instead of real system. The level 2 subsystem is used to control the process of schedule generation. The supervisor is a software frame that ties all component together and provides the interface human controllers.

NEWMAN AND KEMPF (1985) presented a real time rule-based system to schedule a robot tending machine tool in a manufacturing cell. The task specific production rules were used to sequence the robot operations. The real-time scheduler generates the nest step commands before they are requested by the robot. The scheduler has sufficient time to make intelligent decisions based on about *250* production rules in knowledge base. The rules are divided into six levels. All the six levels' rules are based on heuristic that were acquired from simulation of manufacturing cell. The performance of expert system was also tested in a simulated environment.

RAHR (1986) reported on a research of production replanting system based on MRP system. The objectives of the system are:

To detect critical events.

To provide scheduling alternatives, and

To facilitate the rescheduling.

Rahr suggest that an expert system plays the role of a filer to produce several feasible schedules to be selected by the decision maker.

MORTON and SMUT (1986) developed an expert system, PATRIARCH. for solving FMS problem including project planning and scheduling. The system has following four hierarchical structure:

Level 1: Strategic planning; 'manual' decision support system,

Level 2: Capacity planning: semi-automatic decision support system,

Level 3: scheduling; heuristic solutions, generated using operations research approaches,

Level 4: Dispatching; 'mixed', uses level 3 heuristic, simple rules of thump and occasional human help.

They discussed level 3 and 4 of the system more detail. For scheduling problem in level 3, resource utilization and due dates are consider to be most important constraints for the problem solving. A system of priorities for operations and machines is developed. In the level 4, the following constraints are considered: time when operation is actually available, temporary interruption such as tool unavailable, intervention of a human operator.

THESEN and LEI (1986) developed an expert system for scheduling robots in a flexible electroplating system. The scheduling system considers:

K different types of parts,
M machines,
N robot to transfer parts.

The objectives of expert scheduling system are:

Maximization of the manufacturing line throughput,
Meeting machine sequence requirement,
Meeting process time requirement.

To give some insight into the system. two sample heuristic rules are presented:

Each robot is responsible for N machines,
Dispatch a closest robot to the job.

The heuristic rules can be easily transformed into IF-THEN rules. The metal-rules for activating heuristic rules are generated by simulation system. The development of the system is an example of knowledge acquisition using the simulation method.

FELLENSTEIN et al (1985) develop an expert system for solving a capacity planning problem for a manufacturing. The system plans the test machines and the inventory requirements to meet the production objectives. The knowledge is represented as facts and syllogisms. Each of the syllogisms consists of several English-like sentences. The meaning of a syllogism is that IF each of the sentences above the line is true, THEN the sentences bellow the line is also true.

RENHA UZSOY et al (1991) represent an experimental expert system for process planning of sheet-metal parts. A basic framework for representing the necessary knowledge and part geometry information is outlined. The system, which is developed in

Turbo Prolog and implemented for planning of simple bent and punched, is described.

Process planning is defined as systematic determination of the method by which a product can be manufactured. It constitutes an intermediate stage between product design and manufacturing. Process plans contain information the necessary operations to manufacture the parts, their sequence, the necessary machines and tooling, the standard and set-up time, and the material requirement.

The system falls into generative-type process-planning category. The expert knowledge is heavily empirical and consists mainly of heuristics such as

"If there is a hole on a bent edge, do the hole before the bend"

The expert system was developed using a rule-based knowledge representation. The knowledge required were extracted from conventions with the process planners and die designers, and from die design and metal forming handbook Two main aspects addressed in the development of the expert system were the representation of the part geometry and the development of knowledge base.

The experimental system is currently is running for simple bending and hole-making operations, and its performance is similar to the results obtained by experts in the area. Work is continuing on broadening the knowledge base and developing a more user-friendly environment.

YUNUS KATHAWALA and WILIAM R. ALLEN (1992) repeat background of expert systems arid summarize some current Expert System in Job Shop Scheduling.

Artificial Intelligence (AI) research has begun to yield commercially attractive results. Among these are robotics, natural language systems, exploratory programming, and expert systems. The expert system is aimed at capturing the expert knowledge of human problem solvers. There are three general classifications of problem confront businesses:

- Well defined and relatively simple tasks that are currently done by the experts.

- Well understood problem that, due to the overwhelming flow data, humans often solve poorly. The authors would classify job shop scheduling in this group.

- Poorly understood problem that is poorly solved by humans. Improving the profitability / a business would fit this classification.

The first classification is ideally suited for expert system development. The second should be approached with caution, while the last should be completely avoided.

The main components of an expert system are: The inference engine, the knowledge base, the knowledge update facility, the explanation facility, user interface.., in which inference engine and the knowledge are the heart of the expert system.

For expert system application in scheduling task. the goal is not to be infinitely adaptable to the many environments. Rather, expert system is designed to fit the environment. Thus, it cannot affect the source of the orders. nor change the degree of complexity. but an expert system designed for specific environment can be flexible. Because the flexibility comes from external sources, a new algorithm is added so a good expert system can easily be reprogrammed to account for such changes.

Some Expert System Application in Job Shop Scheduling: ISIS (intelligent scheduling and information systems) is an expert system designed for use at a large turbine component job

shop. The system of Kerr/Ebsary is an expert system developed for a small Australian manufacturer. The 2xpert System Scheduler, an expert system has been developed to aid in the overall goal of speeding product to the marketplace.

R.M.KERR.R.V.EBSARY (1995) described the experimental implementation of a rule based expert system for production scheduling in a small manufacturing company. An attempt was made to capture the local knowledge and informal heuristic used by the experienced human production scheduler and to reduce these to a set of rules which would operate on a relational database representing current shop floor status and project future loading; the objective was for the system to produce schedules similar to those of human. There are two main alternatives' types of approach was initially considered for the computerized scheduling system:

A deterministic approach in which the environment is assumed to remain static over a short planning horizon, and the schedule is optimized over this period according to seine chosen criterion.

A heuristic approach involving development of a Set of local or global 'rule' for loading of work centres and dispatching of jobs.

To present the decision making behaviour of human scheduler:

The computer database must contain continuously updated representation of both the projected forward loading and the current situation on the shop floor.

The rule-base must determine the way in which the effects of a particular external event will be propagated through the database in the iterative search for satisfying schedules.

Set of ru[1]es consists of: order priority rules. job/operation precedence ordering rules. work centre loading rules, job dispatching rules, general contingency rules, time conversion rules.

FRENCH.S (1982) mentions concept of line balancing for assembling line. Assembling line is used in many cases of industrial production. The simplest way to picture is to imagine a convey belt along which are situated a number of stages (work stations). At each stage a number of assembly operation is performed. The convey belt moves the partially assembled product between stage; pauses for a length of time to allow the stages complete their task. We can see that: Each stage has nearly the same of time to complete its operation. The length of time is equal with processing time plus the time needed to move parts between stage. In assembling line, our task is to assign the operation to the stage. The objective may be to maximize production rate, or minimize wok-in-process. More generally, we may wish to minimize the unit cost of production, which related both to capital investment and labor cost. Each stage would be assigned the same amount of work. So each stage does not complain if one has to work harder than another. It because of its intention to "balance" the workload evenly along the assembly line that the problem has its name.

CHAPTER THREE

MATERIALS PANNING

3.1 Introduction

In the recent days, manufacturing and business people are facing increasing challenge both from domestic and international competitors in the market place. No matter what about satisfaction of customer such as quantity of orders, right information and evidence etc. are very important things in business. In order to surviving, various companies have to able to manage the dynamic market variables and satisfy their customers better than their competitors. The MRP system is a very good choice in business and industrial sector. The MRPII system (Manufacturing Resource Planning) is widely accepted by many manufacturing and business organizations in this region. Now the MRP II system is the third generation of the Materials Planning System after Materials Requirement Planning (MRP) system in the first generation and Closed-loop MRP in the second generation. This MRP II system helped management people in decision making to run the business through the status of integrated business and operational information. The MRP II system has purpose of usage closely to the Closed-loop MRP by MRP II can link various functional activities in a firm. The MRP II system integrated Master Production Scheduling (MPS), Material Requirement Planning (MRP), Capacity Requirement Planning (CRP), Marketing Planning, Production Planning, Purchasing, Shop Floor Control and the last one is financing together and distributed output in the form of financial report or other required report.

3.2 MRP- Material Requirements Planning

MRP has been a well-known acronym for the last four decades just as it is a famous system in may companies because of its simple concepts and simple calculation algorithm. The MRP is an approach to production planning and control in discrete parts manufacturing and assembly.

The basic idea of MRP is to plan material requirements. So MRP is used to coordinate orders that come both from within the factory and from outside the factory. Those from outside are called **Purchase Orders**. Those from within the factory are called **Jobs** or **work orders**. It deals with two basic dimensions of production control: quantities of parts and time.

According to BOM data, MRP also requires information concerning demand, which comes from the **Master Production Schedule** (MPS) containing gross demand, the current inventory status known as **on-hand,** and the status of orders known as **Scheduled Receipts.**

The basic process of MRP is simple. For each level in BOM, starting with end items, MRP does the following:

1. Determine **net demand** by subtracting on-hand inventory and any schedule receipts from the gross demand.
2. Compute **lot sizes** for jobs
3. Offset the due dates of the jobs with **lead times** to determine start times.
4. Use start times and the quantities at the present level to generate demand for the components at the next level.

And the basic outputs of an MRP system are **planned order releases, change notices,** and **exception reports**. Figure 3.1 represents a schematic of the process.

3.3 CLOSED-LOOP MRP

This system includes **capacity requirement planning (CRP)** and rechecked for capacity feasibility before any orders are released. This recheck is made through the feedback loop until the plan compiles with validity capacity. This feedback enables the management to decide when a corrective action is required. The MRP schedule must be subsequently checked for capacity feasibility before any orders are released. If sufficient capacity will not be available to meet the planned work orders as well as the shop orders already released, it may be necessary to revise the MPS or increase capacity. Adjustments are made as shown through the feedback loop until the plan compiles with valid capacity projections.

