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Master production scheduling system under a GT cell

Seung-Ryeol Kim
Iowa State University

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MASTER PRODUCTION SCHEDULING SYSTEM UNDER A GT CELL

Iowa State University

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Master production scheduling system
under a GT cell

by

Seung-Ryeol Kim

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Department: Industrial Engineering
Major: Engineering Valuation

Approved:

Signature was redacted for privacy.

Members of the Committee:

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

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1984

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CHAPTER 1. INTRODUCTION

Preface

A production system operates most effectively when the input and the output of the production system flow smoothly. But there are frequently overstocks or shortages in the inventory and unbalanced loads in the shop flow. Therefore, a system plan must consider the variation in the product quantity, place, and time. A planning system should be carefully designed to improve the efficiency of the total production system.

The following points indicate that the importance of the Master Production Schedule (MPS) is increasing.

1. In the hierarchy of production planning processes, the MPS should be the basis of all operational level schedules. Therefore, the impact of the MPS on the efficiency of the total production system is tremendous.

2. Material Requirement Planning (MRP), where the MPS is the primary input, is replacing the traditional ordering point system in the requirement planning of materials.

3. The MPS is frequently used as an essential part to observe an overall effectiveness for the organization in the decision making of strategic
level which is the final phase of development of management information systems.

Group technology (GT) has the promise of meeting the following challenges in modern manufacturing (19).

1. 75% of manufactured parts will be small lot sizes in coming years. This compares with 25% to 35% now.

2. Customized products require special options and are composed of components with high reliability and closer tolerances.

3. The need to integrate the activities of design and manufacturing is increasing.

This research is to propose an aggregate production planning model and methodologies deriving a Tentative Master Production Schedule (TMPS) for a GT cell where MRP is the production planning and control system. Since the MPS interacts with several functions in the planning system, this research deals with planning subsystems including the Aggregate Production Plan (APP) and MPS. A production plan presents a general outline of the manufacturing activity during the planning horizon. This outline should agree with the objective of the work force, the production capacity, and the customer service level in the aggregate level. The APP has been developed for this purpose. The MPS is derived from the production plan or all demand sources while
minimizing the total production cost.

The objective of the research is to find a more formal, responsible method to develop a TMPS which would have the ability to plan the future work load under the available and the authorized capacity limits.

Background

Production planning process

A formal planning system In the hierarchy of the production planning processes, the MPS is the basis for the lower level plans such as the material and the capacity requirement plan. It is constrained by higher level plans such as the marketing plan and the production plan. Robert McCormick (41) described a formal planning system (Figure 1). He pointed out that the MPS is the planning keystone for a manufacturing company utilizing a formal planning and execution system.

The business plan is the long-term objective of the business and the guideline for the marketing plan, the production plan, and the resource allocation plan for the mid-term period. The marketing plan is developed to meet the income level of the business and the existing and potential customer demand. The production capacity works as a constraint for this marketing plan. The production plan is the time phased statement of the production rate, and it
FIGURE 1. A formal planning system defines the boundary for the future production process. The resource plan functions for all key resources in the company during the production planning horizon. Resources range from drafting-room personnel to cash to capital equipment.
and plant square footage (47). The resource plan is prepared to follow up the production plan.

If the MPS is feasible, the material/capacity requirement planning is derived to expedite the MPS. If the material or the capacity cannot be prepared on time, the MPS may be changed. An MRP method can be used for the requirement planning of the material. A load profile which is derived from the Bill of Material (BOM) and the routing file are the bases for the Rough Cut Capacity Plan (RCCP).

This research is concerned with the Production Plan and the MPS, which will be respectively described in the following sections. The MPS is derived from the production plan and is evaluated by the RCCP which calculates the impact of the MPS on the key resources. If there is no production planning function, the MPS is derived from all the demand sources.

**Aggregate production plan**  The production plan may be defined as the time phased statement of the production rate required to meet the customer demand with the minimum total cost. The production plan establishes the manpower requirement, the equipment requirement, and the level of the anticipated inventories. At this point, managers are required to make many decisions such as smoothing the plant production load, adjusting the capacity target and coordinating with production support functions. The
production plan works interactively with the marketing function, the manufacturing function and other supporting functions such as the financing function and the material procurement function.

When there are constraints in the company resources, the production plan is not consistent with the customer demand. Therefore, the company needs the production plan to satisfy the fluctuating customer demand. This suggests that the production plan ought to consider the sales volume, the production volume, and the inventory level in the aggregate level. A production plan is developed to minimize the total production cost constituting the facility, the inventory, the overload and delay penalty cost, etc. The APP has been developed and used for this purpose.

This research considers the APP where the planning horizon is from one month to one year. Buffa and Taubert (5) described the inputs required, the nature of the plans which are the outputs, and the variables which are under managerial control for the aggregate plan (Table 1). This research addresses the aggregate production planning problem where there are conflicting, multiple objectives. The production plan becomes not only the guideline but also the constraint on the MPS.

Master production schedule An MPS, which may be derived from the production plan, is the expected
TABLE 1. I/O and managerial variables for APP

1. Inputs: Forecasts of:
   - Amount and timing of sales
   - Costs
   - Supply
   Policies and constraints on:
   - Overtime
   - Hiring and firing
   - Inventories
   - Capital
   - Long-range plans

2. Outputs: Aggregate plans and schedules for the use of various sources of capacity

3. Variables under managerial control:
   - Size of work force
   - Production rate
   - Inventory
   - Subcontracting

manufacturing schedule for the major assemblies or the shippable end items. There are several factors affecting the development of the MPS such as the product level to be
scheduled, the planning horizon, and the time bucket. The master scheduled items are identified by the part number in the BOM. McCormick (41) gives some guidelines for the product level to be scheduled in the BOM. He suggested that the BOM level which minimizes the number of potential master scheduled items should meet two criteria.

1. The master scheduled items must be forecastable by marketing.
2. They must represent the bulk of the capacity resources required to manufacture the shippable end items.

The planning horizon of the MPS is larger than the lead time of the master scheduled items. The lead time is constituted of component manufacturing, subassembly and final assembly, etc. Orlicky (47) stated that one week is the suitable time bucket for a MPS, when MRP is implemented.

There are many variations of the MPS among companies. However, the development procedure for the majority of the MPSs can be stated in the following way.

1. The marketing plan and the production plan which are at a higher level than the MPS are built up. The marketing plan is developed by the customer demand or the forecast. The production plan is coordinated with the marketing plan.
2. A TMPS is derived from the production plan and
the marketing plan.

3. The feasibility of a TMPS is tested by calculating the cumulative load on the key functions of the company.

4. Step 2 and Step 3 are repeated by the "trial and error" method until a feasible TMPS is proposed.

5. A TMPS is finalized by a coordinating function such as a master production scheduling committee.

This research handles the development of a tentative master production schedule from the production plan or all demand sources to minimize the production cost.

Rough Cut Capacity Plan (RCCP) The purpose of the RCCP is to check the feasibility of the MPS. The analysis of the MPS can be performed by calculating the impact on the key functions which may be critical resources in the company. The key manufacturing functions may be any critical resources such as bottleneck machines, or entire work centers, final assembly, or vendors who supply a key raw material (41). When the RCCP shows that the proposed MPS is not feasible, the "trial and error" method is used to find a feasible MPS. The result of using RCCP necessitates one of two changes, i.e., to the MPS or to the capacity. If the infeasibility of the MPS is not resolved by subcontracting or overtime, this fact affects the MPS or the higher level plans such as the production plan, the
marketing plan, and the resource plan.

The cumulative load which is derived by the proposed TMPS is compared with the available capacity limit to evaluate the feasibility of the proposed MPS. The load profile is used instead of the BOM and the routing file to calculate the time-phased cumulative load. The load profile is the planning data representing the time-phased load on each resource to produce one end item. The success of the RCCP depends on the load profile which should be carefully designed and prepared. The logic of the RCCP is just simple calculation to get the cumulative load via the MPS and the load profile. Therefore, the critical factor is the load profile and not the logic of the RCCP.

**MRP and GT**

**MRP**  The basic principle of MRP is that the quantity and timing of the raw materials/components are determined by the known or forecasted requirements for the end product. Using MRP keeps the inventory balance at the minimum level by supplying the raw materials/components just prior to the date of need, and makes up for the drawbacks of the traditional order point system where shortage and over-stock occur by considering only the past requirements. Wight and Plossl (59) pointed out that "the number of items in inventory that can best be controlled by MRP outnumbers those that can be controlled effectively by the order point
The advantages of MRP are well-known, but successful implementation of an MRP system has not been easy. A great many of MRP systems are still "order launching systems coupled with computer aided dispatching and there have been a number of failures" (56). One U.S. consultant has commented that only about one in a hundred MRP systems might be regarded as "successful" (45).

There may be many factors affecting the successful implementation of an MRP system, but this low rate of success does reflect the inherent problems of the MRP system. Colin New (45) described the drawbacks of MRP:

1. Load input variability is significantly greater than master schedule levels because of the random initiation of orders and their phasing.

2. It is inevitable that component sets will not "match" assembly requirements, because the lot sizes are set in relation to the individual component rather than to a production cycle. This increases inventories and may cause allocation problems when shortages occur.

3. Groups of components with the same setup requirements will rarely be ordered at the same time because of independent component batching. Thus, the scope for setup savings is severely
All these problems are caused by the complex routings of components and complex interactions among jobs based on the functional layout.

**Group technology** A GT cell is the production cell which is determined by the component similarity rather than the machine similarity. The production cell is composed of a small group of humans and machines which produce a component set from the raw material. A coding and classification scheme is used to classify similar components and the product families.

A GT cell offers some distinct advantages compared to the functional layout. Reduced throughput time, decreased Work In Process (WIP) and finished goods inventory, increased flexibility to handle forecast errors, and reduced paperwork are some advantages mentioned by actual users (21).

The components must be produced with the right quantity at the right time to meet the final assembly. Correct components should be produced on the scheduled time to get the advantage of GT. This requires a production planning and control system which is suitable for GT cells.

**A GT based MRP system** Several authors (21, 45, 56) proposed that MRP can be used as a production planning and inventory control system on a group layout producing small
batch large variety products. Throughput time is more rapid and more deterministic in the group layout than in the functional layout, but the quantity and the timing of the raw material or components should be derived from the final end item requirements. MRP can be used for this purpose, but it inherently generates the planned order based on the lot sizing of each component, and each planned order has a different multiple cycle. The MRP with multiple cycle ordering also generates the loading on the GT cell irregularly, which makes it difficult to expedite the operation on the GT cell smoothly and consistently.

To solve this problem, Colin New (45) suggested UPBC (Unique Period Batch Control) of which the essential feature is that all components are ordered on the same cycle. Hyer and Wemmerlöv (21) pointed out that no method for economically determining family lot sizes has been found in the literature dealing with GT cell production. They proposed the NRN rule (Nice Round Numbers rule) for the ordering trigger.

This research hypothesizes that MRP can accommodate the production planning and control system of the GT cell, and handles the production planning subsystem under a GT based MRP system.

Master scheduled items can consist of end items or a classes of similar parts. The load profile which is derived
from the BOM and routing file is used as a tool of master production scheduling. Therefore, the process stages of the master production scheduled items are considered in developing the load profile. This research handles only one level of the production process and does not consider the process stages of the master production scheduled items or interrelationships of the parts. Further, the application of this research is in a GT environment as described by short lead times, small volumes, and requirement of a load profile. While parts classification may be included in developing the load profile, the existence of a classification system is not mandatory to this research. As such the application to a GT cell or a small shop are equally effective.

Need for the Study

The traditional method for master production scheduling is as follows. The master production scheduler develops a TMPS, based on experience, intuition and business sense. It is not known, however, whether a TMPS is reasonable or not until the RCCP of the proposed TMPS is developed. Therefore, the "trial and error" method must be used to get a better TMPS. Even though there is an integrated production planning and inventory control system, the master production scheduling logic usually does not include the
resource constraints. It does include netting logic to derive the production requirement from the gross requirement and on-hand inventory. There are also many designed logic structures to minimize the sum of production and inventory holding cost in order to find the optimal MPS, but the feasibility of the MPS with respect to capacity is also evaluated by the RCCP. A trial and error method is also used to get a better TMPS.

In the traditional "trial and error" method, if multiple items and resources are involved it is almost impossible to balance the work-load on the resources in one iteration. Even several retrials cannot assure the balancing of the work-load. The "trial and error" method has been used because the capacity limit is not considered in developing the TMPS.

There are several reasons why the traditional approach does not include the capacity as a criterion to get the optimal MPS.

1. It is not easy to determine the capacity target/capacity limit because there are so many control variables and elements. The capacity target/capacity limit is derived by compromising available capacity and required capacity. Required capacity is derived from the authorized production plan or the production requirements,
and it is the guideline to determine the available capacity which is the basis for finding the feasible and authorized MPS.

2. There are several analytical approaches to these problems, but either the models are too ideal, or the solution procedures requiring computing time are excessive. Exact methods are computationally limited to the relatively small size of problems.

3. In the simulation approach, it is difficult to generate the realistic test problems because the capacity patterns and the cost functions vary too much. Therefore, it requires excessive computing efforts to simulate all combinations of the system parameters.

4. It is not easy to measure the deviation between the near optimal solution of the proposed approach and the real optimal solution. "Goodness" of the proposed method should be evaluated.

The objective of this research is to find a better methodology than the traditional "trial and error" method. In other words, the research is to develop a TMPS which minimizes the production cost by effectively smoothing the work-load under a GT cell with capacity limits, thus reducing the frequencies of the RCCP application. This is
possible by including a critical capacity limit in the master production scheduling logic as a constraint.

Research Scope and Objectives

This research deals with the case where the business type is make-to-stock under a GT cell. An MRP system accommodates the production planning and control function for this GT cell. The demand pattern of the end items is seasonal, and the capacity limit during the scheduling period is constant. The proposed master production scheduling system is a decision support system, therefore, the TMPS which is the output of the proposed system will be finalized by coordinating functions such as the master production scheduling committee. That is, the process to generate the finalized MPS is not included, but only the process to get the TMPS.

There are several ways to derive the production requirements. They may be derived from the on-hand inventory and all demand sources, which are composed of actual demand (order on the book) and potential order (forecast demand). There may be two categories in deriving a production requirement. First, if there is a production planning function, a TMPS is guideline by the production plan. A weekly production requirement is derived from the monthly production plan and the customer order entries.
Second, if there is no production planning function, then a weekly production requirement is determined by all demand sources such as customer order, interplant requirements, warehouse requirements, etc. The methods to derive a production requirement depend on their source and the level of the MPS. The combination of the methods to obtain the production requirements is given in Table 2. In this research, only case B is handled, and the interaction between the production plan and the MPS is excluded. When a heuristic procedure is proposed for the combinatorial problems, the number of test problems may be so large that it is highly impractical to test all the combinations of the system parameters. Therefore, this research will only evaluate the proposed procedure for a family of the specific test problems.