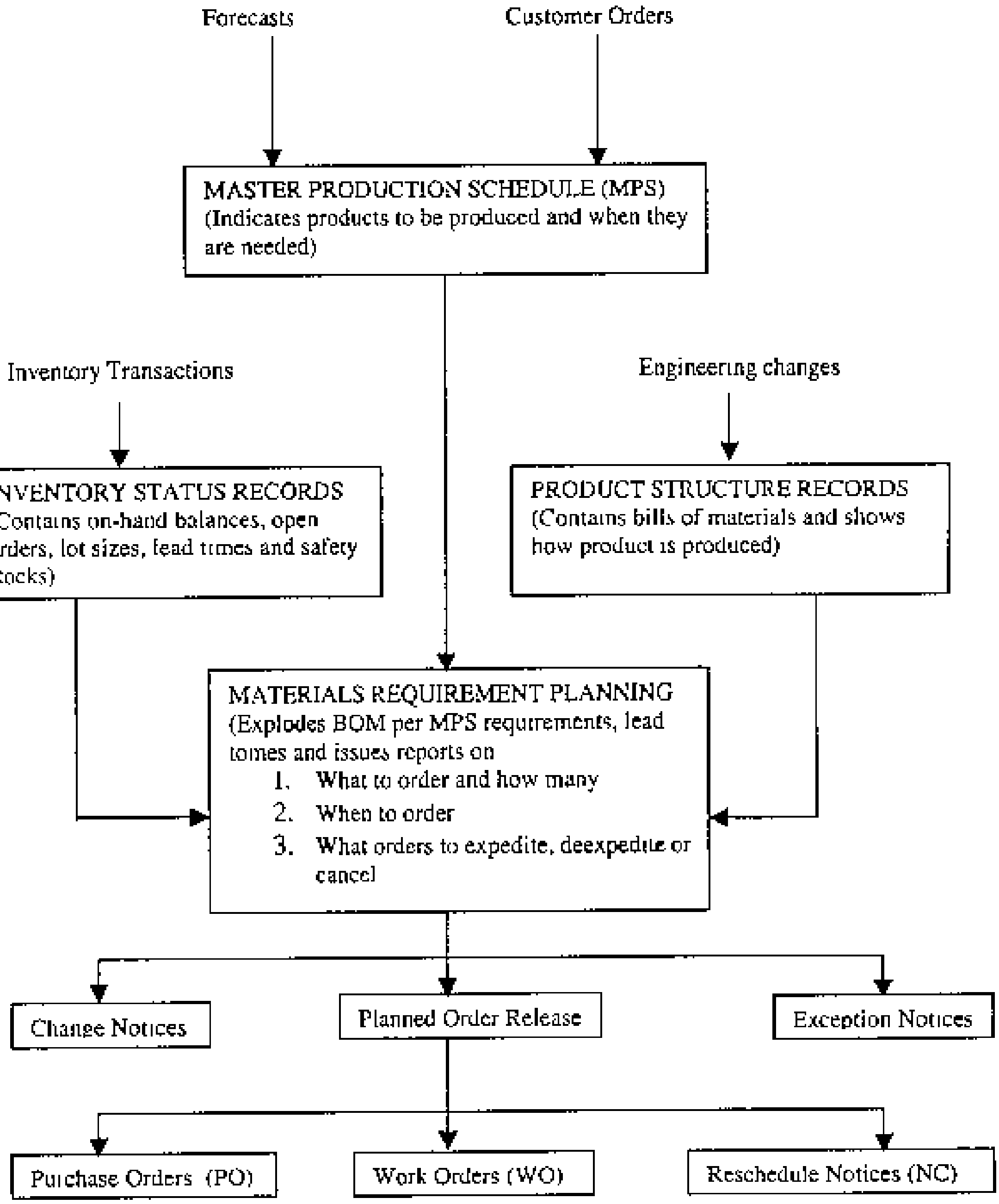


Figure 3.1 MRP Schematic [Tersine R.J. 1994]

3.4 Manufacturing Resource Planning – MRPII

Manufacturing Resource Planning is a much more sophisticated system which incorporates information from manufacturing, marketing, and finance into a total operations plan for the organization. The concepts are relatively simple and are easily implemented using a computer. Figure 3.2 shows an instance of the MRPII hierarchy.

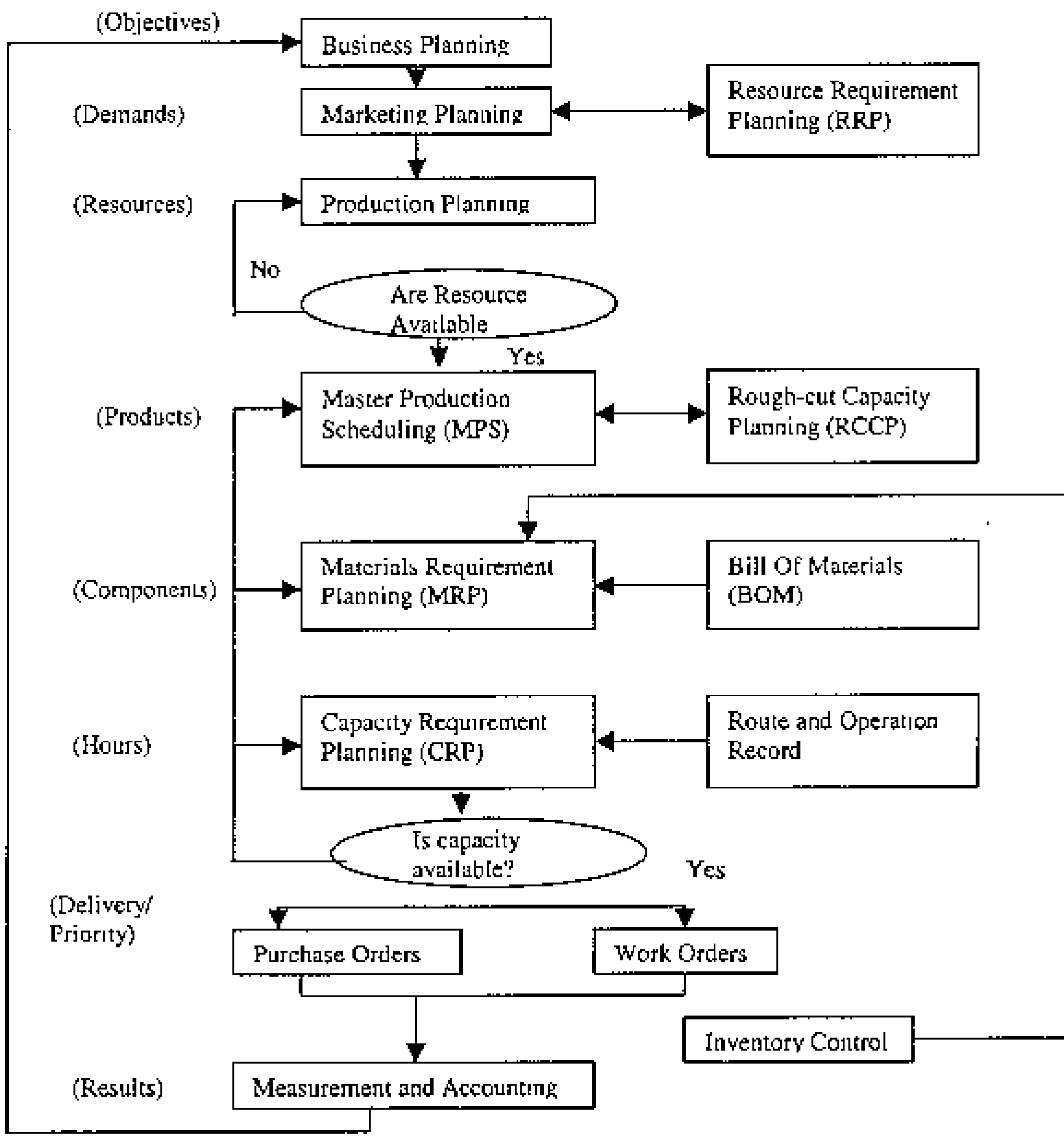


Figure 3.2 MRPII Hierarchy

3.4 Capacity Management in MRP II System

1. **Resource Requirement s Planning (RRP)** is concerned with long-range capacity resource requirements and is directly linked to production planning. It involves changes in manpower, capital equipment, product design or other facilities that take a long time to acquire and dispose of.
2. **Rough Cut Capacity Planning (RCCP)** is used to provide a quick capacity check of a few critical resources to ensure the feasibility of the master production schedule. But RCCP cannot perform any offsetting of MPS, it just detects an infeasible MPS.
3. **Capacity Requirement Planning (CRP)** provides a more detailed analysis of production plans than is available from rough-cut capacity planning. Necessary inputs include all planned order releases, the exiting WIP position, routing data, as well as capacity and lead-time data for all process centers. CRP predicts job completion times using the lead time data ad then compares predicted loading over time with the capacity scheduler. Instead, CRP performs what is called infinite forward loading by taking the single value of the lead-time through the shop and dividing it into segments corresponding to each process center on a particular product's routing. These individual lead times are then used along with the current WIP position to estimate arrival times of work to each process center at during each planning period on the MPS.

3.5 The Limitations of Existing MRPII System

A major problem of MRP II system is that it cannot generate and schedule orders within the capacity available in the shop floor control system. To extend this problem, when Bill of Materials (BOM) process generate some orders. Then these orders are sequenced by approximation or trial and error to fit the available capacity but because of limitation on lot sizing and scheduling. Therefore, MRP II may generate infeasible scheduling of orders in a high possibility. And other several difficulties arises in practice includes unpredictable production lead times, unpredictable external demand for components, random yields, defective items and changes in the final product schedule.

3.6 Scheduling and Sequencing usage in MRP II System

The term scheduling is used to refer to the setting of operation dates and delivery dates for manufacturing orders (or jobs or lots), short term horizon t refer to time horizons of days or weeks and the term real-time to refer to decisions that will have and almost instantaneous effect, within minutes even seconds. In an MRP II system, a scheduling algorithm that is usually included in the production control module carries out scheduling for the short-term horizon. This algorithm assigns starting and ending dates to the operations within each manufacturing order. [Kamantzky 1985].