**Research objectives** The purpose of this research is to develop the following objectives in a GT based MRP System:

1. To develop a master production scheduling procedure deriving a TMPS which minimizes the total production cost when there is a constraint of capacity limit. The total production cost is composed of setup, holding, overload and delay penalty cost.
2. To develop an aggregate production planning model
TABLE 2. The method to determine a production requirement

<table>
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<th>The Level of the Production Plan and That of the MPS</th>
<th>Equal</th>
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<td>Source of the Production Requirement</td>
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<td>Optimal Production Plan</td>
<td>Case A</td>
<td>Case B</td>
</tr>
<tr>
<td>All Demand Sources</td>
<td>Case B</td>
<td>Case B</td>
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which will coordinate the objectives of the marketing, financing, production, and management functions in the production planning level.

3. To develop a method balancing the load within a GT cell.

4. To develop a procedure for getting the optimal capacity target for the critical resources.

5. To develop a procedure to evaluate the heuristic method of getting a TMPS.
Uniqueness of the MPS under a GT Based MRP System

When a functional layout is changed into a GT layout, there are several advantages in master production scheduling. Several characteristics of the MPS under a GT based MRP system and the reasons for them are described below (6). These characteristics will justify the approach to develop the optimal TMPS.

1. The lead time of an end item which includes setup time, queuing time, and transporting time can be reduced.
   a. The total setup time can be reduced because similar parts are ordered together, therefore, changeover is decreased.
   b. The queuing time and WIP can be reduced, because the material flow and the routings of components and the interactions among the jobs are simplified.
   c. Transportation time can be reduced. Because machines in a group are close together, continuous transfer is possible.

2. The MPS has the capability to accommodate the market changes quickly because of the reduction in the lead time of the production. This also makes it possible to promise quick delivery to the customer, resulting in increasing the customer service level and potential orders. This implies that the MPS is
elastic to the other external variables; then, the firm planned period in the planning horizon is not mandatory.

3. The feasibility of the proposed TMPS can be evaluated interactively. Similar parts are classified by the coding and classification scheme and they are planned in one family. That is, the scheduling approach is based on the tooling and the material families; therefore, the complexity of the master production scheduling is reduced and the implementation of the interactive MPS system is easier than the other MPS systems under a different environment.

4. Expediting the MPS over the GT cell is simple because the workers have common aims and know their contribution to the company. They understand all operations on a part instead of one operation and work together well because of the minimal external control and the reduction in co-ordination with the other functions.

5. The scheme developing a load profile is different from that of the other environments. A coding and classification scheme and the MRP logic with the single cycle and single phase ordering are used to develop the load profile.
CHAPTER 2. LITERATURE REVIEW

Aggregate Production Plan

There are four widely recognized traditional approaches such as the linear decision rule, management coefficient model, parametric production planning approach, and search decision rule in the aggregate production planning problem.

The pioneering research of the aggregate planning methods was made by Modigliani et al. (43). They developed the linear decision rule as a means of making aggregate employment and production rate decisions. The objective function of the linear decision rule model is to minimize a quadratic total cost function. The total cost is composed of the costs caused by regular work force level, hiring/firing, overtime/idle time, and inventory holding.

Bowman (2) developed the management coefficient model on the premise that the managers are aware of and sensitive to the variables which are important in the aggregate planning decisions, but they are inconsistent in using their knowledge. He proposed to establish the form of decision rules for aggregate planning through rigorous analysis. On the contrary, the coefficients for these decision rules were setup through the multiple regression analysis of the management's past decisions.

The parametric production planning approach developed by
Jones (24) is a heuristic approach to discover the decision rules for work force and production. This approach is to evaluate all of the possible combinations of parameters for these rules and to find a parameter set minimizing the cost function. The selected parameters are incorporated with the work force rule and the production rule.

The search decision rule developed by Taubert (57) can cover more realistic problems. The more realistic the model is, the more difficult the analysis is. The search decision rule uses the heuristic optimum-seeking procedures to reach the optimum of an objective function.

Elwood S. Buffa and William H. Taubert (5) classified the decision rule approaches to the aggregate planning problem into mathematically optimal decision rule approach, heuristic decision rule approach and search decision rule approach.

This research is devoted to the mathematically optimal decision rule approach to solve the problem where there are conflicting multiple objectives. The mathematical decision rule approach contains the linear decision rule, linear programming, dynamic programming, goal programming, etc.

Several authors cited below extended the linear decision rule (5). Hanssman and Hess attempted to formulate an approximating linear model to the original non-linear cost terms. Hanssman-Hess linear programming model is equivalent
to the linear decision rule model in terms of general structure. The decision variables and the cost criterion function are the same, but there is a difference that in the Hanssman-Hess linear programming model the cost criterion function is linear, but in the linear decision rule model it is quadratic. Sypkens identifies plant capacity as a decision variable in addition to the work force and production rate. Chang and Jones generalized the linear decision rule methodology to yield both aggregate and disaggregate planning in a multi-product environment. Bergstrom and Smith have developed the basic linear decision rule model to one involving both multi-products and the inclusion of a revenue term.

Some authors described below tried to solve the aggregate production planning problem by applying linear programming (5). Bowman proposed the use of the distribution model of linear programming for aggregate planning. McGarrah developed a basic simplex model of aggregate planning for one period where change and inventory cost functions have the general forms. The specific applications of the simplex model in the industrial aggregate planning situations are reported by Eisemann and Young in the study of a textile mill and by Greene, Chatto, Hicks and Cox in the packing industry.

Several authors tried to solve the problem where there are multiple objectives by applying goal programming. Veikko Jääskelainen (23) used three separate and incompatible
goals, the levels of production, employment and inventories. He defined the preemptive priority factors associated with goals so that goals in a lower rank are satisfied only after those in a higher rank are satisfied or reach points beyond which no improvements are possible under the given constraints. Lee (30) and Kornbluth (26) suggested that goal programming can provide an improved model for the aggregate scheduling problem. Lee (30) pointed out that one advantage of goal programming is that it can be solved by a modified version of the familiar simplex method. Goodman (18) developed a goal programming approach to the problem of scheduling aggregate production and work force. He demonstrated that the effectiveness of such an approach is highly dependent upon the degree of nonlinearity which the goal programming model must approximate. The results indicate that, for relatively low degree models, goal programming may provide an efficient and effective solution approach, while for higher degree models the approach may be inappropriate. Lawrence and Burbridge (29) presented a multiple goal linear programming model for coordinating production and logistics planning. S. M. Lee, R. L. Morris and L. Franz (31) presented an integer goal programming approach to the problem involving fixed costs and multiple goals. A. G. Lockett and A. P. Muhlemann (34) handled the problem achieving a balance between a smooth work-load on the factory and matching production with promised delivery dates.
Classification

Each company may have its own master production scheduling procedure. This can be shown from the fact that most literature of the master production scheduling procedure published from the industry has its own uniqueness. Some authors tried to classify the Master Production Schedule types. Mather and Plossl (38) reviewed ten different types of the master schedule. Paul Maranka (36) discussed the classification of Mather and Plossl and pointed out that a number of combinations of the ten master schedule types under one roof can be encountered and this required the master schedule process to be defined general enough so that any of the types or the combination, thereof, could be incorporated into one planning group. He identified the master schedule type with one of three basic business types—continuous process; production lots made-to-stock and/or option-to-order; and make-to-order. David I. Leo (33) made the abstracts of the COPICS (Conversational Oriented Production and Inventory Control System), where the master production schedule planning flow is classified into—make-to-stock, assemble-to-order, and make-to-order. A. L. Steven (55) suggested three criteria: make-to-stock, make-to-order, and the completely engineered product for the MPS classification.
Special topics

Many authors have concentrated on conceptualizing the development of Master Production Schedules within the hierarchy of production plans.

A. L. Steven (55) described the closed loop MRP system where the relationships among production plan, master schedule and RCCP are represented. David O. Nellemann (44) explained the production planning and the master scheduling as the management's game plan. Robert McCormick (40) discussed the interdependence of the master schedule to the other planning functions including production plan, forecasting, rough cut capacity planning, and planning BOM, plus its interface with downstream modules of material requirements planning and the final assembly schedule. Richard W. Malko (35) stressed that the master scheduling system is the key sub-system for the successful manufacturing control systems and needs the help of other sub-systems to generate the final results. He also wrote about how the raw data can be acquired at the beginning and what techniques are used to remain consistent. John F. Proud (48) introduced the twelve principles of good MPS.

Several companies announced the master production scheduling system in specific business types. Robert W. Kohankie II, Waterbury Farrell and Richard R. Morency (25) implemented a system for preparing a master schedule in a
consumer goods company. They developed the master schedule to convert the production forecast into specific product code level demands that can then be used to schedule each production line against current capacities. W. H. Gaw (17) showed the "team approach" can be used to develop and maintain the master scheduling in a "make-to-order" manufacturing firm. In the process industrials, John Burt (7) discussed the appropriate levels of MPS, techniques for integrating multiple levels, use of planning, inverted BOM, and the relationships with forecasting, production planning and scheduling design. Romeyn C. Everdell and Woodrow W. Chamberlain (16) discussed master scheduling in a multi-plant environment.

Several authors discussed one aspect of MPS. Darnton and Garton (11) described the factors that lead to the changes in the company's planning and control systems, and described the means used to monitor effectiveness of the system. James R. Schwendinger (50) stressed that order promising is a by-product of the MPS process which makes it feasible to make significant improvements in dealing with customers. Ernest C. Huge (20) stressed that lead time management is the key to successful master scheduling and proposed a method to establish a successful lead time management program. Scott R. Miller (42) showed that the Master Production Schedule can compromise the objectives of marketing and production and inventory control. John. J. Bruggeman
and Kathleen T. Merkin (4) described how the master scheduling project is responsible for coordinating the efforts of the other organizational specialists to insure the development of a comprehensive, feasible master production plan. Hal Mather (37) pointed out the importance of the BOM for a successful MPS and excessive protectionism within the various organizations that use the BOM prevents the development of its improvements.

**Interface with other functions**

J. Gaylord May (40) stressed that an accurate forecast of customer demand is, perhaps, the most important ingredient to establish a good master schedule. So, he focused on the concepts which are designed to improve customer demand forecasts in front of manufacturing lead-times. Russel Copeman (9) covered a specific approach used to integrate product line forecasts with actual orders and actual satellite assembly plant requirements into a single master schedule, where it includes the make-to-stock and make-to-order type of customer orders together. Linda M. Smith (51) stressed that order factors have an effect on the success of any MRP-master schedule coordination.

**GT Based MRP System**

As far as the literature survey is concerned, only four papers have dealt with MRP and GT in combination. Colin New
(45) said that the combination of MRP and GT is the new strategy for the component production. The SCRAGOP (Short Cycle Requirements and Group Organized Production) system works well for the component production if the production order trigger is UPBC (Unique Period Batch Control). Nallan C. Suresh (56) pointed out that the optimal production system in a small batch/large variety situation, where the conditions are appropriate for the GT, consists of the following: A group layout; a "short cycle-flow control" approach for direct materials planning and ordering; and a scheduling approach based on tooling, and material families in addition to the other relevant factors. He explained the short cycle-flow control approach which is required in a GT situation can be met by an MRP system. Hyer and Wemmerlöv (21) explained that MRP and GT are a viable combination in a general framework for production planning and control. They discussed the drawback of the period batch control and proposed NRN (Nice Round Numbers) rule to find the order quantity. Spencer (52) explored the scheduling components for the GT lines producing diesel engines in a company.

Capacitated Lot Sizing for Multi-Items

Lot sizing is used to determine the timing and sizing of production to minimize the setup and the holding cost. The first effort to develop the lot sizing technique for multi
items with the capacity limit was made by Eisenhut (15). He defined a priority index from a modified Silver-Meal heuristic for a single product without capacity constraints. Then the production lots are assigned to the current scheduling period until either the capacity constraint is violated or all marginal cost reductions become negative. But this method may generate an underload in an earlier period; therefore, it will result in an infeasible solution. Lambrecht and Vanderveken (28) proposed a backtrack routine to solve this problem by extending the Eisenhut heuristic. Dixon and Silver (13) presented an alternative modified heuristic which guarantees the generation of a feasible solution (if one exists) to avoid the above situation. Ali Dogramaci et al. (14) developed four-step algorithm which improves the feasible solutions obtained to get a better solution. Reuven Karni and Yaakov Roll (49) also developed a lower bound solution by improving the feasible solution so obtained until no further improvement can be made. The above heuristics can be described as period-by-period methods. Newson (46) developed another technique by using a modified Wagner-Whitin algorithm. Newson's heuristic is based upon a series of the shortest path calculations for a network representing the uncapacitated problem.
Evaluation Method of the Heuristic Solution

When a heuristic solution is developed for the large combinatorial problems, a solution standard is necessary to evaluate the proposed solution or procedure. An optimal solution can be used for the solution standard, but it is almost impractical to find the optimal solution for the combinatorial problems in most cases. Therefore, a near optimal solution can be used for the solution standard. Several researchers developed inference procedures to get an estimation of the minimum using small order statistics of a large sample. Lauren de Hann (12) constructed a procedure to derive a confidence interval for the minimum of a function using asymptotic theory. Weissman (58) constructed a procedure to develop confidence intervals based on the lower extreme values of a large sample for the threshold parameter (unknown minimum-life) of a life distribution.

After getting the solution standard, a question is raised, "How does one use the solution standard to evaluate the heuristic solution and procedure?" Dannenbring (10) classified the measurement of a solution goodness as follows:

1. Comparative measure
2. Achievement measure
3. Distributional measure

Comparative measure determines the magnitude of the difference between the solution standard and the value of the
heuristic solution. Achievement measure determines whether
the heuristic solution value is equal to the solution stan­
dard or not. Distributional measure is aimed at finding the
chances that a solution could have been obtained with a value
better than that for the heuristic solution being evaluated.
Achievement measure gives a simple yes or no statement for
an individual problem; therefore, this measure is useful
when it is used together with other measures. Distributional
measure requires the generation of the possible solution set
to determine the distribution pattern of the solution.

Summary

1. An aggregate production planning problem with
   multiple objectives has been developed to coordinate
   the conflicting objectives of each function in an
   organization. This type of an APP problem is solved
   by goal programming technique.

2. Considerable research has been devoted to the con­
   ceptual aspect of master production scheduling, but
   there is little research in the methodology of master
   production scheduling.

3. Several researches have been handled concerning
   operational level scheduling in a GT cell, but not
   much concerning managerial level scheduling.
Little research has been made in master production scheduling with the time phasing effect of the load and the capacity limit.

Little research has been done in multi-item lot sizing rules, and these lot sizing rules may be used for the master production scheduling tool. But, there are more managerial factors to be considered in master production scheduling; therefore, these multi-item lot sizing rules cannot be directly used for master production scheduling.

Little research has been done under the environment where MRP is used as the production planning and control system on a GT cell.

Comparative measures other than distributional measures and achievement measures have been mostly used to evaluate the heuristics for the combinatorial optimization problems.
CHAPTER 3. PROBLEM DEFINITION

Characteristics and Assumptions

Contrasts between this research and the papers of Eisenhut and Newson are shown in Table 3. The characteristics of this research can be described as follows. The time phasing effect of load, overload cost, and delay penalty cost are considered in the process of scheduling. The methods in the research include the traditional period-by-period method and the shortest path algorithm. A tree search scheme is also included as a heuristic search method for the optimal solution. A left threshold parameter of an unknown distribution is used as a solution standard instead of a solution from the Wagner-Whitin (W-W) algorithm. The need for production smoothing is reduced because available capacity is compromised in the process of master production scheduling. Multi-resource cases are also allowed in this research.