The term sequencing is used to refer to decisions concerning the sequence in which manufacturing orders will be processed at a given production center. This definition implies that sequencing also concerns the sequence of setups and tear-down in a given production center. [Kamantzky 1985].

3.7 The Relationship between MRP II and Scheduling and Sequencing

There are several works to be done with respect to integration MRP II and Production Scheduling and Sequencing. Most of researches are in the form of finite capacity MRP system. These use linear programming formulation to create the scheduling & sequencing model. Some of the researches are:

Peter J Billington. John O McClain and Joseph Thomas, (1983): developed linear programming snf mixed integer-linear programming formulations of the problem. These formulations compute the required production lead times according to the demands on available capacity, thereby reducing in-process inventory compare to the traditional MRP. The model simultaneously addresses three problems [Kamantzky 1985]:

- Scheduling production so that demands for finished products and dependent demands for components are met.
- Scheduling production without exceeding equipment capacities
- Scheduling production so as to minimize the sum of inventory carrying costs, setup costs, overtime costs and underutilization costs.

However, there are drawbacks of this model. One drawback of this approach is that all operations in a route are performed during the same period. This assumption requires that the planning periods be as long as the average lead time for the products being manufactured, or that routings be kept very short, at least in the model's input data. This can be done by artificially extending the bills of materials through the assignment of a part number to the output of every operation in a routing [Kamantzky 1985]. Other drawbacks are the solution time is very long for large problems with lot size restrictions and only one type of lot sizing rule (periodic setup cost or minimum lot size) is possible to be considered. [Nagendra et al 1994]

R Van Landeghem, 1993: presents Leitstand type scheduling systems This journal describes the planning functions (such as MRP or OPT) that the Leistand adequately support. Leistand type of scheduling is a powerful combination of scheduling algorithms with the power and graphic capabilities of current workstation and PC technology. A traditional Leistand can be described as an electronic planning wall, on which all operation steps)or tasks) of a manufacturing order can be scheduled. It normally runs in a multi-tasking environment (such as OS/2 or UNIX) in order to let all of its components work simultaneously, including real-time networking.

Spearman M.L. and Hopp W.L., 1994: developed algorithm that called capacitated materials requirement planning or MRP-C. The basic algorithm of MRP-C provides a feasible solution to problem (1) by using a fast greedy heuristic. It turns on that this sub-optimal algorithm provides very good solutions when compared with optimal (and much slower) approaches. However, it has a problem that is about heuristic solution and therefore is not optimal.

Nagendran P., Das S., and Chao X., 1994: introduced a new MRP algorithm that models the capacity constraints. The algorithm utilizes both linear programming and heuristic to generate the schedule. The new algorithm is able to accommodate a variety of lot sizing rules. This algorithm is designed to work in a computer database environment, and is able to provide a solution in realistic time. But the algorithm is not yet perfect and gives rise to several research questions in realistic time. From some testing with the algorithm, there are some interesting insights into the problem. For instance, since the MRP-LP has no knowledge about lot sizes, it does not make full use of the back order feature.

Taal M. and Wortmann J.C., 1997: provided on solving these capacity problems by improving capacity planning at the materials requirement planning (MRP) level through integration of MRP and finite capacity planning. This obtains in a planning method for simultaneous capacity and material planning. The planning method is based on a new and more accurate primary process modes, giving the planning algorithm more flexibility in solving capacity problems. The algorithm is based on advanced scheduling techniques and uses aggregated information, thus combining speed and accuracy The algorithm is designed to use the available flexibility: alternative routing, Safety stock, and replanning of production orders and requirements.

Samuhavinyoo K. and Hasin M.A.A., 1998: his thesis presents a plan to generate a MPS in accordance with the available rough-cut capacity in case of Siemens, an electrical equipment manufacturing company in Thailand. This thesis also presents the algorithm used in software to support this time consuming and complex iterative computation process

CHAPTER FOUR

COMPANY AND PRODUCT PROFILE

4.1 A General Overview of Plastic Companies in Bangladesh

According to the publication of Bangladesh Bureau of Statistics, there is information about the total plastic manufacturing companies in Bangladesh, but no classified information is available here.

Title	1991-92	1992-93	1993-94	1995-96	1997-98
Number of factories	167	166	172	210	178
Avg. annual employment (admin)	3214	2996	3337	5001	3660
Avg annual employment (production)	2391	2179	2930	3599	2476
Fixes Asset (in million taka)	376	527	387	740	775
Industrial Cost (in million taka)	816	658	631	608	541

4.2 The Organization

The plastic manufacturing company is located at Tongi, Dhaka. They get orders from several companies that produce oil (both mustard and Soybean) and mineral water. The bottles are of many different sizes and shapes. The ordering characteristic is lumpy in nature. Thus, it is a perfect example of order-based batch manufacturing process.

4.3 Process Description

The companies in Bangladesh that produce bottles basically of two types: some produce bottle form raw materials (plastic, resin etc.) and other produce it from preforms. "Preform" is nothing but a plastic product from which bottles of different shapes can be produced. The company now buys preforms from India in batches. Then using the preforms, they produce bottles in a single stage production cycle. There are three similar machines, which produce bottles simultaneously. Thus, it is a perfect example of Parallel Machine Sequencing Problem, as outlined in 'Scheduling'.

The bottle manufacturing process has the following steps of operations, in this company:

Blowing Stage

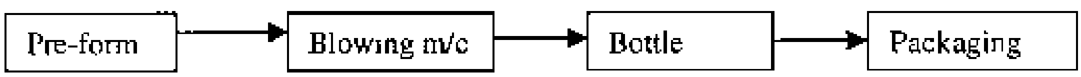


Figure 4.1 Blow Molding Operation.

4.4 Product Description

As stated earlier, the company imports preforms from India, all white in color. They produce three sizes of bottles, which are generally classified by weights. The categories are:

- 54 gram pre-form for producing 2 liter bottle
- 45 gram pre-form for producing 1 liter bottle
- 42 gram pre-form for producing 500 cc bottle

The 2-liter and 1-liter bottles are used for mineral water, whereas, 1-liter and 500-cc bottles are used for oils.

4.4 Machine Capacity

All three machines are identical, and have equal capacity. As the machines are old, they cannot produce up to maximum capacity. Each machine can produce 500 bottles per hour.

CHAPTER FIVE
THEORETICAL CONSIDERATIONS

5.1 Scheduling

Scheduling is the allocation of resources over time to perform a collection of tasks. This rather general definition of the term does convey two different meanings that are important in understanding the purpose of this topic. First, scheduling is a decision-making function; it is the process of determining a schedule. In this sense, much of what we learn about scheduling can apply to other kinds of decision-making and therefore has general practical value. Second, scheduling is a body of theory; it is a collection of principles, models, techniques, and logical conclusions that provide insight into the scheduling function. In this sense, much of what we learn about scheduling can apply to other theories and therefore has general conceptual value. Thus there are two purposes of scheduling; it is meant to provide both a practical and a conceptual learning experience. Let us look more closely at the scheduling function and at scheduling theory [Baker 1974, French 1986].

5.2 The Scheduling Function

The practical problem of allocating resources over time to perform a collection of tasks arises in a variety of situations. In most cases, however, scheduling does not become a concern until some fundamental planning problems are resolved, and it must be recognized that scheduling decisions are of secondary importance to a broader set of managerial decisions. For example, in manufacturing applications, the fundamental managerial questions involve selecting a product to be manufactured and determining the scale of production. After market studies and economic analyses are used to resolve such issues, technological planning focuses on the question of how the product should be manufactured. Only after these planning questions have been answered, and the availability of resources is known, does it become appropriate to consider problems of scheduling. As another example, the fundamental managerial questions in the delivery of health care require the fundamental managerial questions in the delivery of health care require the designation of services to be provided and the level at which each service will be offered. Then technological planning deals with questions of facility design, equipment utilization, and personnel deployment. Once these decisions have provided a profile of the resources available, it is then possible to deal with scheduling problems.

These examples indicate how the fundamental managerial decisions address themselves to three kinds:

(1) What product or service is to be provided?

(2) On what scale will it be provided?

(3) What resources will be made available?

Determining answers to these questions is the *planning* function; in contrast, the *scheduling* function presumes that answers to these questions already exist. Therefore, the function of scheduling *per se* becomes relevant in a situation where the nature of the tasks to be scheduled has been described and the configuration of the resources available has been determined.

In practice, of course, the scheduling and planning functions may not be completely independent. To illustrate these two functions, here is a typical scenario. The planner first identifies the tasks to be carried out and sets limits on the amount of recourse available The scheduler then takes this information as given and determines how to allocate the available resources to perform the specified tasks. When a tentative schedule is constructed, the scheduler can evaluate it and convey this evaluation to the planner. The planner may not be satisfied with the performance achieved by the tentative schedule and may alter the planned resource capacities (or even the tasks themselves), thereby providing revised input for the scheduler. The interplay between these two roles might be repeated in this manner over several exchanges before a final planning decision is reached. Ultimately, however, planning decisions represent the longer-range commitments, such as design or expansion of facilities, purchase and installation of equipment, and the determination of the labor force. While these decisions may be made originally by considering how scheduling would be accomplished, once they are resolved they determine the limits within which the scheduling function must be performed over a long period of time. Therefore, the scheduling process most often arises in a situation where resource availabilities are essentially fixed by the long-term commitments of a prior planning decision.

With the background in mind, we can describe the steps by which scheduling decisions are reached as the *system approach*. Used informally, this term may mean only a rational method of arriving at decisions; but the systems approach does exhibit a formal structure, one that has found more and more support in contemporary managerial practice. The four primary stages of the systems approach are formulation, analysis, synthesis and evaluation. In the first stage, basically, a problem is identified and the criteria that should guide decision-making are determined. This is often a subtle and complicated activity, but good decisions can seldom be expected without a clear definition of the problem in hand and an explicit recognition of objectives. Analysis is the detailed process of examining the elements of a problem and their interrelationships. This stage is aimed at identifying the decision variables and also at specifying the relationships among them and the constraints they must obey. Synthesis is the process of building alternative solutions to the problem. Its role is to characterize the feasible options that are available. Finally, evaluation is the process of comparing these feasible alternatives and selecting a desirable course of action. This selection is, of course, based on the criteria that were developed at the outset.