This research deals with two subsystems of the production planning and control system for a GT based MRP system. These subsystems include the aggregate production planning and the master production scheduling systems. The APP, the output of the aggregate production planning system, is the basis for the production plan which may be the primary input to the master production scheduling system. If there is no APP function in the production planning
### TABLE 3. Contrasts of the research with other works

<table>
<thead>
<tr>
<th></th>
<th>Eisenhut(15)</th>
<th>Newson(46)</th>
<th>Kim</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time Phasing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of Load</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Backlog &amp; Overload</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Cost Factor</strong></td>
<td>Setup</td>
<td>Setup</td>
<td>Setup</td>
</tr>
<tr>
<td></td>
<td>Holding</td>
<td>Holding</td>
<td>Holding</td>
</tr>
<tr>
<td></td>
<td>Overload</td>
<td>Overload</td>
<td>Penalty</td>
</tr>
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<td><strong>Approach</strong></td>
<td>Period-by-</td>
<td>Shortest Path</td>
<td>Period-by-period</td>
</tr>
<tr>
<td>Method</td>
<td>Period</td>
<td></td>
<td>Shortest Path</td>
</tr>
<tr>
<td></td>
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<td>Tree Search</td>
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<tr>
<td><strong>Solution</strong></td>
<td>W-W</td>
<td>W-W</td>
<td>Threshold Parameter</td>
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<tr>
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<td>Algorithm</td>
<td>Algorithm</td>
<td>Estimation</td>
</tr>
<tr>
<td><strong>Need for</strong></td>
<td>More</td>
<td>More</td>
<td>Less</td>
</tr>
<tr>
<td>Production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoothing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multi-Resource</strong></td>
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<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Problem</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
system, then the production requirements are determined from all demand sources. The following assumptions are made in the development of the aggregate production planning and the master production planning systems.

1. The marketing plan and the APP are represented on a per month basis, and the MPS is on a per week basis.

2. A company has a controllable number of end items made from multiple component parts.

3. A structured BOM exists and end items in the TMPS are identified by part numbers in the BOM. The business type is make-to-stock.

4. The demand pattern is seasonal. All production lead times of end items are known and deterministic.

5. The relative importances among conflicting goals can be quantified.

6. Every end item has a load profile which represents the measurable load on the critical resources.

7. Capacity limitations of critical resources can be defined and constant during the scheduling period.

8. There is a one to one correspondence between a TMPS and a total cost which is composed of set
up, holding, overload, and delay penalty cost.

Aggregate Production Plan

The APP is the plan of production, inventories and work force at an aggregate level to respond to fluctuating demands on a production system (32). The function of the aggregate production planning system is to keep a balance of work-load and to match production with the promised delivery dates and the expenditure plan. For work-load smoothing, load profiles and capacity limitations are used. Therefore, load profiles, capacity limitation of the critical resources, and the marketing and financing plans are prepared in advance.

Load profile refers to the estimated capacity requirements of the item in the MPS on a limited number of the key departments (41). For every manufacturing end item in a TMPS, the standard load on each machine for a GT cell should be defined. In the production planning level, only the capacity limitations of several critical resources are considered, instead of considering all resources. The marketing plan is a guideline for the monthly APP. The marketing department develops the marketing plan on a per month basis. The financing plan is prepared in the same way.

The aggregate production planning system must consider
the balance between external demand and internal supply in a production system. The objective function in the aggregate production planning system is to minimize the weighted deviations from the desired goals. These goals are defined as follows:

1. Satisfy the requirement that the production cost is consistent with the production budget.
2. Satisfy all of the forecast requirements of the marketing department during the planning horizon.
3. Satisfy the sales requirements for each period.
4. Insure that the actual production load is equal to the average capacity limit of the GT cell for each period.
5. Insure that the total amount of inventory during the planning horizon is less than a given value.
6. Insure that the actual workload is equal to the regular workload in the supporting departments for each period.

The production planner uses the output of the aggregate production planning system to build up the monthly production plan which may be translated into a weekly TMPS. The aggregate production planning problem can be represented in the following goal programming model:

1) Variable Definitions

The variables in the model are defined as follows:
\( X_{it} \): production quantity of end item i in month t

\( S_{it} \): sales requirement of end item i in month t

\( B_t \): available budget for the production in month t

\( I_{it} \): on hand inventory level of end item i at the end of month t

\( L_{ijkt} \): load of end item i assigned to machine K in the jth group at the period t, \( t=1,2,...,T \) where T is the total lead time.

\( L_{i***} \): a set which is composed of \( L_{ijk} \), \( L_{ij} \), \( L_{ik} \).

\( L_{ijk} \): total load of end item i assigned to machine K in the jth group = \( \sum_t L_{ijkt} \)

\( L_{ij} \): sum of the weighted load of each machine in group j = \( \sum_k W_k \cdot L_{ijk} \).

\( L_{ik} \): total load of end item i on machine K = \( \sum_j L_{ijk} \).

\( L_{i*} \): total load of end item i on the shop floor

\( = \sum_j L_{ij} = \sum_k W_k \cdot L_{ik} \).

\( A_{**} \): a set which is composed of \( A_{jk} \), \( A_{j} \), \( A_{k} \), \( A_{*} \).

\( A_{jk} \): average load of machine K in the jth group

\( = (1/T) \sum_{i} S_{it} X_{it} \cdot L_{ijk} \).

\( A_{j} \): average load of the jth group = \( (1/T) \sum_{i} S_{it} X_{it} \cdot L_{ij} \).

\( A_{k} \): average load of machine K = \( (1/T) \sum_{i} S_{it} X_{it} \cdot L_{ik} \).

\( A_{*} \): average load of total shop floor = \( (1/T) \sum_{i} S_{it} X_{it} \cdot L_{i*} \).
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\( L_{ij\ast t} \): load of end item i assigned to jth key department at period \( t, t=1,2,\ldots,T \) where \( T \) is the total lead time.

\( L_{ij\ast} \): total load of end item i assigned to the jth key department = \( \sum_t L_{ij\ast t} \)

\( A_{j\ast t} \): regular available capacity of key department in month \( t \)

\( L \): maximum accumulated dollar amount of the inventory item during the planning horizon

\( C_i \): inventory holding cost per unit per period for the end item i

\( CM_i \): manufacturing cost per unit for the end item i

\( CV_i \): dollar amount of the end item i

\( W \): vector of weighting factors for the deviation variables

\( D \): transposed vector of the deviation variable

2) Model Formulation

The objective function and the constraints of the model are defined as follows:

(1) Objective Function: Minimize the total weighted deviation derived from the gap between the desired goal and the achieved goal. Several goals are developed by financing, marketing, manufacturing, management, and other major supporting functions.

Minimize \( Z = WD \)
Constraints: Several goals described above are transformed into the following constraints. All variables and constraints need not be considered simultaneously. Critical variables and constraints are included in the model. The deviation variables with subscript n and p are, respectively, under achieving and over achieving for each goal.

1. Financing:
\[ \sum_i (C_i \cdot (I_{it}) + CM \cdot X_{it}) + D_{nt} - D_{pt} = B_t, \]
for all \( t \)

2. Marketing:
\[ \sum_i X_{it} = \sum_i S_{it}, \] for all \( i \)

3. Shop Floor:
\[ \sum_i X_{it} \cdot L_{i**t} + D_{n**t} - D_{p**t} = A_{**t}, \] for all \( t \)

4. Management:
\[ \sum_i \sum_i CV_i \cdot (I_{it}) + D_n - D_p = L \]

5. Others:
\[ \sum_i X_{it} L_{ij*} + D_{nj*t} - D_{pj*t} = A_{j*t}, \] for all \( t \)
\[ I_{i,t-1} + X_{it} - S_{it} = I_{it}, \] for all \( i,t \)

A small size problem for a GT cell is illustrated in Chapter 5.

Master Production Schedule

The purpose of the master production scheduling system is to derive a TMPS which satisfies the objective function
from the demand requirements. The quantity of end items in a period of the MPS may represent a gross requirement, a production requirement, or a planned order. This research presupposes that the quantity of end items in the MPS implies production requirements or planned order. If the quantity is the gross requirement, it can be changed into the production requirement by considering the on-hand inventory. The demand requirements of end items can be determined from all demand sources or derived from the production plan. If the capacity target can be derived from capacity planning, it can be used, if not, the capacity limit is used instead of the capacity target. The problem is to derive a TMPs from the demand requirements which is derived from the production plan or all demand sources. The objective function to be minimized is the sum of setup, carrying, overload, and shortage penalty cost. There is a per end item setup cost parameter for each product group and a per unit carrying cost parameter for each product group in one week period. There is also machine-hour or man-hour cost for overload for each critical resource. It is not easy to determine the shortage penalty cost, which is determined for each product group in a one week period. In general, the shortage penalty cost includes loss of goodwill and business, loss of revenue, etc. In this research, the shortage penalty cost only includes the shut down cost of the assembly department when an order misses a due date.
There are two constraints, the capacity and the due date. The capacity constraint includes parameters describing the maximum machine-hours or man-hours available during each period. Infinite shortage penalty cost implies that the due date should be kept, and infinite overload cost implies that the capacity limit should be kept. If the shortage penalty cost and the overload cost are finite, small values, then the system will compromise the trade off between the overload cost and the shortage penalty cost to minimize the total cost. The master production scheduling problem can be represented in the following model:

1) Variable Definitions
   
i : item to be produced (i=1,2,...,I)
   t : production period (t=1,2,...,T)
   S_{it} : demand for the item i in the period t
   X_{it} : units of the product i to be produced in the period t
   E_{it} = \sum_{t'=1}^{t} (X_{it'} - S_{it'})
   excess or shortage of the production of item i from period 1 to period t over the demand of item i from period 1 to period t
   [E_{it}]^+ = \begin{cases} E_{it} & \text{if } E_{it} \geq 0 \\ 0 & \text{if } E_{it} < 0 \end{cases}
   [E_{it}]^- = \begin{cases} 0 & \text{if } E_{it} \geq 0 \\ -E_{it} & \text{if } E_{it} < 0 \end{cases}
\[ d(X_{it}) = \begin{cases} 
0 & \text{if } X_{it} = 0 \\
1 & \text{if } X_{it} > 0 
\end{cases} \]

\( RC_t \) : capacity limit during the period \( t \)

\( S_i \) : setup cost of the item \( i \)

\( C_i \) : carrying cost per unit of the item \( i \) per period carried

\( P_i \) : penalty cost per unit of the item \( i \) per period delayed

\( O_t \) : cost per man-hour or machine-hour of labor or machine which is overdriven in the period \( t \)

\( L_{ij} \) : load of the end item \( i \) in the period \( j \), where \( j=1,2,\ldots,J \) and the total lead time(\( J \)) is less than three in the test problems.

\[ L_{ijk} = L_{i,k-j+1} \cdot X_{ij} \]

\( OC_t \) : the total required load minus the available load in period \( t \)

\[ [OC_t]^+ = \begin{cases} 
OC_t & \text{if } OC_t > 0 \\
0 & \text{if } OC_t < 0 
\end{cases} \]
2) Model Formulation

(1) Objective Function

\[
\text{Minimize } Z = \sum_i \sum_t d(X_{it}) \cdot S_i + \sum_i \sum_t [E_{it}]^+ \cdot C_i \\
+ \sum_i \sum_t [E_{it}]^- \cdot P_i + \sum_t [OC_t]^+ \cdot O_t
\]

(2) Constraints

\[\sum_t X_{it} = \sum_t S_{it}, \text{ for all } i\]
\[\sum_i (L_{it-2,t} + L_{it-1,t} + L_{it,t}) = RC_t + OC_t, \text{ for all } t\]

If the value of subscript is non-positive, the corresponding load is zero.
CHAPTER 4. THE APPROACHES

Preliminary Work

Input data

The time bucket in the aggregate production planning level is one month but at the master production scheduling level is one week. All input variables discussed in Chapter 3 can be summarized as follows. The related function and the necessities of each variable are summarized in Table 4:

(1) Load Profile

\( L_{ijkt} \): load of end item i assigned to machine k in the jth group at period t, \( t=1,2,...,T \) where \( T \) is the total lead time.

\( L_{ij*t} \): load of end item i assigned to the jth key department at period t, \( t=1,2,3,...,T \) where \( T \) is the total lead time.

\( L_{ij} \): load of end item i in the period j, \( j=1,2,...,J \) where \( J \) is the total lead time.

In the master production planning level, only one resource is observed. This load profile can be derived from \( L_{ijkt} \) and \( L_{ij*t} \).

(2) Policy Variables

\( S_{it} \): sales requirement of end item i at month t.

\( B_t \): available budget for the production at month t.
L: maximum accumulated dollar amount of the total inventory for all items during the planning horizon.

A_{j,t}: regular workforce level of the jth key department at month t.

RC_t: production capacity limit on the shop floor which is defined by each critical resource.

(3) Cost Parameters

S_i: setup cost of end item i.

P_i: penalty cost per unit of end item i per period delayed.

C_i: inventory holding cost per unit per period for the end item i.

O_t: the cost of overload for the critical resources.

(4) System Output

PP: production plan determined by the APP which is the output of the aggregate production planning system.

TMPS: tentative master production schedule which is the output of the master production scheduling system.

(5) Others

CM_i: manufacturing unit cost for the end item i.

CV_i: market price of an end item i.

W: set of weighing factors for the
### TABLE 4. Input data summary

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Var</th>
<th>Related Function</th>
<th>APP</th>
<th>MPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Load Profile</td>
<td></td>
<td>Production</td>
<td>M*</td>
<td>M*</td>
</tr>
<tr>
<td>2. Policy Var.</td>
<td>S_{it}</td>
<td>Marketing</td>
<td>O</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>B_t</td>
<td>Financing</td>
<td>O</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>Management</td>
<td>O</td>
<td>.</td>
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<tr>
<td></td>
<td>A_{j,t}</td>
<td>Supporting</td>
<td>M*</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>RC_t</td>
<td>Production</td>
<td>.</td>
<td>M*</td>
</tr>
<tr>
<td>3. Cost Para.</td>
<td>S_i</td>
<td>Accounting</td>
<td>O</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>P_i</td>
<td>Accounting</td>
<td>O</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>C_i</td>
<td>Accounting</td>
<td>O</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>O_t</td>
<td>Accounting</td>
<td>.</td>
<td>M*</td>
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<tr>
<td>4. System Output</td>
<td>PP</td>
<td>APP</td>
<td>.</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>TMPS</td>
<td>MPS</td>
<td>.</td>
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</tr>
<tr>
<td>5. Others</td>
<td>CM_i</td>
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<td>O</td>
<td>.</td>
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<tr>
<td></td>
<td>CV_i</td>
<td>Accounting</td>
<td>O</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>Planning</td>
<td>M</td>
<td>.</td>
</tr>
</tbody>
</table>

1 M: mandatory input data  
O: optional input data  
*: system needs only the value of critical resources  
•: not necessary.
deviation variables.

Load profile

The most important prerequisite for the analysis is the existence of the load profile for each end item. The element of the load profile of the end item \( i \) is defined for the shop floor and the key departments. Key departments include sub-assembly, final assembly, and other critical supporting departments. To get the load profile, an explosion simulator and a detail operation scheduling and loading system are used. The general system flow of these two functions is given in Figure 2.