The study of scheduling model and methods will help develop these skills. Formulating a decision-making criterion is perhaps the most difficult of the four stages, but the scheduling problems illustrate the types of goals commonly found in practice. The processes of analysis and synthesis are aided by a familiarity with suitable models. The models to be studied contain the important elements and relationships that frequently arise in scheduling problems, and they also suggest how feasible solutions can systematically be constructed. Finally the process of evaluating alternatives may be a complicated task in large scheduling problems, and sophisticated solution techniques are often a vital part of the scheduling function.

Formal models are available to aid decision making in a variety of scheduling problems. For example, one of the simplest and most widely used models is the Gantt chart, which is a graphical representation of scheduling relationships. In its basic form the Gantt chart is a graph of resource allocation over time. Generally, specific resources are shown along the vertical axis and a time scale is shown along the horizontal axis. Since the graph breaks down resource allocation by time, it conveys basic information about system status for scheduling purposes. In this concise format, analysis of the graphical relationships can yield inferences about the behavior of a given schedule, while manipulation of the graphical elements can yield comparative information about alternative scheduling decisions. In this way, the Gantt chart serves as a focus for implementing the systems approach in scheduling. The following sections will examine algebraic, logical and simulation models, as well as graphical models, all of which can play the same valuable role in the scheduling function.

A final caveat needs to be added regarding the role of models in scheduling. We noted that models are inherent in the systems approach and provide a direct basis for making decisions when the systems approach is utilize. Indeed, when a model is actually a faithful representation of reality, it can become an integral part of the scheduling function. On the other hand, coarse and somewhat oversimplified models can also be of value, for on this level their role is to represent the general structure and essential properties of scheduling problems. It is the theory of scheduling that has developed this type of model, providing a useful framework for performing the scheduling function effectively.

5.3 Scheduling Theory

Scheduling theory is concerned primarily with mathematical models that relate to the scheduling function, and the development of useful models and techniques has been the continuing interface between theory and practice. The theoretical perspective is predominantly a quantitative approach, one that attempts to capture problem structure in concise mathematical form. In particular, this quantitative approach begins with a translation of decision-making goals into explicit constraints.

Ideally, the objective function should consist of all costs in the system that depends on scheduling decisions. In practice, however, such costs are often difficult to measure, or even to identify completely. In fact. the major operating costs – and the most readily identifiable – are determined by the planning function, while the short-term costs are difficult to isolate and often tend to appear fixed. Nevertheless, three types of decision-making goals seem to be prevalent in scheduling; efficient utilization of resources, rapid response to demands. and close conformance to prescribed deadlines. Frequently an important cost-related measure of system performance (such as machine idle time. job waiting time, or job lateness) can be used as a substitute for total system cost, and quantitative approaches to problems with these criteria appear throughout the literature on scheduling.

Two kinds of feasibility constraints are commonly found in scheduling problems. First, there are limits on the capacity of available resources and, second, there are technological restrictions on the order in which tasks can be performed. A solution to a scheduling problem is any feasible resolution of these two types of constraints. so that 'solving' a scheduling problem amounts to answering two kinds of questions;

1. Which resources will be allocated to perform each task?
2. When will each task be performed?

On other words, the essence of scheduling problems gives rise to

(1) allocation decisions and

(2) sequencing decisions. The scheduling literature is replete with mathematical models for these two kinds of decision problems.

Traditionally. scheduling problems have viewed as problems in optimization subject to constraints – specifically, problems in allocation and sequencing. Sometimes. scheduling is purely allocation, and in these cases mathematical programming models can usually be employed to determine optimal decisions. These general techniques are described in many available literatures. On the other hand, problems that are purely sequencing are germane to the scheduling field.

The vital elements in scheduling models are resource and tasks. In the scheduling literature resources are typically characterizes in terms of their qualitative and quantitative capabilities, so that a model describes the type and the amount of each resource. An individual task is described in terms of such information as its resource requirement, its duration, the time at which it may be started, and the time at which it is due. In addition, a collection of tasks may sometimes be described in terms of the technological constraints (precedence restrictions) that exist among its elements.

The theory of scheduling also includes a variety of techniques that are useful in solving scheduling problems. Indeed, the scheduling field has become a focal point for the development, application, and evaluation of combinatorial procedures, simulation techniques, network method, and heuristic solution approach. The selection of an appropriate technique depends on the complexity of the problem, the nature of the model, and the choice of a criterion as well as other factors; in many cases it might be appropriate to consider several alternative techniques. For this reason, scheduling theory is perhaps as much the study of methodological as it is the study of models.

To classify the major scheduling models it is necessary to characterize the configuration of resources and the behavior of tasks. For instance, a model may contain one resource type or several resource types. If it contained one resource type, tasks are likely to be single tasks, while multiple-resource models usually involve multistage tasks, and in either case resources may be available in unit amounts or in parallel. In addition, if the set of tasks available for scheduling does not change over time, the system is called *static*, in contrast to cases in which new tasks arises over time, where the system is called *dynamic*. Traditionally, static models have proven more tractable than dynamic models and have been subjected to more extensive study. Nevertheless, static models have often captured the essence of more complex, dynamic systems, and the analysis of static problems has frequently uncovered valuable insights and sound heuristic principles that are useful in more general situations.

Many of the early developments in the field of scheduling were motivated by problems arising in manufacturing. Therefore it was natural to employ the vocabulary of manufacturing when describing scheduling problems. Now even though scheduling work is of considerable significance in many non-manufacturing areas, the terminology of manufacturing is still frequently used. Thus, resources are usually called 'machines' and basic task modules are called "jobs". Sometimes, jobs may consist of several elementary tasks that are interrelated by precedence restrictions; such elementary tasks are referred to as "operations". Therefore, it is possible to encounter, for example, a problem in the scheduling of outpatient visits to specialists in a diagnostic clinic and to find the system described generally as the processing of "jobs" by "machines".

5.4 Sequencing Algorithms

The pure sequencing problem is a specialized scheduling problem in which an ordering of the jobs completely determines a schedule. Moreover, the simplest pure sequencing problem is one in which there is a single resource, or machine. As simple as it is, however, the single machine case is still very important for several reasons. First, in the learning process, the single machine problem is significant in that it can illustrate a variety of scheduling topics in a tractable model. It provides a context in which to investigate many different performance measures and several solution techniques. It is therefore a building block in the development of a comprehensive understanding of scheduling concepts, an understanding that should ultimately facilitate the modeling of complicated systems. In order to understand completely the behavior of a complex system, it is vital to understand the workings of its components, and quite often the single-machine problem appears as an elementary component in a larger scheduling problem. Sometimes, it may even be possible to solve the imbedded single-machine problem independently and then to incorporate the result into the larger problem. Foe example, in multiple-operation processes there is often a bottleneck stage, and the treatment of the bottleneck itself with single-machine analysis may determine the properties of the entire schedule. At other times, the level at which the properties of the entire schedule. At other times, the level at which decisions must be made may dictate that the processing facility should be treated in the aggregate, as a single resource.

The basic single-machine problem is characterized by these conditions.

C1. A set of n independent, single-operation jobs is available for processing at time zero.

C2. Setup times for the jobs are independent of job sequence and can be included in processing times.

C3. Job descriptions are known in advance.

C4. One machine is continuously available and is never kept idle while work is waiting.

C5. Once processing begins on a job, it is processed to completion without interruption.

Under these conditions there is a one-to-one correspondence between a sequence of the n jobs and a permutation of the jobs Indices 1,2,....,n. The total number of distinct solutions to the basic single-machine problem is therefore $n!$, which is the number of different permutations of n elements. Whenever a schedule can be characterized by a permutation of integers, it is called a *permutation schedule,* which is a classification that extends beyond single-machine cases. In describing permutation schedules, it is helpful to use brackets to indicate position in sequence. Thus [5]=2 means that the fifth job is in sequence is job 2. Similarly, $d_{[1]}$ refers to the due date of the first job in sequence.

After covering some preliminaries in this section, we review in the subsequent sections the elementary single-machine sequencing results for problems containing no due dates, and the elementary results for problems involving due dates. This is organized to show how differences in the choice of a criterion will often lead to differences in methods of solution. In the next section we shall examine several general-purpose methodologies that can be applied to single-machine problems.

5.5 Parallel Machine Problem

According to the definition given in earlier sections, the process of scheduling in general requires both sequencing and resource allocation decisions. When there is only a single resource, as in the single-machine model, the allocation of that resource is completely determined by sequencing decisions. Consequently there is no distinction between these two decision problems in the models covered in the foregoing chapters. To begin to appreciate this distinction we must examine multiple processor models. This chapter and the two that follow are addresses to the elementary multiple processor models; parallel machine systems, flow shop systems, and job shop systems. The next section of this chapter treats parallel machine problems involving identical processors and independent jobs and treats dependent jobs.

5.6 Parallel Identical Processes And Independent Jobs

In scheduling problems it is often possible to take advantage of parallelism in resource structure. A simple context for investigating the effects of parallel resources is the problem of single-stage sequencing with several machines. As in the model, suppose there are n single-operation jobs simultaneously available at time zero. Also suppose that there are m identical machines available for processing, and that a job can be processed by at most one machine at a time. Once again, it is possible to deal with the fundamental performance measures, only this time scheduling decisions will reflect resource parallelism.

5.7 Algorithm

(Minimizing F with parallel Identical Machines)

Step 1. Construct an SPT ordering of all the jobs

Step 2. To the machine with the least amount of processing already allocated, assign the next job on the ordered list of jobs. (Breaks ties arbitrarily) Repeat until all jobs are assigned.

Except for ties, this algorithm will produce a unique schedule and, of course, it will be one of the schedules that might be produced by the m-jobs-at-a-time approach. This heuristic algorithm, however, has two special virtues. First, the algorithm is a dispatching procedure, so that scheduling decisions can be implemented in order that they are made. Second, the algorithm can be extended in an obvious way to deterministic problem involving intermittent arrivals and to stochastic problems involving random arrivals. Neither property holds for the m-jobs-a-time procedure.