The BOM (Bill of Material) specifies the composition and the process stages of the end item in the MPS. An MRP system and a coding and classification system are used for the explosion simulator which generates the planned order schedule for all manufactured components by exploding the end item in the BOM through all levels. The Bill of Labor (or Capacity) provides the standard hours of labor (or Capacity) requirements for each operation. The planned order schedule and the Bill of Labor (or Capacity) are the inputs for the operation scheduling system which determines the sequence of the planned order for the made parts. The loading system determines the standard hours representing the estimated labor (or capacity) requirements of an end item on each key resource in a company. These standard data
FIGURE 2. A system flow for load profile
are the load profile which represents the time phased load on each key resource to produce one unit of end item.

Aggregate Production Plan

The given aggregate production planning problem is a typical multi-goal optimization problem. All variables and constraints need not be handled simultaneously. The critical resources and the constraints are selected by the user. A matrix generator program creating the input of the aggregate production planning system is necessary to make the system more flexible. In this research, several critical resources and constraints are selected for an illustrative example. The goal programming model is converted into the linear programming model in the following ways. The machine K in the Jth group and Lth supporting department are only critical resources. The other cases can be handled in the same way.

The objective is to minimize $WD$, i.e.,

$$\text{Min} \left\{ \sum_t (W_{nt} \cdot D_{nt} + W_{pt} \cdot D_{pt}) + \sum_j \sum_k \sum_t (W_{njkt} \cdot D_{njkt} + W_{pjkt} \cdot D_{pjkt}) + (W_n \cdot D_n + W_p \cdot D_p) + \sum_l \sum_t (W_{nlit} \cdot D_{nlit} + W_{plt} \cdot D_{plt}) \right\}$$

All deviation variables with subscript $n$ should have
positive values, therefore constraints are changed in the following way:

\[ D_{nt} = B_t + D_{pt} - \sum_i (C_i \cdot I_{it} + CM_i \cdot X_{it}) \geq 0 \]

therefore

\[ \sum_i (C_i \cdot I_{it} + CM_i \cdot X_{it}) - D_{pt} \leq B_t \quad (1) \]

In the similar manner,

\[ D_{njk} = A_{jk} + D_{pjk} - \sum_i (X_{it} \cdot L_{ijk}) \geq 0 \]

\[ \sum_i (X_{it} \cdot L_{ijk}) - D_{pjk} \leq A_{jk} \quad (3) \]

\[ D_n = L + D_p - \sum_i \sum_t (CV_i \cdot I_{it}) \geq 0 \]

\[ \sum_i \sum_t (CV_i \cdot I_{it}) - D_p \leq L \quad (4) \]

\[ D_{nl} = A_{lt} + D_{p} - \sum_i (X_{it} \cdot L_{il}) \geq 0 \]

\[ \sum_i (X_{it} \cdot L_{il}) - D_{p} \leq A_{lt} \quad (5) \]

The number in parentheses is the constraint number in Chapter 3. If we substitute all deviation variables with subscript n into the objective function and drop the constant term, we can get the following objective function:

Objective Function

\[
\begin{aligned}
MIN[& \sum_t (W_{nt} + W_{pt}) \cdot D_{pt} - W_{nt} \cdot \sum_i (C_i \cdot I_{it} + CM_i \cdot X_{it}) \\
+ & \sum_j \sum_k (W_{njk} + W_{pjk}) \cdot D_{pjk} - W_{njk} \cdot (\sum_i X_{it} \cdot L_{ijk}) \\
+ & (W_n + W_p) \cdot D_p - W_n \cdot \sum_i \sum_t (CV_i \cdot I_{it}) \\
+ & \sum_l \sum_t (D_{plt}) \cdot (W_{nl} + W_{pnt}) - W_{nl} \cdot \sum_i (X_{it} \cdot L_{il}) ]
\end{aligned}
\]
A small size illustrative example for a GT cell will be shown in Chapter 5.

Heuristics to Develop a TMPS

The following functions are defined to explain the heuristics developing a TMPS.

AVA(t) : available capacity in the time period t. When the production quantity \( X_{i,t+1-j} \) is scheduled, AVA(t) is updated. If AVA(t) is a negative value, this means that there is overload in the time period t. \( \text{AVA}(t) = [\text{AVA}(t) - \sum_j (L_{ij} \cdot X_{i,t+1-j})], \) \( j=1,2,3 \)

OC(i,t,q) : the amount by which the cumulative capacity exceeds the capacity limit when the requirement q of the item i is scheduled in the period t. \( \text{OC}(i,t,q) = \sum_j [(L_{ij} \cdot q) - \text{AVA}(t-1+j)]^+ \)

A(i,t,q) : overload cost which is caused by scheduling the demand requirement q of the item i in the period t. \( \text{A}(i,t,q) = O_t \cdot \text{OC}(i,t,q) \) where \( O_t \) is the overload cost per unit resource.

B(i,t,q) : penalty cost caused by delaying the requirement q of the item i in the period t by one period.
\[ B(i,t,q) = P_i \cdot q + (1-d(S_{i,t+1})) \cdot (S_i) \]

where \( d(S_{i,t+1}) = \begin{cases} 
0 & \text{if } S_{i,t+1} = 0 \\
1 & \text{if } S_{i,t+1} > 0 
\end{cases} \)

**C(i,j,t)**: penalty cost when the requirement \( S_{i,t-j+1} \), \( S_{i,t-j+2}, \ldots, S_{i,t} \) are scheduled in the period \( t+1 \). The value of \( J \) is the difference between the current period \( t \) and the earliest period \( t \) where \( S_{i,t} \) is not scheduled at period \( t \).

\[ C(i,j,t) = \sum_{j=1}^{J} (S_{i,t-j+1} \cdot j \cdot P_i) + S_i \cdot d(S_{i,t+1}) \]

**U1(i,t)**: Eisenhut Formula: Expected cost reduction by including \( S_{i,t} \) in the present lot.

\[ \frac{S_{i-I(i,t)}}{t \cdot t \cdot S_{i,t}} \]

**U2(i,t)**: Lambrecht and Vanderveken Formula: Expected cost reduction by including \( S_{i,t} \) in the present lot.

\[ \frac{S_{i+I(i,t-1)}-C_i \cdot (t-1) \cdot (t-1) \cdot S_{i,t}}{t \cdot (t-1) \cdot S_{i,t}} \]

**I(i,T)**: inventory cost of the item \( i \) when the order cycle is length \( T \).

\[ I(i,T) = h(i)E_t (t-1) \cdot S_{i,t} \]
M(i,j,T): subtraction of I(i,T) from S_i based on the shortest path from the first period to the period j.

N(i,j,k): total cost composed of setup, holding and overload cost for producing the demand of item i for the period j+1 to k at the very end of the period j.

Method A: period-by-period method

The basic principle of this approach is to increase the lot size with the demand requirement where the marginal cost reduction is positive until there is an overload. If there is an overload at the current requirement, backtracking and delaying are also considered together, and a decision with minimum cost is made to minimize the total cost. Scheduling is performed in the following way from the beginning month to the end month of the planning horizon (See Figure 3).

Step 0. Preliminary Analysis: Determine the supply and the demand, i.e., the allowable capacity and the required capacity during the scheduling horizon. If the average overload is not acceptable, the master production scheduler should appeal to the upper production planning level or revise the production requirements. The allowable overload should be determined by the master production scheduler. This analysis is performed in the lump.
Step 1. Initialize all system parameters: System parameters include cost and resource parameters. There are four cost elements, i.e., setup, holding, overload and shortage penalty cost. Resource parameter implies the capacity limit or the capacity target. The net production requirement and the load profile are also determined. In the net production requirement matrix, the element $S_{it}$ of the matrix represents the requirements for the product $i$ in the period $t$ where $i = 1,2,...,I$ and $t = 1,2,...,T$. Find $T_{12} = 3 - k$ where $L_{ik} = \text{MAX}(L_{i1},L_{i2},L_{i3})$.

Step 2. If there are waiting requirements in the waiting list, schedule the requirements with the penalty cost $C(i,j,t)$ as a priority. The value of $j$ is recalled by the system. The higher penalty cost will have the higher priority. After calculating positive and finite $U_1(i,t)$ for the current period, schedule current requirement with the priority of high $U_1(i,t)$. If the waiting and current requirements cannot be scheduled without overloading, go to Step 5. Otherwise, calculate the positive $U_2(i,t)$ for all $i$ and $t$ if $S_{it}$ is not zero.

Step 3. Search the highest $U_2(i,t)$ in the coming periods. If the corresponding $S_{it}$ does not generate an overload, add the $S_{it}$ to the production quantity of
FIGURE 3. Flow diagram of Method A
the current scheduling period. This step is repeated until there is an overload. If there is an overload, get the next item which does not generate an overload.

Step 4. Update the requirements matrix by subtracting the scheduled amount from the corresponding requirements of the matrix, and make the next scheduling period number one. Repeat Step 2, Step 3 and Step 4 until the end of the scheduling horizon.

Step 5. Check to determine whether backtracking is possible. Calculate $TAVA_i$ and $TL_i$ where

$$TAVA_i = AVA(t-T_i) + AVA(t-T_i+1) + \ldots + AVA(t-T_i^2)$$

$$TL_i = (L_{i1} + L_{i2} + L_{i3}) \cdot S_{it}$$

The value of $T_i$ equals $\min(t, AA / ((C_i \cdot S_{it})))$ where $AA = \min(A(i,t,S_{it}), B(i,t,S_{it})).$

If the condition of backtracking is satisfied, i.e., $TAVA_i$ is larger than $TL_i$ and there is no waiting requirement at the beginning of scheduling in the current period, go to Step 7. If not, go to Step 6.

Step 6. Calculate overloading and penalty cost, then follow the policy which has the minimum cost.

1) If overloading occurs in the waiting list of schedules in the current period,

Calculate $A(i,t,WA_{it})$ and $C(i,j,t)$ for the
remaining waiting items in the waiting list, then follow the policy which has the minimum cost. \( WA_{it} \) is the total waiting quantity of item \( i \) and the value of \( j \) is recalled by the system. If \( A(i,t,WA_{it}) \) is larger than \( C(i,j,t) \) for an item in the waiting list, the following items in the waiting list and all current demands should wait. If \( A(i,t,WA_{it}) \) is smaller than \( C(i,j,t) \) for all items in the waiting list, then, calculate \( A(i,t,S_{it}) \) and \( B(i,t,S_{it}) \) for all current demand requirements. Also follow the policy which has the minimum cost.

2) If overloading occurs at the current requirements, calculate \( A(i,t,S_{it}) \) and \( B(i,t,S_{it}) \) for the remaining current requirements, then follow the policy which has the minimum cost and go to Step 4.

Step 7. Find \( T_{i3} \) where \( T_{i3} = T_{i1} + T_{i2} \) and \( AVA(T_{i1}) = \max(AVA(t-T_{i1}+1),AVA(t-T_{i1}+2),\ldots,AVA(t-T_{i2})) \). If \( A(i,t,S_{it}) \) which is less than \( AA \), can be found in the period \( t \) where \( t \) lies between \( t = T_{i3} \) and the current period, then shift \( S_{it} \) to period \( t \) leftwards. If not, calculate \( A(i,t,S_{it}) \) and \( B(i,t,S_{it}) \), then follow the policy which has the minimum cost. If all items are scheduled, go to Step 4; otherwise, go to Step 5.
Method B: shortest path method

There is always a one-to-one correspondence between the path from the node 0 to the node t and a TMPS. For example, in a single product (Figure 4), if the path is composed of two arcs, 0-2 and 2-4, then this path corresponds to a TMPS which will produce the $S_{11}$, $S_{12}$ at the beginning of the period 1 and $S_{13}$, $S_{14}$ at the beginning of the period 3.

The addition of the node 0 is used for the graphical representation of the lot sizing problem (46). If the planning horizon is T, then the total number of possible paths from the period 1 to the period T is $2^{T-1}$, and the total number of arcs is $T \cdot (T+1)/2$. In the above example where T equals 4, the total number of paths is $2^3 = 8$, and the total number of arcs is $4 \cdot 5/2 = 10$. The basic principle of Method B is to get the shortest path from the node 0 to the node T while allocating the required capacity for each item. Scheduling is performed in the following way item-by-item (see Figure 5).

Step 0. Same as Method A except that the priorities among all items should be defined.

Step 1. Same as Method A except that backlogging is not allowed. Set $i=1, j=1, k=1$. The value of i is the item number which implies the priority sequence among all items. An arc is made of the node j and the node k, i.e., j is the beginning node number and
k is the ending node number.

Step 2. If all items are scheduled, stop the process.

Calculate the positive $M(i,j-1,k)$. If the net requirement of the current period is zero, then the product $i$ is disregarded, and if the net requirement of the future period is zero, then $M(i,j-1,k)$ will have a very large value. If $M(i,j-1,k)$ is positive, then go to Step 5, otherwise go to Step 3.

Step 3. If $j$ equals $T-1$, then go to Step 6. If not, go to Step 4.

Step 4. Find the shortest path from the node 0 to the node $j$ and update the resource in the work area based on this shortest path. Increase $j$ and $k$ by 1 respectively, then go to Step 2.

Step 5. Calculate the value of $N(i,j-1,k)$, and put this value into the corresponding position of the matrix $N(i,T-1,T)$. Increase $k$ by 1 and go to Step 2.

Step 6. Find the shortest path from the node 0 to the node $T$. The corresponding TMPS is the proposed TMPS of item $i$. Update the resource and get next item number and set $j$ at 1 and $k$ at 1, then go to Step 2.

**Method C: tree search method**

Method C is proposed when splitting of the production quantity is allowed. The splitting of the quantity is usually constrained by several restrictions such as batching
<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Requirement</td>
<td>$S_{11}$</td>
<td>$S_{12}$</td>
<td>$S_{13}$</td>
<td>$S_{14}$</td>
</tr>
<tr>
<td>MPS</td>
<td>$X_{11} = S_{11} + S_{12}$</td>
<td>$X_{12} = 0$</td>
<td>$X_{13} = S_{13} + S_{14}$</td>
<td>$X_{14} = 0$</td>
</tr>
</tbody>
</table>

FIGURE 4. A shortest path representation of a MPS
FIGURE 5. Flow diagram of Method B
rules. But there is no restriction for splitting in method C to simplify the problem. Method C is incorporated with the TMPS which is derived from Method A or Method B. A mechanism to derive a random sampling TMPS is defined as follows to describe Method C.

**Sampling procedure**

Available capacity in each period is determined from the capacity limit and the required capacity, which is calculated from the load profile of each end item and the proposed TMPS. The process to generate a TMPS is performed in the following ways:

Case A. When there is overload

The total cost of a TMPS can be primarily decreased by reducing overload cost, but there is a trade-off between overload cost and holding cost. When production quantity shifts leftwards, the overload cost may be reduced, but inventory holding cost is increased. The sampling process is performed as follows.

1. Determine the period spans where there is overload or underload during the scheduling period. If there are several underload and overload spans, the selection of a consecutive underload and overload span is determined randomly.

2. An Origin Period (t=OP) during the overload period span is determined randomly.
3. A Destination Period \(t=DP\) during the underload period span which is the previous span of the above overload period span is determined randomly. Item number \(i\) is also determined randomly. When the corresponding production quantity is zero, all items and periods during the overload period span are scanned to search a positive production quantity. If the search fails, repeat 1, 2, and 3 until the predetermined counter number is reached.

4. A production quantity is determined by dividing the available capacity at period DP by \(L_{ij}\) \((j=1,2,3)\) where the value \(j\) is determined randomly. The Left Shift Quantity (LSQ) is the smaller quantity between this production quantity and corresponding scheduling quantity \((X_{it})\).

5. Shift the amount of LSQ in the period OP to the period DP leftwards.

6. Modify the previous TMPS and calculate the total cost of the new generated TMPS.

Case B. When there is no overload

The total cost of a TMPS can be decreased by reducing the inventory holding cost and the setup cost. The inventory holding cost only can be decreased by shifting the production quantity rightwards, but right shifting should
not be allowed to generate a penalty cost. The sampling procedure is performed as follows.

1. For every end item and scheduling period, find positive Eit.
2. For each above case, find the maximum right shift period which does not generate delay penalty cost.
3. Select the item number (i) and the Origin Period (t=OP) randomly. Right Shift Quantity (RSQ) is the smaller quantity between Eit and Xit.
4. Modify the previous TMPS and calculate the total cost of the new proposed TMPS.

Tree search method Method C is a myopic search method to get a better TMPS from a good W-W type TMPS. An improved TMPS is selected among random TMPSs of size n. Random sampling is performed from the above improved TMPS until predetermined number of levels is reached (See Figure 6). Method C is described as follows (Figure 7).

Step 1. Start from a good W-W type TMPS. Method A or Method B can be used to determine a good W-W type TMPS.
Step 2. If the search level is a predetermined number, then stop the process. The best schedule which is found so far, is the proposed TMPS of Method C.
Step 3. Generate random TMPSs of size n by using the above random sampling procedure.
Step 4. Choose the best TMPS among random TMPSs of size n.
Step 5. Update the schedule and all the related statistics, i.e., the available capacity and all cost statistics.
Step 6. Branch from the best TMPS and increase the search level by 1. Then, go to Step 2.

Four independent random samples of the TMPS are selected and the predetermined number for the search level is also four in the experimental test of this research.

Characteristics of the Methods

Several characteristics of the methods to develop a TMPS can be described as follows:

1. Capacity target/capacity limit is considered in order to develop the best MPS.

2. The total cost function includes setup, holding, overload and shortage penalty cost. The trade off between the capacity and the due date is considered.

3. The load profile is used as a tool for the master production scheduling. This is possible because the lead time of each end item is short. The firm planning period need not be included, because of a quick response to customer orders. Manual intervention is possible where there is a
FIGURE 6. Tree search method
FIGURE 7. Flow diagram of Method C
trade off between the capacity and the due date; therefore interactive programming is favorable to implement this approach. The master production scheduling system under a GT based MRP system can be interactive.

4. This approach can be used even though there is no total production planning and inventory control system. That is, an MPS alone system is possible, if the load profile and other auxiliary system parameters are determined manually.

5. The use of a RCCP function is not necessary because the capacity target/capacity limit is already considered in order to develop the MPS.

6. If the lead time and queuing time are short, this approach can be used for the master production scheduling system of the other environments.

7. The scheduling procedure considers the time phasing effect of the production load.

8. This approach is capacity-sensitive in developing the TMPS, therefore it will make up for the capacity-insensitivity of MRP.
CHAPTER 5. EXPERIMENTAL TEST

Aggregate Production Plan

Illustrative example

An illustrative example, where the total number of items is 2 and the planning horizon is 6, is given as follows. The critical resources are a machine in a GT cell and a supporting department. The sales requirements which are given in Table 5 are generated from the equation (5.1) where $a = 67$ and $a = 125$, and the average demand is 300 for item 1 and 400 for item 2.

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM</td>
<td>1</td>
<td>111</td>
<td>302</td>
<td>226</td>
<td>393</td>
<td>413</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>274</td>
<td>410</td>
<td>405</td>
<td>384</td>
<td>452</td>
</tr>
</tbody>
</table>

All weighting factors which are presented in Table 6 are independent of the time period, and the highest weighting is given to the over utilization of a machine. The corresponding deviation variable can be found from the corresponding index of the weighting factors. The choice of
these values can be best determined by the management function based on the relative importance of the goals.

TABLE 6. Weighting factors of each goal

<table>
<thead>
<tr>
<th>Variable</th>
<th>( W_{nt} )</th>
<th>( W_{pt} )</th>
<th>( W_{nit} )</th>
<th>( W_{pit} )</th>
<th>( W_n )</th>
<th>( W_p )</th>
<th>( W_{nlt} )</th>
<th>( W_{plt} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weighting Factor</td>
<td>0.3</td>
<td>0.1</td>
<td>0.8</td>
<td>0.1</td>
<td>0.7</td>
<td>0.2</td>
<td>0.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

TABLE 7. Values of cost parameters

<table>
<thead>
<tr>
<th>Item Variable</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_i )</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( CM_i )</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>( CV_i )</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

The value of \( C_i \), \( CM_i \), and \( CV_i \) for each item are given in Table 7. The maximum inventory amount (\( L \)) is 16500 and the regular available capacity of the critical department is
5670. The average load of the critical machine is also 5670 and planned budget is 2700 every month. The required loads on the machine and the supporting department are 5 and 10 for the item 1 and the item 2, respectively. The resulting linear program has 77 variables and 34 constraints which are solved by MPSX, taking 1.7s of CPU time. The production plan is given in Table 8, and the required and the planned load are given in Table 9. Overload and underload of required capacity is 2925 respectively, but these value of planned capacity becomes 820 respectively. Table 10 shows the budgeted and the planned expenditures.

**TABLE 8. Production plan**

<table>
<thead>
<tr>
<th>Item</th>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
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<tbody>
<tr>
<td>1</td>
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<td>111</td>
<td>515</td>
<td>128</td>
<td>420</td>
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<td>2</td>
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<td>593</td>
<td>310</td>
<td>503</td>
<td>357</td>
<td>269</td>
<td>425</td>
</tr>
</tbody>
</table>

Using a higher weighting factor for over utilization will result in lower overload.

**Discussion of the model**

The proposed model is related with the work of Krajewski and Bradford (27); Lockett and Muhlemann (34).
TABLE 9. Required and planned load

<table>
<thead>
<tr>
<th>Load</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required</td>
<td>3295</td>
<td>5610</td>
<td>5180</td>
<td>5805</td>
<td>6585</td>
<td>7545</td>
</tr>
<tr>
<td>Planned</td>
<td>6485</td>
<td>5675</td>
<td>5670</td>
<td>5670</td>
<td>5670</td>
<td>4850</td>
</tr>
</tbody>
</table>

TABLE 10. Budgeted and planned expenditure

<table>
<thead>
<tr>
<th>Cost</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budgeted</td>
<td>2700</td>
<td>2700</td>
<td>2700</td>
<td>2700</td>
<td>2700</td>
<td>2700</td>
</tr>
<tr>
<td>Planned</td>
<td>2913</td>
<td>2698</td>
<td>2702</td>
<td>2700</td>
<td>2700</td>
<td>1940</td>
</tr>
</tbody>
</table>

The variables and the system parameters are defined for a GT environment. There are several differences between this research and the other works. Even though the solution method is that of Lockett, the environment of the problem and the flexibility of the model are quite different. The proposed model includes a large number of managerial factors for decision making and can handle many critical resources. Therefore, the proposed model is more practical and realistic than the other models. This model is formulated for a GT environment, but can be easily revised for other environments.
Existing software, MPSX, can be used to solve this model. The above example of the small size problem included 77 variables and 34 constraints. The total number of the variables and the constraints in the proposed model is not small, but the program logic of MPSX provides for a maximum of 16,383 rows (and virtually an unlimited number of columns) on a 1024 K system (22). Therefore, the capacity of MPSX releases the restriction of the problem size under the real environment.

A small problem was given and encoded manually for the example. Yet the encoding task for the input of MPSX for a larger problem would be a tremendous task, and the interpretation of the output of MPSX would require much time if the number of constraints and variables is large. Therefore, a matrix generator and report writing program are desirable to implement this model for a real situation. Critical resources are included in the model instead of all resources. It is shown that MPSX can be used to solve the proposed problem. The model does not allow the backlogging case, but backlogging is possible, if the balance equation of the constraints is changed.

How is it possible to get the input data for the matrix generator or MPSX? The prerequisite of implementation of this model is the existence of the standard performance data such as load profiles and cost parameters. The decision
variables can be determined by a decision maker, but the standard performance data which can be derived from the accumulated historical data are not easy to determine. These standard data should be accumulated systematically or given by another related system.

The relative importances of the conflicting goals are not easy to determine. The most suitable decision maker to determine the weighting factor is the manager who can control and compromise the conflicting objectives in each function. There are many ways to determine these weighting factors. For example, when they are trying to determine the weighting factors for overload and over-expenditure, and if the cost of overload is expensive, then they may give higher weighting for overload. The amount of the weighting factor depends on the overload cost and the expenditure caused by loaning. If this model is incorporated with qualitative managerial factors, this model is a very dynamic approach to the production planning problem where there are conflicting objectives.

Master Production Schedule

Test problem generation

A number of test problems are generated to test the proposed methods. The test problem parameters include the pattern of demand, the pattern of capacities and the setup
and holding costs. The method to determine these parameters is extended from the literature of Kenneth R. Baker et al. (1). Load profile, overload cost and shortage penalty cost are also determined.

The sales requirement in period t is given by

\[ d_t = \mu + \sigma \cdot z_t + a \cdot \sin\left(\frac{2\pi t}{b} + \frac{b}{4}\right) \]  

(5.1)

where

- \( \mu \) = weekly mean demand
- \( \sigma \) = standard error
- \( a \) = amplitude of the seasonality component
- \( b \) = length of seasonal cycle, in periods, and
- \( z_t \) = independent, identically distributed standard normal random deviates.

There are four parameters in the above equation. The mean demand has the value of 200, 300, and 400; standard error is 67 or 237 and the amplitude of seasonality is 0 or 125. Twelve items are defined based on the above three parameters (Table 11). The cycle length (b) is equal to the planning horizon if the planning horizon is 6, otherwise the cycle length (b) equals 12. If the demand generated was negative, it was set to zero. In the small size problem, the two cases for average demands are considered (Table 12). Two cases are also considered for the amplitude of seasonality and the standard error (Table 13.)
TABLE 11. A pool of all test items

<table>
<thead>
<tr>
<th>ITEM NO</th>
<th>μ</th>
<th>a</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>0</td>
<td>67</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>0</td>
<td>237</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>125</td>
<td>67</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>125</td>
<td>237</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>0</td>
<td>67</td>
</tr>
<tr>
<td>6</td>
<td>300</td>
<td>0</td>
<td>237</td>
</tr>
<tr>
<td>7</td>
<td>300</td>
<td>125</td>
<td>67</td>
</tr>
<tr>
<td>8</td>
<td>300</td>
<td>125</td>
<td>237</td>
</tr>
<tr>
<td>9</td>
<td>400</td>
<td>0</td>
<td>67</td>
</tr>
<tr>
<td>10</td>
<td>400</td>
<td>0</td>
<td>237</td>
</tr>
<tr>
<td>11</td>
<td>400</td>
<td>125</td>
<td>67</td>
</tr>
<tr>
<td>12</td>
<td>400</td>
<td>125</td>
<td>237</td>
</tr>
</tbody>
</table>
TABLE 12. Two cases of average demand for small size problem

<table>
<thead>
<tr>
<th>Case</th>
<th>Item</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>400</td>
</tr>
</tbody>
</table>

TABLE 13. Two cases of demand pattern for small size problem

<table>
<thead>
<tr>
<th>Case</th>
<th>Item</th>
<th>Amplitude</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>.0</td>
<td>237</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>67</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>125</td>
<td>237</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>125</td>
<td>67</td>
</tr>
</tbody>
</table>
TABLE 14. Summary of test data

<table>
<thead>
<tr>
<th>Problem</th>
<th>Size(N)</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2,5</td>
<td>1,2,3,4,5,6</td>
<td>1,2,...,12</td>
</tr>
<tr>
<td>Group of</td>
<td></td>
<td>4,7</td>
<td>4,5,6,7,8,9</td>
<td></td>
</tr>
<tr>
<td>Items</td>
<td></td>
<td>6,9</td>
<td>7,8,9,10,11,12</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8,11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scheduling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period(T)</td>
<td></td>
<td>6,12</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td></td>
<td>3 Cases</td>
<td>3 Cases</td>
<td>3 Cases</td>
</tr>
<tr>
<td>Capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limit</td>
<td></td>
<td>3 Cases</td>
<td>3 Cases</td>
<td>3 Cases</td>
</tr>
<tr>
<td>Problem</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set</td>
<td></td>
<td>72</td>
<td>27</td>
<td>9</td>
</tr>
<tr>
<td>Replication</td>
<td></td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Problem Set</td>
<td></td>
<td>360</td>
<td>135</td>
<td>45</td>
</tr>
</tbody>
</table>
In the medium size problem, 6 items are selected. The selection is made to represent the all possible combinations of all demand varieties. The large size problem includes all 12 items. Table 14 shows the summary of the test problem sets.

Five replications were made for each problem by changing the seed of random number generator for the demand pattern and the load profile. Only the case of constant capacity, which represents a stable status of a company, was studied. The required capacity is calculated from the load profile and the demand requirements. The capacity limit is represented in terms of the ratio of allowable capacity to required capacity. The ratio 1.1, 1.2, and 1.3, which are used as the capacity limit, corresponds to a capacity utilization of 90.9%, 83.3%, and 76.9% respectively. There are four cost parameters, that is, setup, holding, overload, and penalty cost. The last three costs are referenced from real data in industry (52, 53, 54)\(^1\), and the setup cost is determined systematically. The holding, overload, and penalty cost are 1.38/item*period, 15/unit*period, and 695/item*period respectively. For testing purposes, it was assumed that the setup cost is independent of time period.

\(^1\) The cost ratios are arbitrarily defined and set by the author following personal communication with a master scheduler in industry.
Instead of the ratio of the setup cost to the holding cost, both setup and holding costs are related with the optimal solution. EOQ time supply of each product has been used to represent the set of setup and holding costs (1). The selected EOQ time supply is one, three, and six periods. Three cases were considered for each problem size to represent the various cases of the problem. Table 15 shows the number of items in the problem size and the EOQ time supply. Setup costs are determined from the selected holding cost and the EOQ time supply (Table 16). Table 17 shows the ratio of the setup cost to the holding cost. The spectrum of the ratios covers the band of the ratios which are used in industry and that used by other author (8).