By contrast, no direct algorithm has been developed for constructing an optimal schedule when F_w is the criterion. Dynamic programming formulations are possible, but in this case the "curse of dimensionality" renders a dynamic programming procedure impractical for problems of even moderate size. Two theoretical properties apply to this problem First, as should be evident, any optimal solution must have WSPT job ordering at each machine. (If this were not true, a simple pairwise interchange on one machine could improve the schedule.) Second, a lower bound on the optimum value of F_w can be computed, as shown by Eastman, Even, and Isaacs. Let,

$B(1)$ = the minimal value F_w for the given job set if there were only one machine (obtained via WSPT)

$B(n)$ = the minimal value of F_w for the given job set if there were n machines (obtained by assigning each job to a different machine)

Then a lower bound for m machines ($1<=m<=n$) is

$B(m)=[(m-1)B(1)+2B(n)]/2m$

Clearly, B =max {$B9m)$} is also a valid bound, and may be better because of the rare occasions in which $B(m)<B(1)$.

The m jobs-at-a-time procedure is incorporated into a heuristic procedure denote H_m, which works in this way.

Step 1. From a priority list of all unscheduled jobs according to some rule, R.

Step 2. Assign the first "m" jobs on the list to "m" different machines. Repeat Step 2 until all jobs are scheduled and then go to Step 3.

Step 3. Apply WSPT sequencing to each machine.

The complementary heuristic procedure, called H_1, assign one job at a time

Step 1. From a priority list of all unscheduled jobs according to some rule, R.

Step 2. Assign the first job on the list to the machine with the least amount of processing allocated. Repeat until all jobs have been assigned. Then go to Step 3.

Step 3. Apply WSPT sequencing o each machine.

These two heuristic algorithms are applied to a particular case of bottle manufacturing. which is a "Single Machine", "Parallel Identical Machine", problem, having "Batch Oriented" manufacturing system.

CHAPTER SIX

RESEARCH METHODOLOGY

6.1 Introduction

The research is based on the classical ideas of operations management, which says that a particular plan should be selected based on the minimum total costs, which includes inventory cost, overtime cost, shortage cost (opportunity loss), and subcontract cost. The plans are obtained using appropriate rules, or algorithms of scheduling and sequencing. Heuristic rules are tested. as those are able to give a near optimum solution in a feasible time frame. Three plans are obtained in such a way. Then those are examined using the above cost elements. Once the total costs are found, two criteria are used to select the best approach for scheduling in this particular situation. The first criteria is minimum average flow time, which is the most widely used objective of scheduling, and total materials cost, which is the most widely used criteria for selecting a plan, out of many feasible plans. Thus, basically, the schedules are verified twice.

6.2 Data and Analysis

The following steps are followed:

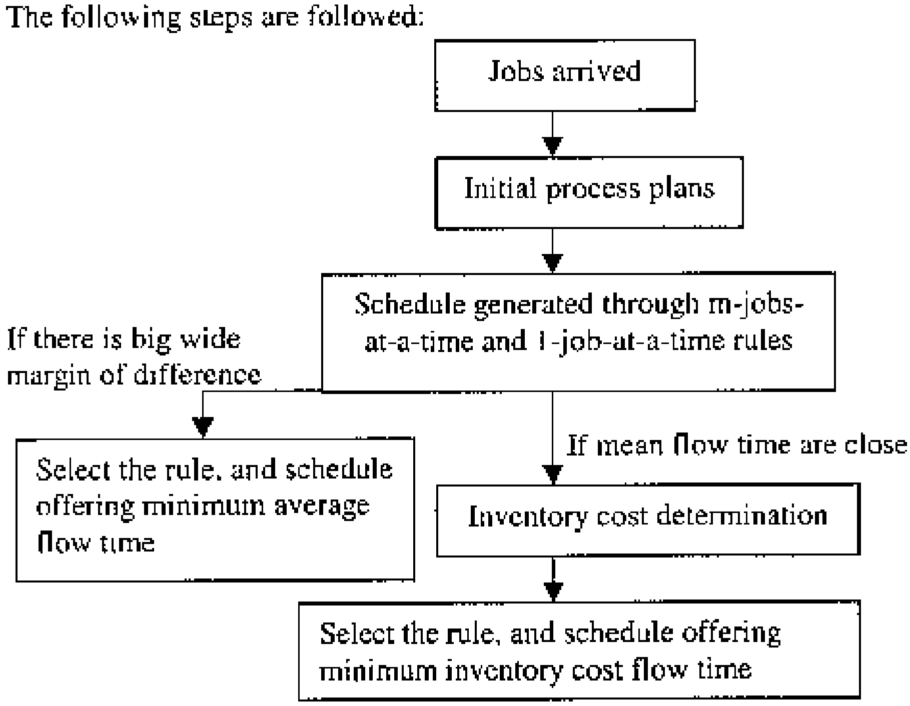


Figure 6.1 Step-by-step Methodology

In addition to schedules, some performance indices were computed in order to know the materials management performance. Some of those indices are as follows [Gopalakrishnan 1984]:

- Material Planning Indices

Planning efficiency index = Number of rush orders placed/ total no. of orders

- Inventory and Stores

Raw material, spare parts, finished goods inventory and work-in-progress indices:

1 Week's inventory on hand ratio = Material on stock/ average inventory
2 Inventory turnover ration (finished goods) = annual sales/average inventory
3 Inventory turnover ratio (raw materials) = annual consumption/ average inventory

- Store Indices

1 Store efficiency index = No. of requisitions delivered on time/total no. of requisitions
2 Scrap disposal index = value of scrap disposal / total value of scrap
3 Scrap loss index = value of scrap sold / value at which bought

CHAPTER SEVEN
ANALYSIS

7.1 Schedule Generation

The schedules are generated using two rules m-jobs-at-a-time, parallel identical machine algorithm and one-job-at-a-time parallel identical machine algorithm. Both rules are heuristic in nature.

7.2 Scheduling Using H_m and H_1 Heuristic Algorithms Without Considering Setup Time

There are three identical machines, for which m=3 is considered. Processing times per jobs are listed below. The jobs are received in a period of a month.

Table 7.1: Job processing time and weightage

Job j	1	2	3	4	5	6	7	8	9	10
t_j	5	15	6	13	18	20	8	8	10	4
w_j	2	4	2	4	5	5	3	3	3	2
t_j/w_j	2.5	3.75	3.0	3.25	3.6	4.0	2.67	2.67	3 33	2.0

Here, t_j is the processing time for job j, w_j is the weightage for job j.

Under H_m (= H_3) an initial ordering must be specified in Step 1. Then three jobs are assigned simultaneously to three machines. Then the final sequencing is done based on weightages of the jobs.

Under H_1, suppose again, that the jobs are initially ordered by WLPT. The procedure then simply assigns the jobs one at a time, and finally reorders all jobs so that WSPT prevails on each machine. The schedule that results has a slighty smaller value F_w than the one produced above by H_m.

The comparative study examined several variations of these heuristic procedures and concluded that their relative behavior was extremely difficult to characterize. The study found that

(a) H_l and H_m will in general produce different schedules, and either method will typically produce different schedules when the initial ordering R is varied.

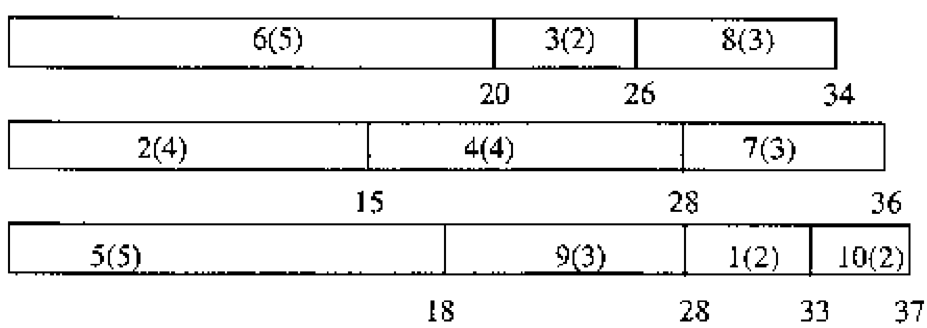
(b) neither H_l *or* H_m can guarantee optimality; and

(c) it does not appear possible to identify a "best rule" R for H_l or for H_m

a) H_m heuristic rule:

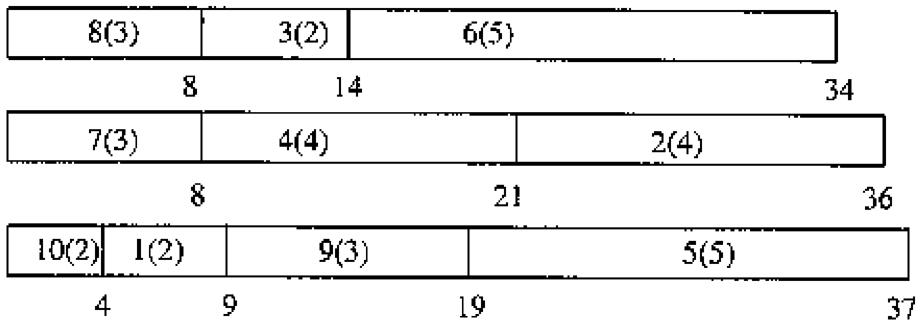
Initial Job List: {6, 2, 5, 9, 4, 3, 8, 7, 1, 10}.