The load profile is determined from the uniform random number generator which gives an integer between 0 and 9. The selected sample problems will be diverse and a representative problem set to evaluate the proposed methods.
TABLE 15. Cost structure

<table>
<thead>
<tr>
<th>EOQ Time</th>
<th>Prob. Supply</th>
<th>1</th>
<th>3</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply</td>
<td>Case</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Size</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Large</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Size</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>
TABLE 16. Setup cost summary

<table>
<thead>
<tr>
<th>EOQ Time</th>
<th>Avr. Supply</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>138</td>
<td>1242</td>
<td>4968</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>207</td>
<td>1863</td>
<td>7452</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>276</td>
<td>2484</td>
<td>9936</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 17. S/H summary

<table>
<thead>
<tr>
<th>EOQ Time</th>
<th>Avr. Supply</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>1.9</td>
<td>17.3</td>
<td>69.0</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>2.9</td>
<td>29.5</td>
<td>103.5</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>3.8</td>
<td>34.5</td>
<td>138.0</td>
<td></td>
</tr>
</tbody>
</table>
Evaluation measure

The ratio \((R)\) of the total cost which is calculated from the proposed TMPS to the solution standard is used as an evaluation measure. The total cost includes setup, inventory, overload, and penalty cost. Solution standard is the near optimal cost which is derived from the small order statistics by using the method of Weissman (58). When there is a large sample, then small order statistics can be used to derive the left threshold of the population distribution. Suppose a distribution function \((df)\) \(F\) has a finite left threshold \(\mu\). A confidence interval can be derived by using the order statistics \(T_1 < T_2 < \ldots < T_k\) from a sample whose \(df\) is \(F\). The pivotal ratio

\[
W_k = \log \frac{T_{k-1}}{T_1} - \frac{k-1}{\sum_{i=1}^{k-1} \log \frac{T_{k-1}}{T_i}} (k \geq 3)
\]

is the basis for the confidence interval for \(\mu\). Given a confidence level \(r\) and a lower error-probability \(P_1 (0 < r + P_1 < 1)\), determine \(W_1 = W_k(P_1)\) and \(W_2 = W_k(r + P_1)\).

\(W_k(p)\) is the quantiles of \(W_k = Y_{k-1}/\sum_{i=1}^{k-1} Y_i\), where the \(Y_i\) are the order statistics from an exponential sample of size \(k-1\). Put

\[
G(\mu) = \frac{k-1}{\sum_{i=2}^{k} \log \frac{T_{k-1}}{T_i}} (\mu \leq T_1), \quad H(\mu) = \log \frac{T_{k-1}}{T_1} (\mu < T_1)
\]
and \( U_i = \frac{W_i}{1-W_i} \) (i=1,2). Then the set
\[
\{ \mu: W_1 < W_k < W_2 \} = \{ \mu: U_1 G(\mu) < H(\mu) < U_2 G(\mu) \}
\]
is an asymptotically exact (as \( n \to \infty \) and \( k/n \to 0 \)) confidence set for \( \mu \) with confidence level \( r \) for df \( F \) which satisfies
\[
\lim_{x \to 0} \frac{F(\mu + cx)}{F(\mu + x)} = C^\alpha \quad (\alpha > 0)
\]
for every \( C > 0 \). Unfortunately, this does not guarantee the solution, i.e., there may be null set for this equation.

"Median-unbiased" estimator of \( \mu \) (i.e., estimators which are too large with 50% probability and too small with 50% probability) when \( r \) is .50 is used as a solution standard. The df \( F \) near the left threshold is assumed to satisfy the regularity condition. Three hundred random total costs of TMPS is generated from a good \( W-W \) type schedule which is derived from Method A or Method B and the smallest 10 total costs among 300 are used as the small order statistics.

A quick estimate of \( \alpha \), suggested by Weiss, was used (58).

\[
\alpha = \log \frac{k-1}{m-1} / \log \frac{T_k - T_1}{T_m - T_1}
\]

where \( k=10, \ m=4 \). As the value of \( \alpha \) increases beyond 1, it is known that the approach of Weissman becomes less reliable. When the value of \( \alpha \) is larger than 1.1, the
smallest value among all samples is used as the evaluation criteria.

Discussion of the experimental tests

Experimental procedure is shown in Figure 8. Method A and Method B are applied to each test problem and develop TMPS A and TMPS B respectively. Method C uses a good W-W type TMPS which is better between TMPS A and TMPS B and generates TMPS C. Each TMPS is associated with a cost which will be compared with a near optimal cost.

The evaluation measure, when the total number of end item is 2 and the amplitude of seasonality is 0 or 125, is shown in Table 18. The measures in the Tables represent the values of R multiplied by 100. Method B is superior to Method A when there is seasonality in demand. The evaluation measures for all types of the test problem sets are given in Figure 19. The results show that Method B is better than Method A for the small size problem set, but Method A is better than Method B for the medium and large size problem sets. The average cost ratios are 1.25, 1.65, and 1.05 for Method A, Method B, and Method C, respectively. As the number of items is increased, Method B becomes less reliable. The defect of Method B is that scheduling is performed item-by-item. Therefore, all items can not be considered simultaneously in each scheduling period. An MPS which is derived from Method B depends on the priority of
FIGURE 8. Experimental procedure
TABLE 18. R for constant and seasonal demand patterns

<table>
<thead>
<tr>
<th>Method</th>
<th>Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.1</td>
</tr>
<tr>
<td>a</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

end items. Therefore, Method B becomes less reliable as the total number of end items increases. As the capacity ratio decreases, i.e., the utilization of capacity increases, all methods become less effective. It is interesting that these phenomena are similar to that of other heuristics under different environments (49).
TABLE 19. Summary of evaluation measures

<table>
<thead>
<tr>
<th>Number of Items</th>
<th>Scheduling Period</th>
<th>Scheduling Method</th>
<th>Capacity Ratio</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>Avr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6</td>
<td>A</td>
<td>152</td>
<td>135</td>
<td>130</td>
<td>139</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>130</td>
<td>132</td>
<td>118</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>108</td>
<td>106</td>
<td>107</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>A</td>
<td>156</td>
<td>161</td>
<td>133</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>167</td>
<td>144</td>
<td>129</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>117</td>
<td>113</td>
<td>102</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>A</td>
<td>110</td>
<td>113</td>
<td>107</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>180</td>
<td>162</td>
<td>146</td>
<td>163</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>106</td>
<td>102</td>
<td>101</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>A</td>
<td>104</td>
<td>104</td>
<td>101</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>253</td>
<td>226</td>
<td>201</td>
<td>227</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>103</td>
<td>103</td>
<td>100</td>
<td>102</td>
<td></td>
</tr>
</tbody>
</table>

| Average         | A                | 130              | 128            | 117 | 125 |
|                 | B                | 182              | 166            | 148 | 165 |
|                 | C                | 108              | 106            | 102 | 105 |
TABLE 20. Distribution of evaluation measures

<table>
<thead>
<tr>
<th>N</th>
<th>T</th>
<th>R</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
<th>1.8</th>
<th>1.9</th>
<th>2.0</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>72</td>
<td>28</td>
<td>16</td>
<td>7</td>
<td>6</td>
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The distributions of R for each category are given in Table 20. When the number of items is 2 and scheduling period is 6, frequencies between 1.1 and 1.2 are 16 for Method A. Table 21 classified evaluation measures by cost structure. It is difficult to conclude in the lump which cost structure
TABLE 21. Evaluation measures by cost structure

<table>
<thead>
<tr>
<th>Number of Items</th>
<th>Scheduling Period</th>
<th>Scheduling Method</th>
<th>Cost Structure Case</th>
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<tr>
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<td>C</td>
<td>104 101 101</td>
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</table>
TABLE 22. Characteristics of solution standard (Frequency)

<table>
<thead>
<tr>
<th>Number of Items</th>
<th>Scheduling Period</th>
<th>Improved $a &gt; 1.1$</th>
<th>Improved $a &lt; 1.1$</th>
<th>Unimproved $a &gt; 1.1$</th>
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<td>17</td>
<td>138</td>
<td>216</td>
<td>65</td>
<td>98</td>
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</table>

gives a good or bad solution. When the total number of items is 12 and scheduling period is 24, it can be said that, if the portion of small EOQ time supplies is large, then the result is poor. Table 22 and Table 23 show the frequencies of the lower bound and the ratios of each case. "Improved" implies that the lower bound is improved from a good W-W type MPS. "Unimproved" implies that the lower bound is the smaller value between the total costs of Method A and that of Method B. To find the lower bound, 40% of all problems used Weissman's approach and 28.8% of all problems used the smallest value among all samples. Among the test
TABLE 23. Characteristics of solution standard (Ratio)

<table>
<thead>
<tr>
<th>Number of Items</th>
<th>Scheduling Period</th>
<th>Improved</th>
<th>Unimproved</th>
<th>Total</th>
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</thead>
<tbody>
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<td>43.4</td>
<td>5.6 10.0 1.7</td>
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<tr>
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<td>3.0 34.0</td>
<td>52.6</td>
<td>4.4 3.7 2.2</td>
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<td>12</td>
<td>24</td>
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<td>51.1</td>
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<td>3.2 25.6</td>
<td>40.0</td>
<td>12.0 18.1 1.1</td>
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</table>

problems, 31.2% have not improved the lower bound from a good W-W type TMPS. This portion may be caused by poor estimation procedure of the lower bound or good heuristics of master production scheduling. X implies that α can not be calculated because of insufficient number of sample data. When the lower bound is not improved and α is less than 1.1, this implies that there is a null set of solutions in the interval estimation of Weissman. These figures show that the frequencies of application of Weissman's approach for large size problem is more than that for the small and medium size problems.
TABLE 24. A Wilcoxon's signed-rank test for cost factors

<table>
<thead>
<tr>
<th>Number of Items</th>
<th>Scheduling Period</th>
<th>Setup Cost A : B</th>
<th>Holding Cost A : B</th>
<th>Overload Cost A : B</th>
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<tr>
<td>12</td>
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<td>Total</td>
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Setup cost, holding cost, and overload cost are observed separately. Method A and Method B give a paired data of setup, holding, and overload cost for each test problem. The Wilcoxon's signed-rank test is performed for the paired data of three costs to test the different effect of Method A and Method B. The null hypothesis \( H_0 \) is \( M_a = M_b \) and the alternate hypothesis \( H_a \) is \( M_a \neq M_b \) where \( M_a \) is the median of the cost distribution from Method A and \( M_b \) is the median of the cost distribution from Method B. Equality in Figure 24 shows that the null hypothesis \( H \) is accepted and
inequality means that the alternate hypothesis \( H \) is accepted at 0.05 level of significance respectively.

Average setup cost from Method A is less than that from Method B and holding cost from Method A is larger than that of Method B in any case. When the total number of items is 2 and the scheduling period is 6, the average overload cost from Method A is larger than that from Method B, but when the problem size is the largest, the results are reversed. The other problem sets show that there is no significant difference between the overload cost from Method A and that from Method B. In the overall sense, there is strong evidence that the setup cost from Method A is less than that from Method B and holding cost from Method A is larger than that from Method B. There is no significant difference between Method A and Method B for overload cost.
CHAPTER 6. SUMMARY AND CONCLUSION

There are several evidences that the importance of master production scheduling is increasing and GT is the future oriented manufacturing concept. A master production scheduling system is discussed under a GT cell where MRP can be used as a production planning and inventory control system. An aggregate production planning problem where there are multiple conflicting objectives is considered, and a practical model is proposed. Traditional lot sizing problems do not consider the capacity limit or can not violate capacity limit. Three heuristics for master production scheduling are discussed when the capacity limit can be violated, i.e., overloading and subcontracting are allowed.

In Chapter 2, it was shown that goal programming can be used to coordinate the conflicting objectives in the aggregate production planning problem under a GT cell. The master production scheduling problem is important, but little attention is given to this area for following reasons.

1. Master production scheduling problems are diverse in industry.
2. Master production scheduling system is complex because of interrelation with other systems.
3. It is difficult to verify the proposed heuristics
for combinatorial optimization problems.

In Chapter 3, the aggregate production problem is characterized by the goal programming model. The master production scheduling problem is formulated, but linear programming or mixed integer programming are both inefficient methods when there are many end items and the scheduling period is long. This will justify the necessity of heuristics for master production scheduling.

In Chapter 4, the goal programming model for the APP problem is converted into a linear programming model and three heuristics for master production scheduling are discussed. Method A and Method B consider only a W-W type schedule, i.e., demand requirement can not be split for the production requirement. Method C allows splitting the demand requirement in the production scheduling requirement. Method A is the traditional period-by-period method and Eisenhut's marginal cost reduction is used as a priority for scheduling. Method B uses the shortest path algorithm and tries to find a TMPS item-by-item. Method C uses a good W-W type schedule which may be derived from Method A or Method B and searches a TMPS by shifting the production quantity leftwards or rightwards. The search pattern is similar to a tree search scheme.

In Chapter 5, an APP problem where the total number of end items is 2 and the planning horizon is 6 is selected as
an illustrative example. All input data are encoded manually and the output of MPSX is discussed. Diverse sets of the test problems are generated to verify the three proposed heuristics for master production scheduling. There are several system parameters of the test problem sets: the demand pattern, the type of load profile, the capacity limit, and cost parameters. These parameters are determined systematically or referenced from the data of the industry. Five hundred and forty test problems are generated and Method A, Method B, and Method C are applied to each problem respectively. The evaluation measure is the ratio of the total cost from the proposed method to the near optimal total cost which is derived from small order statistics. The left threshold parameter of the distribution of the population is determined by the method of Weissman. When the Weissman's method can not be applied, the smallest value among 300 random costs from sampled TMPSs is used as the near optimal cost.

In Chapter 6, it is shown that Method B dominates Method A where the problem size is small and the pattern of demand requirement is seasonal. Method A is better than Method B for the other cases. Method C can be only applied for a hypothetical situation, i.e., there is no restriction in splitting of the demand requirement for the production quantity. There should be many variations for Method C but
a typical splitting scheme is shown in this research. All heuristics become less reliable as the capacity utilization is increasing. The average cost ratios of Method A, Method B, and Method C are 1.25, 1.65, and 1.05 respectively. A Wilcoxon's signed-rank test is performed to check the effect of Method A and Method B for setup, holding, and overload cost respectively.

The following areas are categorized as areas for further research:

1. It is not surprising that Method B becomes less reliable as the total number of items increases. The defect of Method B is that scheduling is performed item-by-item, therefore, all end items can not be observed simultaneously in every scheduling period. Therefore, TMPS from Method B depends on the priority of end items and investigation of the effect of the priority of end items will compensate for the defects of Method B. This research determines the priority among end items randomly. The priority can be determined based on average load of each end item or lead time, etc.

2. The quality of the solution depends on the quality of the lower bound, therefore, the solution standard is important in the evaluation
process for a proposed heuristic. An optimal solution is characterized by solution space which depends on the restriction of production size in the real situation. This research assumes that there should be corresponding MPS for the near optimal total cost which is derived from the approach of Weissman. The analytical approach for the optimal solution is ineffective when the problem size is large, but it may be effective when the problem size is small. When the lower bound is determined based on small order statistics, the quality of the lower bound depends on the quality of sampling and estimation procedure. Test results show that sampling procedure and Weissman's approach are useful when the problem size is large, but poor when the problem size is small. The investigation of the procedure to develop the lower bound is valuable for the evaluation of heuristics for general combinatorial problems. Among the total test problems, 31.2% show no improvement of the total cost of the W-W type MPS in this research. This research does not verify whether the lack of improvement comes from the lower quality of the evaluation procedure or from the higher quality
of the proposed heuristics. There should be many variations in the splitting scheme of production requirement, but the research to derive W-W type optimal MPS is required for the case where the production requirement can not be split. The analytical approach to get the optimal schedule is possible for small problems, but the analytical approach is ineffective for medium and large size problem, therefore, this research only used small order statistics to estimate the lower bound to keep consistency for all size problem sets.