Assignment of jobs to machines:



Jobs (w_j)	Machine Assigned
6	1
2	2
5	3
9	3
4	2
3	1
8	1
7	2
1	3
10	3

Final Schedule



Computations of Weights of individual machines:

$m_1 \Rightarrow 34x5+14x2+8x3=222$

$m_2 \Rightarrow 36x4+21x4+8x3=252$

$m_3 \Rightarrow 37x5+19x3+9x2+4x2=268$

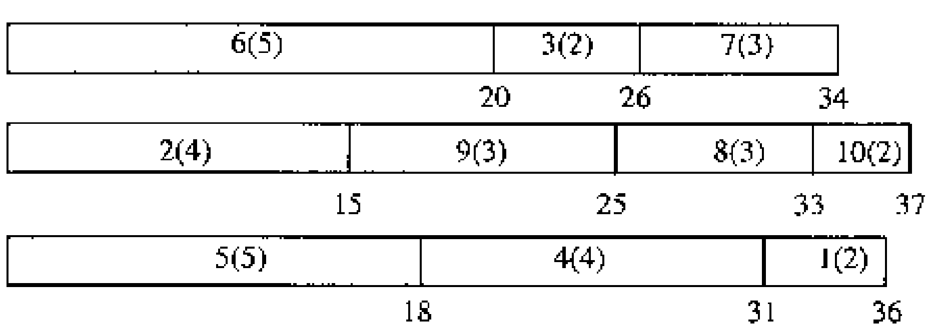
Computation of weighted mean flow time:

$$F_w = \frac{\sum_{j=1}^{3} W_j F_j}{\sum_{j=1}^{3} W_j} = \frac{222+252+268}{2+4+2+4+5+5+3+3+3+2} = \frac{742}{33} = 22.48 \text{ hours}$$

<u>b) H_1 heuristic rule:</u>

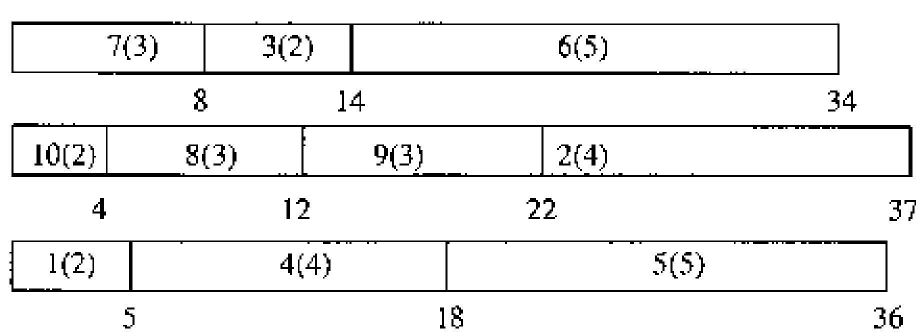
Initial job list: {6, 2, 5, 9, 4, 3, 8, 7, 1, 10}

Initial schedule:



Jobs (w_j)	Machine Assigned
6	1
2	2
5	3
9	2
4	3
3	1
8	2
7	1
1	3
10	2

Final schedule:



Weights of individual machines:

m_1 => 34x5+14x2+8x3=222

m_2 =>37x4+22x3+12x3+4x2=258

m_3 => 36x5+18x4+5x2=262

Computation of weighted mean flow time:

$$F_w = \frac{\sum_{j=1}^{3} W_j F_j}{\sum_{j=1}^{3} W_j} = \frac{222+258+262}{2+4+2+4+5+5+3+3+3+2} = \frac{742}{33} = 22.48 \text{ hours}$$

7.3 Scheduling Using H_m and H_1 Heuristic Algorithms Considering Setup Time

There are three identical machines. Processing times per jobs with considering machine setup time are listed below.

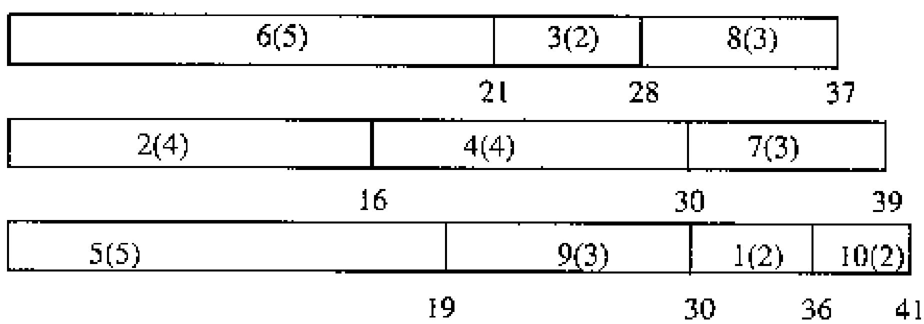
Table 7.1: Job processing time and weightage

Job j	1	2	3	4	5	6	7	8	9	10
t_j	6	16	7	14	19	21	9	9	11	5
w_j	2	4	2	4	5	5	3	3	3	2
t_j/w_j	3	4	3.5	3.5	3.8	4.2	3	3	3.67	2.5

a) H_m heuristic rule:

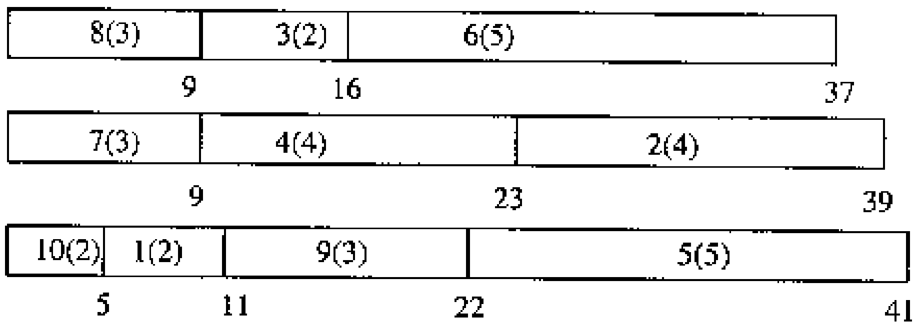
Initial Job List: {6, 2, 5, 9, 4. 3. 8, 7, 1, 10}

Assignment of jobs to machines:



Jobs (w_j)	Machine Assigned
6	1
2	2
5	3
9	3
4	2
3	1
8	1
7	2
1	3
10	3

Final Schedule



Computations of Weights of individual machines:

m_{1}=> 37x5+16x2+9x3=244

m_{2}=>39x4+23x4+9x3=275

m_{3}=> 41x5+22x3+11x2+5x2=303

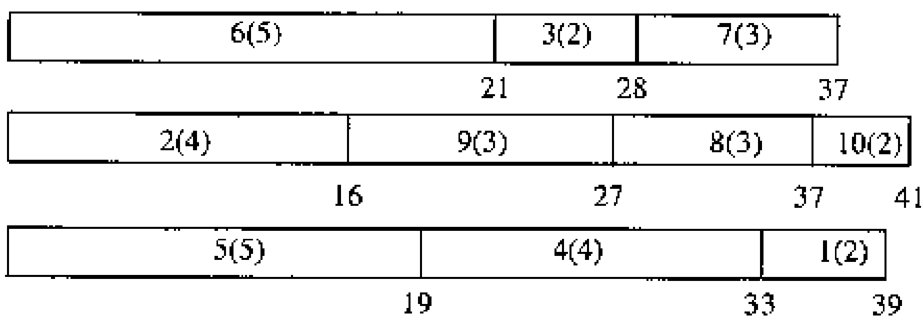
Computation of weighted mean flow time:

$$F_w = \frac{\sum_{j=1}^{3} W_j F_j}{\sum_{j=1}^{3} W_j} = \frac{244+275+303}{2+4+2+4+5+5+3+3+3+2} = \frac{722}{33} = 24.9 \text{ hours}$$

b) H_1 heuristic rule:

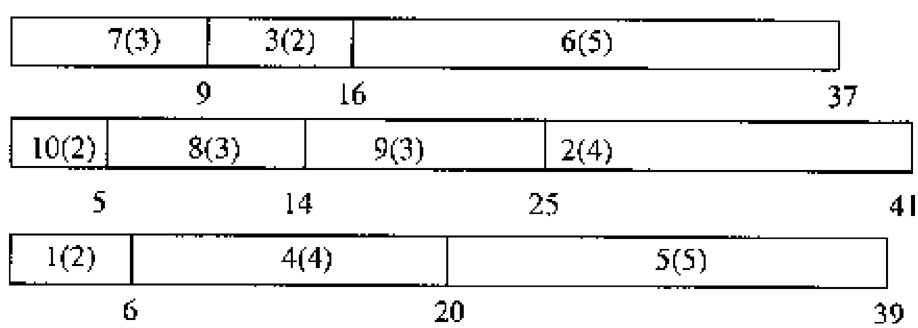
Initial job list: {6, 2, 5, 9, 4, 3, 8, 7, 1, 10}

Initial schedule:



Jobs (w_j)	Machine Assigned
6	1
2	2
5	3
9	2
4	3
3	1
8	2
7	1
1	3
10	2

Final schedule:



Weights of individual machines:

$m_1 \Rightarrow 37x5+16x2+9x3=244$

$m_2 \Rightarrow 41x4+25x3+14x3+5x2=291$

$m_3 \Rightarrow 39x5+20x4+6x2=287$

Computation of weighted mean flow time:

$$F_w = \frac{\sum_{j=1}^{3} W_j F_j}{\sum_{j=1}^{3} W_j} = \frac{244+291+287}{2+4+2+4+5+5+3+3+3+2} = \frac{822}{33} = 24.9 \text{ hours}$$

As can be seen, mean weighted flow times, a widely used scheduling objective. are equal in both cases of H_1 and H_m heuristic rules. Thus, a deadlock is created as to which rule is suitable for this particular case. Thus, further investigation is required to arrive at a decision. Total planning costs, which include inventory holding costs, shortage costs, surplus costs, over time costs, etc are considered with respect to each schedule generated by the above two heuristics rules. The following section illustrates this.

7.3 Total planning costs

Costs for both plans are computed as per aggregate planning concepts. All possible alternative cost elements are included in the following computations as given in the tables:

Table 7.2 *m*-jobs-at-a-time algorithm (on an aggregate basis)

Cost and other elements	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**Total**
Beginning inventory	10,000	3200	3400	3000	2500	2000	
Work days per month (8 hrs/day x 25 days) (8 hrs/day x 20 days) –Feb	200	160	200	200	200	200	
Production hours available (8 hrs + 4 hrs) /day	300	240	300	300	300	300	
Regular shift production (in thousands)	1500	1200	1500	1500	1500	1500	
Demand forecast (in thousands)	1400	1000	1500	1600	1700	1800	
Units over time	0	0	0	100	200	300	
Over time cost (1.5 times)	0	0	0	10000	20000	30000	
Safety stock (10% of forecast) (in thousands)	140	100	150	160	170	180	
Units excess			100		150		
Units shortage loss		100					
Total cost (Taka)							80,245

Table 7.3 One-job-at-a-time algorithm (on an aggregate basis)

Cost and other elements	Jan	Feb	March	April	May	June	Total
Beginning inventory	10,000	3500	3000	2500	2000	1500	
Work days per month (8 hrs/day x 25 days) (8 hrs/day x 20 days) –Feb	200	160	200	200	200	200	
Production hours available (8 hrs + 4 hrs) /day	300	240	300	300	300	300	
Regular shift production (in thousands)	1500	1200	1500	1500	1500	1500	
Demand forecast (in thousands)	1400	1000	1500	1600	1700	1800	
Units over time	0	0	0	50	150	200	
Over time cost (1.5 times)	0	0	0	8000	12000	12000	
Safety stock (10% of forecast) (in thousands)	140	100	150	160	170	180	
Units excess			40		50		
Units shortage loss		120					
Total cost (Taka)							50,178

It can be seen that total planning cost is much lower in case of One-Job-at-a-Time (H_1) rule Thus, for this situation H_1 rule is suggested.

7.4 Additional Measurements on Materials Management Performance

Some additional performance measurements are computed in order to see the performance of plans, though scrap index is not directly related. Still then, it is computed as an additional aspect.

7.4.1 Scrap Index

Table 7.4 % Scrap on Blow Machine on 2000-2001

Month	Production ('000) 2000	Production ('000) 2001	Scrap ('000) 2000	Scrap ('000) 2001	% scrap 2000	% scrap 2001
Jan	1000	1100	5100	4290	5.1	3.9
Feb	1200	1200	6240	4800	5.2	4.0
Mar	1400	1300	7000	5070	5.0	3.9
Apr	1500	1500	7200	5700	4.8	3.8
May	1500	1400	7350	4900	4.9	3.5
Jun	1400	1500	6580	5250	4.7	3.5
Jul	1500	1500	6600	5400	4.4	3.6
Aug	1600	1400	6880	4900	4.3	3.5
Sep	1400	1300	5600	4420	4.0	3.4
Oct	1300	1300	5850	4160	4.5	3.2
Nov	1200	1100	4800	3300	4.0	3.0
Dec	1200	1200	4680	3600	3.9	3.0

The above scrap calculations are for all three machines. It can be observed that the scrap rate is gradually declining, though there is random fluctuation as well, which is very common. This decrease is due to proper maintenance. Though it has nothing regarding scheduling rule selection, but as both are aspects of total quality management, this is also studied.

7.4.2 Customer Service Index

Customer service index is a direct measurement of schedules generated. Since the customer service is measured in terms of order delivery requirements, schedules have much to contribute in this regard [Gopalakrishnan].

Customer Service Index = Units Filled from stock /Total unit ordered

This measure shows the percent of units ordered by customer that were filled immediately from stock without shortage. This is directly affected by the order completion dates, an objective of schedule generation. The detailed data and calculations are given in appendix.

Table 7.5 Customer Service index

Under Current situation:

Product	Order Qty ('000 units)	Unit filled on date ('000 units)	Index
2 liter bottle (water)	3000	2200	0.733
1 liter bottle (water)	9000	7000	0.77
1 liter bottle (oil)	3000	2500	0.833
500 cc bottle (oil)	1800	1500	0.833
		Average index	0.792

Under H_m Rule:

Product	Order Qty ('000 units)	Unit filled on date ('000 units)	Index
2 liter bottle (water)	3000	3000	1.0
1 liter bottle (water)	9000	8000	0.88
1 liter bottle (oil)	3000	2500	0.833
500 cc bottle (oil)	1800	1600	0.88
		Average index	0.898

Under H_l Rule:

Product	Order Qty ('000 units)	Unit filled on date ('000 units)	Index
2 liter bottle (water)	3000	3000	1.0
1 liter bottle (water)	9000	8000	0.88
1 liter bottle (oil)	3000	2700	0.90
500 cc bottle (oil)	1800	1600	0.88
		Average index	0.915

It can be seen that while existing experience-based schedule provides 79% customer satisfaction index, in terms of delivery date fulfillment, it can be raised to 89.8% using H_m algorithm, and to 91.5% using H_l algorithm. Thus, H_l rule seems to be the better choice also in terms of customer satisfaction index. It may be stated that this algorithm was seen a better choice in case of total planning cost also.

7.5 PRODUCT MIX ANALYSIS

Among the three products which product should be produced in which quantity to ensure maximum sell as well as maximum profit, a linear programming analysis is done. With several constraints (Demand, capacity and nonnegative), the objective is to maximize total sells.

7.5.1 Linear Programming

Many people rank the development of linear programming among the most important scientific advances of the mid-twentieth century, and we must agree with his assessment. Its impact since just 1950 has been extraordinary. Today it is a standard tool that has saved many thousands or million of dollars for companies or businesses of even moderate size in the industrialized countries of the world, and its use in other sectors of society has been spreading rapidly. Dozens of textbook have been written about the subject, and published articles describing important applications now number in the hundreds. In fact a very major proportion of all scientific computation on computers is devoted to the use of linear programming and closely related techniques.

Linear programming deals with the problem of allocating limited resources among competing activities in the best possible (i.e., optimal) way. This problem of allocation can arise whenever one must select the level of certain activities that compete for scares resources necessary to perform those activities. The variety of situations to which this description applies is diverse indeed ranging from the allocation of production facilities to products to the allocation of national resources to domestic needs, from portfolio selection of shipping patterns, from agricultural planning to the design of radiation therapy and so on. However, one of the common ingredients in each of these situations is the necessity for allocating resources to activities.

Linear programming uses a mathematical model to describe the problem of concern. The adjective "linear" means that all the mathematical functions in this mode are required to be linear function. The word "programming" does not refer here to computer programming; rather, it is essentially a synonym for planning. Thus, linear programming involves the planning of activities to obtain an "optimal" result that reaches the specific goal best (according to the mathematical model) among all feasible alternatives.

Linear Programming (LP) is a mathematical modeling technique designed to *optimize* the usage of *limited* resources. Successful applications of LP exist in the areas of industry, military, agriculture, transportation, economics, health systems, and even behavioral and social sciences.

The LP model, as in any Operation Research (OR) model, includes three basic elements:

1. Decision **variables** that we seek to determine
2. **Objective** (goal) that we aim to optimize
3. **Constraints** that we need to satisfy

The proper decision of the decision variables is an essential first step toward the development of the model. Once the variables are defined, the task of constructing the objective function and the constraints should not be too difficult.

7.5.2 Formulation As A Linear Programming Problem

To formulate the mathematical (linear programming) model for this problem, let

x_1=number of 2 liter bottles produced daily

x_2=number of 1 liter bottles produced daily

x_3=number of 500 cc bottles produced daily

Thus, x_1, x_2 and x_3 are *decision variables* for the model and the objective is to determine the amounts to be produced of different bottles. A logical objective for the company is to increase as much possible (i.e., maximize) the total daily sales from three kinds of bottle.

Letting z presents the total daily sales, we get

$$z=ax_1+bx_2+cx_3$$

where,

a = selling price of each unit of 2 liter bottle = 1.20 tk

b = selling price of each unit of 1 liter bottle = 0.90 tk

c = selling price of each unit of 500 cc bottle = 0.75 tk

and

x_1 = number of bottles (2 liter size) to be produced

x_2 = number of bottles (1 liter size) to be produced

x_3 = number of bottles (500 cc size) to be produced

thus the objective of the company is

$$\text{Maximize } z = 1.20x_1 + .90x_2 + 0.75x_3$$

The last element of the model deals with the constraints that restrict capacity and demand. The constraints in this problem are.

1) $x_1+x_2+x_3<=18000$

As each machine can produce 500 bottle per day, the total quantity produces in a day is 500x3. Again each machine is operated (8+4) =12 hours in a day. So the first constraint is the capacity constraint which express that they machines would produce less than or equals 18000 products in a day.

2) $x_1 <= 440000$

3) $x_2 <= 660000$

4) $x_3 <= 550000$

The constraints are demand constraints. The demand for specific product must be fulfilled. Usually demand is forecasted and extra 10% of forecasted demand is to be produced in a month. The total number is then divided by 30, days in a month

5) $x_1, x_2, x_3 >=0$ are the non-negative constraints.

Thus the complete problem may be shown as

Maximize z= $1.20x_1+.90x_2+0.75x_3$

Subject to

) $x_1+x_2+x_3<=18000$

$x_1 <= 440000$

$x_2 <= 660000$

$x_3 <= 550000$

$x_1, x_2, x_3 >=0$

7.5.3 Terminology of the Model

The function being maximized, $1.20x_1+.90x_2+0.75x_3$, is called the **Objective Function.** The restrictions are referred to as **Constraints.** The constraints are sometimes called as **Functional Constraints.** Similarly, the $x_i>=0$ restrictions are called as **nonnegative constraints.** As mentioned earlier the x_j variables are **decision variables.**

One may be used to having the term solution mean the final answer to a problem, but the convention in linear programming is quite different. Here, any specification of values for the decision variables (x_1, x_2 and x_3) is called a solution, regardless of whether it is a desirable or even an allowable choice. Different types of solutions are then identified by using an appropriate adjective, as given below.

A feasible solution is a solution for which *all* the constraints are satisfied.

An optimal solution is a feasible solution that has the most favorable value of the objective function.

To solve the problem I have used software called TORA. The calculation in this software is easy and reliable.

7.5.4 About the Software:

The TORA software is written for the IBM/PC/XT/AT and true compatible. It requires 512K RAM and MS-DOS 3.2 or higher. The software uses the notation and procedures developed in: TAHA, H., OPERATIONS RESEARCH:AN INTRODUCTION, 6/e. Prentice Hall, 1997.