3. The ratio of the calculated total cost to the near optimal cost is used as an evaluation measure. A "50%-unbiased median" estimator is used as a lower bound. When the inference of the lower bound is interval estimation instead of point estimation, new evaluation measure should be defined, and the evaluation scheme should be different.

4. Even though the proposed heuristics allow for cases of multi-resource problems, test problems only handled the cases of single resource problems. Therefore, it would be interesting to test the proposed heuristics for the multi-
resource problems. The quality of the heuristics for the master production scheduling system depends on the input data structure of the system, therefore, it is necessary to test the proposed heuristics for other input data structures to verify the proposed heuristics for general cases.

5. There are several factors affecting the value of R. Factors include demand pattern and cost structures, capacity ratio, type of load profile, etc. The contribution of these factors to the value of R is not investigated, because it is not easy to quantify the several factors.

Finally, several conclusions reached are as follows:

1. The aggregate production planning problem where there are multiple objectives can be formulated as a goal programming model. The proposed aggregate production planning model can be used effectively with a matrix generating and report writing program for input and output of MPSX. If the model is incorporated with the qualitative managerial factors, the proposed model is dynamic in the sense that any critical factors varying with time can be included in the model.

2. Method B dominates the traditional period-by-
period Method A in the small size problem where there is seasonality. But, Method A is better than Method B in the other cases. Method C dominates both Method A and Method B in all cases, but there should be many variations and restrictions in Method C. The average cost ratios are 1.25, 1.65, and 1.05 for Method A, Method B, and Method C, respectively. There are defects in Method B which can be solved by considering the effect of priorities among end items. Method A allows delay penalty, but there are no cases of delay for the selected test data. Method A and Method B are used to find a global optima, but Method C is used to search local optima from a good W-W type schedule.

3. The aggregate production planning model and the heuristics for master production scheduling are proposed for a GT cell, but the APP model can be easily revised for other environments, and the heuristics for master production scheduling can be used if the production lead time is short under other environments.

4. The efficiency of the evaluation procedure depends on the quality of the sampling procedure and the estimation procedure. The solution
standard is determined from the Weissman's approach or the smallest sample value among all observations. The portion of Weissman's approach is 40.0% and that of the other case is 28.8%. Among the test problems, 31.2% show no improvement from a good W-W type TMPS.

The expected value and the contributions of this research are as follows:

1. Many decision factors and critical resources can be included in the APP model for a GT cell.

2. A better methodology is presented to develop a TMPS than the traditional "trial and error" method; therefore, reduces the turn around time for a master production scheduler to find the best TMPS.

3. The possibility of eliminating the traditional RCCP evaluation method is raised because the available capacity can be negotiable during the process of master production scheduling.

4. The frequency of running the MRP explosion logic is decreased by providing a practical MPS. Therefore, MRP can be well incorporated in the production planning and inventory control system.

5. A communication tool for finalizing MPS is proposed and the effectiveness of the total
production system is increased by improving the procedure to develop a MPS which is the trigger for the planning of the production support function.

6. An optimization procedure for combinatorial problems is shown and an evaluation procedure for heuristics of combinatorial problems is proposed.


52. Spencer, Michael S. "Scheduling Components for Group
Technology Lines (A New Application for MRP)." 
Production and Inventory Management 21, No. 4 (1980), 43-49.


56. Suresh, Nallan C. "Optimizing intermittent production systems through Group Technology and an MRP system." Production and Inventory Management 20, No. 4 (1979), 76-83.


ACKNOWLEDGEMENTS

I would like to express my gratitude to those people who were instrumental in the completion of this dissertation.

I wish to thank the members of my dissertation committee, professors Eric M. Malstrom, John C. Even, and Vincent A. Sposito for their thoughtful criticisms and suggestions. I am indebted to professor Herbert T. David for his valuable discussions in the estimation of unknown shape parameters. I am extremely thankful to professor Keith L. McRoberts, my committee chairman, for his guidance and assistance in the research and his support throughout my graduate study.

I am also indebted to many others who have helped in this study. The brief discussions with professor William Q. Meeker and Dorea C. Y. Chang were valuable in accomplishing this dissertation. Several letters answering my questions from Michael S. Spencer, William L. Berry, and Colin New were also helpful for this research.

I am grateful to my parents and parents-in-law who have faith in me. Finally, I am grateful for the patience and continuous support of my wife, and to two beautiful daughters who understood my absence when they wanted my attention.
APPENDIX A: AGGREGATE PRODUCTION PLANNING SUBSYSTEM

Program List

PROGRAM
INITIALZ
MOVE(XDATA,'APP2')
MOVE(XPBNAM,'GTMRP')
CONVERT
BCDOUT
SETUP
MOVE(XOBJ,'COST')
MOVE(XRHS,'ZZ2')
PRIMAL
SOLUTION
EXIT
PEND
## Input of MPSX

**NAME** | **APP2**
---|---

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| DP5 | COST | .400000 | R5 | - | 1.00000 |
| DP6 | COST | .400000 | R6 | - | 1.00000 |
| DP11 | COST | .900000 | R9 | - | 1.00000 |
| DP12 | COST | .900000 | R10 | - | 1.00000 |
| DP13 | COST | .900000 | R11 | - | 1.00000 |
| DP14 | COST | .900000 | R12 | - | 1.00000 |
| DP15 | COST | .90000 | R13 | - | 1.00000 |
| DP16 | COST | .90000 | R14 | - | 1.00000 |
| DP   | COST | .90000 | R15 | - | 1.00000 |
| DP1N1| COST | .60000 | R16 | - | 1.00000 |
| DP1N2| COST | .60000 | R17 | - | 1.00000 |
| DP1N3| COST | .60000 | R18 | - | 1.00000 |
| DP1N4| COST | .60000 | R19 | - | 1.00000 |
| DP1N5| COST | .60000 | R20 | - | 1.00000 |
| DP1N6| COST | .60000 | R21 | - | 1.00000 |
| I11  | COST | - | 3.80000 | R1  | 1.00000 |
| I11  | R15  | 5.00000 | R22 | - | 1.00000 |
| I11  | R23  | 1.00000 |      |    |        |
| I12  | COST | - | 3.80000 | R2  | 1.00000 |
| I12  | R15  | 5.00000 | R23 | - | 1.00000 |
| I12  | R24  | 1.00000 |      |    |        |
| I13  | COST | - | 3.80000 | R3  | 1.00000 |
| I13  | R15  | 5.00000 | R24 | - | 1.00000 |
| I13  | R25  | 1.00000 |      |    |        |
| I14  | COST | - | 3.80000 | R4  | 1.00000 |
| I14  | R15  | 5.00000 | R25 | - | 1.00000 |
| I14  | R26  | 1.00000 |      |    |        |
| I15  | COST | - | 3.80000 | R5  | 1.00000 |
| I15  | R15  | 5.00000 | R26 | - | 1.00000 |
| I15  | R27  | 1.00000 |      |    |        |
| I16  | COST | - | 3.80000 | R6  | 1.00000 |
| I16  | R15  | 5.00000 | R27 | - | 1.00000 |
| I21  | COST | - | 7.30000 | R1  | 1.00000 |
| I21  | R15  | 10.00000 | R28 | - | 1.00000 |
| I21  | R29  | 1.00000 |      |    |        |
| I22  | COST | - | 7.30000 | R2  | 1.00000 |
| I22  | R15  | 10.00000 | R29 | - | 1.00000 |
| I22  | R30  | 1.00000 |      |    |        |
| I23  | COST | - | 7.30000 | R3  | 1.00000 |
| I23  | R15  | 10.00000 | R30 | - | 1.00000 |
| I23  | R31  | 1.00000 |      |    |        |
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| I24  | R15  | 10.00000 | R31 | - | 1.00000 |
| I24  | R32  | 1.00000 |      |    |        |
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| I25  | R15  | 10.00000 | R32 | - | 1.00000 |
| I25  | R33  | 1.00000 |      |    |        |
| I26  | COST | - | 7.30000 | R6  | 1.00000 |
| I26  | R15  | 10.00000 | R33 | - | 1.00000 |
| X11  | COST | - | 5.10000 | R1  | 2.00000 |
| X11  | R7   | 1.00000 | R9  | 5.00000 |
| X11  | R16  | 5.00000 | R22 | 1.00000 |
| X12  | COST | - | 5.10000 | R2  | 2.00000 |
| X12  | R7   | 1.00000 | R10 | 5.00000 |
| X12  | R17  | 5.00000 | R23 | 1.00000 |
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**ENDATA**
System Flow of Experimental Test

APPENDIX B: MASTER PRODUCTION SCHEDULING SUBSYSTEM

FT20F001

Method A  Method B

FT30F001  FT40F001  FT50F001  FT60F001

Solution  Method C

Standard

FT90F001  FT70F001

Analysis

Statistics
Program list

Method A

$JOB 'KIM', TIME=(2,03), PAGES=200

* I/O FILE SUMMARY ****************************************************************

  DD NAME   DSN
  1. INPUT  FT20F001  K.I6467.DATA
  2. OUTPUT FT30F001  K.I6467.RESA
     FT50F001  K.I6467.MINA

******** FILE DESCRIPTION **********************************************************

1. K.I6467.DATA
   1) INO: TOTAL NUMBER OF END-ITEM
   2) TNO: TOTAL NUMBER OF PERIOD
   3) DSEED: SEED FOR LOAD PROFILE
   4) OCOST: OVERLOAD COST PER UNIT RESOURCE
   2) IX: SEED FOR DEMAND REQUIREMENT
   3) MEAN: AVERAGE DEMAND
      1) NVAR: STANDARD ERROR
      2) MAMP: SEASONAL AMPLITUDE
   4) RATIO: CAPACITY RATIO (START)
      1) NCT: NUMBER OF CASES OF CAPACITY RATIO (INCREMENT IS 0.1)
   5) P(I), S(I), H(I)

2. K.I6467.RESA
   1) SUMTC: TOTAL COST FROM METHOD A
2) $WDT(I,T)$:
3) $SKD(I,T)$:
4) $AVARES(J,T)$:

3. K.I6467.MINA
1) $SUMTC$: $SUMS+SUMH+SUMP+SUMOC$

- $SUMS$: TOTAL SETUP COST
- $SUMH$: TOTAL HOLDING COST
- $SUMP$: TOTAL PENALTY COST
- $SUMOC$: TOTAL OVERLOAD COST

*************** ARRAY DESCRIPTION ***************

- $ITEM(T)$: PRODUCTION REQUIREMENT AT TIME $T$, $T=1, 2, \ldots, TNO$
- $DT(I,T)$: $WDT(I,T)$: PRODUCTION REQUIREMENT OF END ITEM $I$ AT TIME $T$
  \hspace{1cm} $I=1, 2, \ldots, \text{INO} \hspace{1cm} T=1, 2, \ldots, TNO$
- $RESLIM(J,T)$: CAPACITY LIMIT, $J=1 \hspace{1cm} T=1, 2, \ldots, TNO$
- $LP(I,1,K)$: LOAD PROFILE, $I=1, 2, \ldots, \text{INO} \hspace{1cm} J=1 \hspace{1cm} K=1, 2, 3$
- $P(I)$: PENALTY COST PER UNIT OF THE ITEM $I$ PER PERIOD CARRIED.
- $S(I)$: SET UP COST OF THE ITEM $I$
- $H(I)$: CARRYING COST PER UNIT OF THE ITEM $I$ PER PERIOD CARRIED.
- $WAIT(I,T)$: WAITING AREA FOR SCHEDULING,
  \hspace{1cm} $I=1, 2, \ldots, \text{INO}; \hspace{1cm} T=1, 2, \ldots, TNO$
- $RQRES(J,T)$: REQUIRED RESOURCE, $J=1 \hspace{1cm} T=1, 2, 3$
- $AVARES(J,T)$: AVAILABLE RESOURCE, $J=1 \hspace{1cm} T=1, 2, \ldots, 26$
- $WORK(I,1)$: WAITING COST
- $WORK(I,2)$: WAITING AMOUNT
- $WORK(I,3)$: MAX WAITING PERIOD FROM CURRENT PERIOD.
SWDT(I,2): SORTED ARRAY OF WAITING COST.

SWDT(I,1): WAITING COST/COST INDEX

SWDT(I,2): CORRESPONDING ITEM NUMBER.

SKD(I,T): SCHEDULE OF END ITEM I AT PERIOD T,
I=1,2,...,INO  T=1,2,...,TNO

VARIABLE DECLARATION

INTEGER SW, CT, T, TNO, TO, TT, T1, T2(12), T3, TA, CTMT2, SI, SIM1
INTEGER WORK, TEMP1, CHECK, TNO2
REAL GGNQF, Y, LP
REAL ITEM(24), OCOST, MTAVA, MTLI, MAB
REAL RQRES(1,3), TEMP(12,1,3), E(12,26)
DOUBLE PRECISION DSEED, NDSEED
COMMON /ONE/ P(12), S(12)
COMMON /TWO/ DT(12,24), H(12), U(12,24), SWDT(12,3)
COMMON /THREE/ LP(12,1,3), SKD(12,24), AVARES(1,26)
COMMON/FOUR/ WORK(12,3), WAIT(12,24)
COMMON/FIVE/ CHECK(12)
COMMON/SIX/ WDT(12,24), DSEED, NDSEED, SUMD
COMMON/SEVEN/ OCOST

DO 12345 IJKL=1,5

CALL CLOCK(IC)

J=1
JNO=1
KNO=3
READ(20,10) INO, TNO, DSEED, OCOST
10 FORMAT(2I2, F20.7, F7.2)
IF (TNO.GE.12) THEN
  NTNO=12
ELSE
  NTNO=TNO
ENDIF
TNO2=TNO+2
NDSEED=DSEED
WRITE(6,30) INO, TNO, DSEED, OCOST
30 FORMAT( 'INO, TNO, DSEED, OCOST', 2I3, F20.7, F7.2)

CALL CLOCK(IC)

DO 12345 IJKL=1,5

CALL RANDU(IX)
127

IX=IY
R=R\ast 1000
IR=\text{INT}(R)
\text{WRITE}(6,110) \text{ IR}

110 \text{ FORMAT}(2X,'\text{RANDOM NUMBER}',16)
DO 90 \text{ IB}=1,3
RA=IR/((10)**(3-IB))
LP(III,1,IB)=\text{INT}(RA)
IR=IR-\text{INT}(RA)*((10)**(3-IB))
90 \text{ CONTINUE}
\text{WRITE}(6,130) \text{ IX}