TORA can be executed from the floppy drive (a: or b:) or from the hard disk (c:). A hard disk is recommended.

TESTING:

TORA has a total of 8 modules:

Linear programming

Transportation

Networks

Integer programming

Queueing

Histogramming/forecasting

Inventory

Each module (with the exception of INVENTORY) has one or more example models stored in files with obvious descriptive names suffixed with .OR (e.g., LP.OR is a linear programming model).

7.5.5 Results and Discussion

The results obtained from the linear program seems that in a day the total sell would be 20580 taka and 2 liter bottle should be produced by 14600 nos and 1.5 liter bottle to be 3400 nos. The last product (500cc bottle) should not be produced at all. This is the optimum solutiou. The resnlts merely serve to get an idea about the number of production of the products. For a specific order this decision may be altered as per demand. It is for only for the day of rest, when there is no order of products.

TORA Optimization System - Version 2.0, Oct 1996

Date: Thu May 01 13:01:59 2003

Title: Thesis

	x1	x2	x3		RHS
max	1.2	.9	.75		
Constraint 1:	1	1	1	<=	18000
Constraint 2:	1	0	0	<=	14600
Constraint 3:	0	1	0	<=	22000
Constraint 4:	0	0	1	<=	18300

*** OPTIMUM SOLUTION SUMMARY ***

Title: Thesis
inal iteration No: 3
bjective value (max) =20580.0000

ariable	Value	Obj Coeff	Obj Val Contrib
x1	14600.0000	1.2000	17520.0000
.2	3400.0000	0.9000	3060.0000
.3	0.0000	0.7500	0.0000

Constraint	RHS	Slack(-)/Surplus(+)
(<)	18000.0000	0.0000-
2 (<)	14600.0000	0.0000-
3 (<)	22000.0000	18600.0000-
(<)	18300.0000	18300.0000-

*** SENSITIVITY ANALYSIS ***

Objective coefficients -- Single Changes:

Variable	Current Coeff	Min Coeff	Max Coeff	Reduced Cost
.1	1.2000	0.9000	infinity	0.0000
x2	0.9000	0.7500	1.2000	0.0000
:3	0.7500	-infinity	0.9000	0.1500

ight-hand Side -- Single Changes:

Constraint	Current RHS	Min RHS	Max RHS	Dual Price
1 (<)	18000.0000	14600.0000	36600.0000	0.9000
2 (<)	14600.0000	0.0000	18000.0000	0.3000
3 (<)	22000.0000	3400.0000	infinity	0.0000
4 (<)	18300.0000	0.0000	infinity	0.0000

Objective Coefficients -- Simultaneous Changes d:

Nonbasic Var	Optimality Condition
x3	0.1500 + 1.0000 d2 - d3 >= 0
sx4	0.9000 + 1.0000 d2 >= 0
sx5	0.3000 + -1.0000 d2 + 1.0000 d1 >= 0

Right-hand Side Ranging -- Simultaneous Changes D:

Basic Var	Value/Feasibilty Condition

```
x2          3400.0000 +       1.0000 D1 +      -1.0000 D2 >= 0
.1         14600.0000 +       1.0000 D2 >= 0
.x6        18600.0000 +      -1.0000 D1 +       1.0000 D2 +       1.0000 D3
              >= 0
x7         18300.0000 +       1.0000 D4 >= 0
```

End of Solution Summary

CHAPTER EIGHT
CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusion

This research study aimed at analyzing the current production system, ordering characteristics, due date characteristics, and schedules of jobs in a single, but parallel, identical machines. The study also measured the indices on materials management issue, like scrap, and customer satisfaction, or service.

Upon investigation, it was found that both the H_m and H_l algorithms perform equally if mean weighted flow time is calculated. If total planning costs are considered, the H_l algorithm performs in a better way. Also, if customer service index is considered as a scheduling objective, again the H_l algorithm performs in a better way. Thus, H_l algorithm is suggested.

But selection of a scheduling rule largely depends on production process layout, ordering principle, due date principle, etc. If any one or more of these change, the selection of a rule may change as well. Thus, it can be stated that the H_l rule is the best rule for this particular case, but not for all other cases.

In any case, this basic approach, or methodology is applicable to select an appropriate scheduling algorithm in other manufacturing environment also. The approach would be to generate schedules based on feasible scheduling and sequencing algorithms, and calculate the values of selected performance objectives. If objectives values differ substantially, the better value and its corresponding rule may be selected. If they are very close, then total planning costs for each schedule and customer service index may be calculated. Then based on these the better rule may be selected.

8.2.1 Recommendations

For generating a schedule, the company must study the basic characteristics of ordering policy, and production process.

Then based on these, appropriate rules should be selected. There are varieties of complex scheduling algorithms. It must be remembered that a good algorithm provides more optimality ion results, but become unable to be solved in a feasible time (NP-hardness). So, computational complexity must be taken into account while selecting an algorithm

Once the algorithm is selected, performance objectives must be compared. It must be remembered that a rule proved to be appropriate for a situation, may not be proved suitable for another situation. So, selection of a scheduling rule is case specific.

8.2.2 Recommendations for Further Study

This study considered only, heuristic rules, as they are capable of providing a good solution in a feasible time period. But some other rules like, Branch and Bound algorithm may be tested if a powerful computer system is available.

The study assumes demand as deterministic but in real situation demand can be considered as stochastic. Simulation techniques might be appropriate to solve the stochastic demand in order to increase more accuracy planning.

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APPENDIX – A

Table A.1 Ordering policy (on an aggregate basis): 1998

Orders arrived	Jan-April	Late (amount)	Slack (on an average)
1 liter water (in thousands)	3000	1000	7 days (sub-contract)
1 liter (oil bottles) (in thousands)	1200	300	8 days (sub-contract)
500 cc (oil bottles)	1000	100	12 days (sub-contract)
Units over time (in thousands)	400		

Table A.2 Ordering policy (on an aggregate basis): 1999

Orders arrived	Jan-April	Late (amount)	Slack (on an average)
2 liter (water) (in thousands)	3500	1500	12 days (sub-contract)
1 liter water (in thousands)	5000	1000	8 days (sub-contract)
1 liter (oil bottles) (in thousands)	1000	200	10 days (sub-contract)
500 cc (oil bottles)	1200	300	10 days (sub-contract)
Units over time (in thousands)	400		

Table A.3 Ordering policy (on an aggregate basis): 2000

Orders arrived	Jan-April	Late (amount)	Slack (on an average)
2 liter (water) (in thousands)	4000	2000	14 days (sub-contract)
1 liter water (in thousands)	6000	2000	10 days (sub-contract)
1 liter (oil bottles) (in thousands)	1200	300	8 days (sub-contract)
500 cc (oil bottles)	1300	400	8 days (sub-contract)
Units over time (in thousands)	500		

Table A.4 Ordering policy (on an aggregate basis): 2001

Orders arrived	Jan-April	Late (amount)	Slack (on an average)
2 liter (water) (in thousands)	4200	1000	7 days (sub-contract)
1 liter water (in thousands)	4000	1000	7 days (sub-contract)
1 liter (oil bottles) (in thousands)	1200	300	8 days (sub-contract)
500 cc (oil bottles)	1000	200	9 days (sub-contract)
Units over time (in thousands)	400		

APPENDIX B

a) Customer Service index in different years are shown below. These never went up to 90%.

In 1998:

Product	Order Qty ('000 units)	Unit filled on date ('000 units)	Index
1 liter bottle (water)	10000	8200	0.82
1 liter bottle (oil)	2500	2100	0.84
500 cc bottle (oil)	2000	1600	0.800
		Average index	0.82

In 1998, they produced only three types of bottles.

In 1999:

Product	Order Qty ('000 units)	Unit filled on date ('000 units)	Index
2 liter bottle (water)	2400	1800	0.75
1 liter bottle (water)	8000	6000	0.75
1 liter bottle (oil)	2000	1700	0.85
500 cc bottle (oil)	1000	1000	1.0
		Average index	0.8375

In 2000.

Product	Order Qty ('000 units)	Unit filled on date ('000 units)	Index
2 liter bottle (water)	2800	2300	0.82
1 liter bottle (water)	9500	7500	0.79
1 liter bottle (oil)	3200	2800	0.875
500 cc bottle (oil)	2000	1700	0.85
		Average index	0.833

b) Overtime and Shortage reports.

Table B.1 Over time and loss of sales reports, 2000 (Jan-Jun)

Cost and other elements	Jan	Feb	March	April	May	June	Total
Stock audit report	6.000	4000	3000	4000	3000	2000	22000
Work days per month (8 hrs/day x 25 days) (8 hrs/day x 20 days)–Feb	200	160	200	200	200	200	1160
Production hours available (8 hrs + 4 hrs) /day)	300	240	300	300	300	300	1740
Over time payment (in thousands)	5	5	3.5	2.0	3.50	2.50	21.50
Safety stock (10% of forecast) (in thousands)	140	100	150	160	170	180	900
Urgent orders (all to sub-contractors)	100	150	200	150	200		800
Units shortage loss		100	150	150	100	50	550
Rush orders ('000 Taka)	20	25	35	20	38	40	158
Sub-contractors rejection Orders (in thousands)	20	35	15	20	27	30	147

Table B.2 Over time and loss of sales reports. 2000 (Jul-Dec)

Cost and other elements	July	Aug	Sep	Oct	Nov	Dec	Total
Stock audit report	5.000	3000	3500	4000	3500	2500	21500
Work days per month (8 hrs/day x 25 days)	200	200	200	200	200	200	1200
Production hours available (8 hrs + 4 hrs /day)	300	300	300	300	300	300	1800
Over time payment (in thousands)	3.5	2.5	3.5	1.5	2.5	1.5	15
Safety stock (10% of forecast) (in thousands)	140	100	150	160	170	180	900
Urgent orders (all to sub-contractors)	80	50	20	10	20		180
Units shortage loss		500	250	100	140	150	1140
Rush orders ('000 Taka)	10	30	35	25	40	24	164
Sub-contractors rejection Orders (in thousands)	15	25	10	15	20	40	125