130 \text{ FORMAT}(,' \text{NEW SEED FOR LOAD PROFILE}',118)
STRES=0

\text{C GENERATE DEMAND REQUIREMENTS}

\text{C}
\text{DO 150 I}=1,\text{INO}
STLP=0
\text{DO 170 IT}=1,3
170 STLP=STLP+LP(I,1,IT)
\text{READ(20,190) MEAN,MVAR,MAMP}
190 \text{ FORMAT}(313)
\text{CALL DEMAND(I,MEAN,MVAR,MAMP,NTNO,DT,TNO)}
STRES=STRES+STLP*SUMD
\text{WRITE(6,210) MEAN,MVAR,MAMP}
210 \text{ FORMAT(,' MEAN,MVAR,MAMP',315)}
\text{WRITE(6,230) (DT(I,T),T=1,TNO)}
230 \text{ FORMAT}(2X,12F10.2/)
150 \text{ CONTINUE}
\text{DO 250 I}=1,\text{INO}
SLP=-9E10
\text{DO 270 K}=1,\text{KNO}
\text{IF (LP(I,1,K).GT.SLP) THEN}
SLP=LP(I,1,K)
ISLP=K
\text{ENDIF}
270 \text{ CONTINUE}
T2(I)=ISLP-1
250 \text{ CONTINUE}
\text{UNIRES=STRES/TNO}
\text{READ(20,290) RATIO,NCT}
290 \text{ FORMAT}(F7.2,12)
SRATIO=RATIO

\text{C SIMULATE FOR DIFFERENT COST STRUCTURES}
\text{C}
\text{DO 10000 IIII}=1,3
RATIO=SRATIO
\text{DO 310 I}=1,\text{INO}
\text{READ(20,330) P(I),S(I),H(I)}
SIMULATE FOR DIFFERENT CAPACITY LIMITS

DO 9999 IJK=1,NCT
   J=1
   CALL CLOCK(IH)
   WRITE(6,370) RATIO,IJK
   370 FORMAT(' RATIO,NCT',F7.2,I2)
   DO 390 I=1,INO
       DO 390 T=1,TNO
          390 DT(I,T)=WDT(I,T)
   TAVA=0
   SWAIT=0
   PHI=3.14159
   DO 410 I=1,INO
       DO 410 T=1,TNO
          WAIT(I,T)=0
          410 SKD(I,T)=0
   PH=3.14159
   DO 430 K=L,3
       RQRES(1,K)=0
   DO 450 1=1,INO
       DO 450 IJ=1,3
       WORK(I,IJ)=0
   RC=UNIRES*RATIO
   WRITE(6,470) RC,UNIRES
   470 FORMAT(' RC,UNIRES',2F16.2)
   C DETERMINE CAPACITY LIMIT
   DO 490 I=1,TNO2
       AVARES(I,1)=RC
   490 CONTINUE
   RATIO=RATIO+0.1
   C **************************************************
   DO 1000 T=1,TNO
       DO 510 1=1,INO
          IF (DT(I,T).EQ.0) THEN
             CHECK(I)=0
          ELSE
             CHECK(I)=1
          END IF
   510 CONTINUE
   C WRITE(6,20) ((DT(I,N),N=1,TNO),I=1,INO)
   C WRITE(6,20) ((SKD(I,N),N=1,TNO),I=1,INO)
   C WRITE(6,20) ((WAIT(I,N),N=1,TNO),I=1,INO)
   CT=T
   CT2=CT+2
   SW=0
C SORT WORK(I,1) IN SWDT(I,2)
C PRIORITY OF SCHEDULING IS DETERMINED
IF (SWAIT.EQ.1) THEN
   DO 550 I=1,INO
      SWDT(I,1)=WORK(I,1)
      SWDT(I,2)=I
   550 CONTINUE
C   CALL SRT(SWDT,INO,1)
ENDIF
C
IF (SWAIT.EQ.1) THEN
   DO 570 II=1,INO
      I=SWDT(II,2)
      IF (WORK(I,1).EQ.0) GO TO 570
      DO 590 K=1,KNO
         RQRES(J,K)=LP(I,1,K)*WORK(I,2)
         T1=T+K-1
         TEMP1=AVARES(J,T1)-RQRES(J,K)
      IF (TEMP1.LT.0) THEN
         SW=1
         SI=II
         GO TO 600
      ENDIF
   590 CONTINUE
   DO 610 K=1,KNO
      T1=T+K-1
      AVARES(J,T1)=AVARES(J,T1)-RQRES(J,K)
   610 CONTINUE
C THE REQUIREMENTS IN WAITING AREA IS SCHEDULED
   SKD(I,T)=SKD(I,T)+WORK(I,2)
   CALL CLEARW(I,CT)
   WRITE(6,901)
  570 CONTINUE
SWAIT=0
ENDIF
  630 CONTINUE
   DO 550 II=1,INO
      IF (DT(II,T).NE.0) THEN
         GO TO 670
      ENDIF
   650 CONTINUE
   GO TO 1000
  670 CONTINUE
   DO 590 I=1,INO
      IF ((DT(I,CT).EQ.0)) THEN
         SWDT(I,1)=9E10
      ELSE
         SWDT(I,1)=S(I)/DT(I,CT)
      ENDIF
SWDT(I,2)=I
690 CONTINUE
C
CALL SRT(SWDT,INO,1)
DO 710 II=1,INO
I=SWDT(II,2)
IF (CHECK(I).EQ.0) GO TO 710
DO 730 K=1,KNO
RQRES(J,K)=LP(I,1,K)*DT(I,T)
T1=T+K-1
TEMP1=AVARES(J,T1)-RQRES(J,K)
IF (TEMP1.LT.0) THEN
SW=2
SI=II
GO TO 600
ENDIF
730 CONTINUE
DO 770 K=1,KNO
T1=T+K-1
AVARES(J,T1)=AVARES(J,T1)-RQRES(J,K)
770 CONTINUE
SKD(I,T)=SKD(I,T)+DT(I,T)
WRITE(6,902)
DT(I,T)=0
710 CONTINUE
C SW=1,2 IMPLIES SKD IS NOT POSSIBLE WITHOUT OVERLOADING
IF (CT.LT.TNO) THEN
CALL UNI(CT,INO,TNO)
ENDIF
GO TO 1000
600 CONTINUE
IF ((SWAIT.EQ.L).OR.(SW.EQ.L).OR.(T.EQ.L)) GO TO 870
C CHECK WHETHER THE BACKTRACKING IS POSSIBLE OR NOT
C *************** BACK TRACKING ROUTINE START ***************
DO 790 II=SI,INO
I=SWDT(II,2)
SAVA=-9E10
IF (CT.GT.3) THEN
DO 810 T0=3,CT
IF (AVARES(1,T0).GT.SAVA) THEN
SAVA=AVARES(1,T0)
T1=T0
ENDIF
810 CONTINUE
C T IMPLIES THE TIME OF MAXIMUM AVA(T)
T3=T1-T2(I)
ELSE
T3=1
ENDIF
TAVA=0
DO 830 TO=T3,CT
TAVA=TAVA+AVARES(J,TO)
830 CONTINUE
MTAVA=TAVA/(CT-T3+1)
TLI=(LP(I,1,1)+LP(I,1,2)+LP(I,1,3))*DT(I,CT)
MTLI=TLI/3
IF (((MTAVA.GT.MTLI).AND.(SWAIT.EQ.0)) THEN
  GO TO 850
ELSE
  I=II
  GO TO 870
ENDIF
C FIND MAX AQA
850 Q=DT(I,T)
A1=A(I,T,Q,LP,AVARES)
B1=B(I,T,DT,TN0)
IF (Al.LT.B1) THEN
  MAB=A1
ELSE
  MAB=B1
ENDIF
C
DO 890 TA=T3,CT
HCOST=(CT-TA)*H(I)*Q
AWORK=A(I,TA,Q,LP,AVARES)+HCOST
C
IF (SKD(I,TA).EQ.0) THEN
  DEL=1
ELSE
  DEL=0
ENDIF
AWORK=AWORK+DEL*S(I)
C
IF (AWORK.LT.MAB) THEN
  QTY=DT(I,T)
  CALL SKDING(SKD,I,TA,DT,QTY,AVARES,RQRES,LP,1)
  DT(I,T)=0
  WRITE(6,903)
  GO TO 910
ENDIF
890 CONTINUE
C
C
IF (Al.LT.B1) THEN
  QTY=DT(I,T)
  CALL SKDING(SKD,I,T,DT,QTY,AVARES,RQRES,LP,0)
  WRITE(6,904)
  ELSE
  WAIT(I,T)=DT(I,T)
  WORK(I,2)=WORK(I,2)+DT(I,T)
WORK(I,3) = WORK(I,3) + 1
WORK(I,1) = C(I, WORK(I,3), T, WAIT, DT)
DT(I, T) = 0
SWAIT = 1
WRITE(6, 907)
ENDIF
910 TAVA = 0
790 CONTINUE
C *************** BACK TRACKING ROUTINE END ***************
GO TO 1000
870 SI = II
IF (SW.EQ.1) THEN
DO 930 II = SI, INO
   I = SWDT(II, 2)
   IF (WORK(I, 2).EQ.0) GO TO 930
   TEMP5 = WORK(I, 2)
   AWORK = A(I, CT, TEMP5, LP, AVARES) + WORK(I, 1)
   ITEMP = WORK(I, 3) + 1
   WAIT(I, CT) = DT(I, CT)
   CWORK = C(I, ITEMP, CT, WAIT, DT)
   WAIT(I, CT) = 0
   IF (AWORK.LT.CWORK) THEN
      QTY = WORK(I, 2)
      CALL SKDING(SKD, I, T, DT, QTY, AVARES, RQRES, LP, 1)
      CALL CLEARW(I, CT)
      WRITE(5, 905)
      SWAIT = 0
   ELSE
      C UPDATE WORK AND WAIT AREA
      DO 950 I = 1, INO
         WAIT(I, CT) = DT(I, CT)
         TEMP1 = WORK(I, 3) + 1
         WORK(I, 1) = C(I, TEMP1, CT, WAIT, DT)
         WORK(I, 2) = WORK(I, 2) + DT(I, T)
         WORK(I, 3) = TEMP1
         DT(I, CT) = 0
         SWAIT = 1
      950 CONTINUE
      WRITE(6, 908)
   ENDIF
C
C
930 CONTINUE
ENDIF
    IF (SW.EQ.1) THEN
        SI=1
    DO 990 I=1,INO
        IF (((DT(I,CT).EQ.0)) THEN
            SWDT(I,1)=9E10
        ELSE
            SWDT(I,1)=S(I)/DT(I,CT)
        ENDIF
    SWDT(I,2)=I
 990 CONTINUE
C
CALL SRT(SWDT,INO,1)
ENDIF
  DO 1010 II=SI,INO
    I=SWDT(II,2)
    IF (CHECK(I).EQ.0) GO TO 1010
    AWORK=A(I,CT,DT(I,T),LP,AVARES)
    BWORK=B(I,CT,DT,TNO)
C
IF (AWORK.LT.BWORK) THEN
    QTY=DT(I,T)
    CALL SKDING(SKD,I,CT,DT,QTY,AVARES,RQRES,LP,0)
    WRITE(6,905)
ELSE
C
    WAIT(I,CT)=DT(I,CT)
    TEMP1=WORK(I,3)+1
    WORK(I,3)=TEMP1
    WORK(I,2)=WORK(I,2)+DT(I,CT)
    WORK(I,1)=C(I,TEMP1,CT,WAIT,DT)
    DT(I,CT)=0
C
    WRITE(6,1030) (WORK(I,JJ),JJ=1,3),I,CT,WAIT(I,CT)
 1030 FORMAT(2(4X,6F10.2/))
    SWAIT=1
C
ENDIF
C
1010 CONTINUE
1000 CONTINUE
    WRITE(6,20) ((SKD(I,T),T=1,TNO),I=1,INO)
C
7 WRITE(6,20) ((WAIT(I,N),N=1,TNO),I=1,INO)
20 FORMAT(2(4X,6F10.2))
C TOTAL SETUP COST
C
SETN=0
SUMS=0
DO 4020 I=1,INO
NSETUP=0
DO 4010 T=1,TN0
   IF (SKD(I,T).GT.0) THEN
      NSETUP=NSETUP+1
   ENDIF
4010 CONTINUE
SETN=SETN+NSETUP
SUMS=SUMS+NSETUP*S(I)

C CALCULATE HOLDING/PENALTY COST
C
SUMH=0
SUMP=0
TSUMH=0
TSUMP=0
DO 4035 I=1,INO
   DO 4030 CT=1,TN0
      SDT=0
      SX=0
      DO 4050 T=1,CT
         SX=SX+SKD(I,T)
      4050 SDT=SDT+WDT(I,T)
      E(I,CT)=SX-SDT
      IF (E(I,CT).GT.0) THEN
         SUMH=SUMH+E(I,CT)*H(I)
         TSUMH=TSUMH+E(I,CT)
      ELSE
         SUMP=SUMP-E(I,CT)*P(I)
         TSUMP=TSUMP-E(I,CT)
      ENDIF
   4030 CONTINUE
WRITE(5,4036) SUMH,SUMP
4036 FORMAT(' SUMH,SUMP',2F16.2)
4035 CONTINUE

C CALCULATE OVERLOAD COST
C
SUMOC=0
DO 4070 T=1,TN0
   IF (AVARES(1,T).LT.0) THEN
      SUMOC=SUMOC-AVARES(1,T)
   ENDIF
4070 CONTINUE
TSUMOC=SUMOC
WRITE(6,4071) SUMOC
4071 FORMAT(' OVARES',F16.2)
SUMOC=SUMOC*OCOST

C CALCULATE TOTAL COST
C
SUMTC=SUMS+SUMH+SUMP+SUMOC

WRITE(50,4077) SUMTC, SUMS, SUMH, SUMP, SUMOC

WRITE(50,4077) SUMTC, SETN, TSUMH, TSUMP, TSUMOC

4093 FORMAT(2X, 'SUMTC, SUMS, SUMH, SUMP, SUMOC', 5F16.2)

WRITE(30,4097) SUMTC

WRITE(30,4098) ((WDT(I,T), T=1, TNO), I=1, INO)

WRITE(30,4098) ((SKD(I,T), T=1, TNO), I=1, INO)

WRITE(30,4099) (AVARES(1,LT), LT=1, TNO2)

WRITE(30,4099) (AVARES(1,LT), LT=1, TNO2)

WRITE(30,4099) (AVARES(1,LT), LT=1, TNO2)

WRITE(30,4099) (AVARES(1,LT), LT=1, TNO2)

WRITE(30,4100) (AVARES(1,LT), LT=1, TNO2)

CALL CLOCK(IG)

IHPU=IH-IG

WRITE(6,4092) IH, IG, IHPU

9999 CONTINUE

10000 CONTINUE

CALL CLOCK(ID)

ICPU=IC-ID

WRITE(6,4091) IC, ID, ICPU

4091 FORMAT(' IC, ID, ICPU', 315)

C2345 CONTINUE

STOP

END

REAL FUNCTION A(I,T,Q,LP,AVARES)

REAL TEMP(12,1,3), LP(12,1,3), AVARES(1,26)

INTEGER T

COMMON/SEVEN/OCOST

SUM=0

J=1

DO 5000 K=1,3

TEMP(I,J,K)=LP(I,1,K)*Q

T1=T+K-1

IF (AVARES(J,T1).LT.0) THEN

SUM=SUM+TEMP(I,J,K)

ELSE

WK=TEMP(I,J,K)-AVARES(J,T1)

IF (WK.GT.0) THEN

SUM=SUM+WK

ENDIF

ENDIF

5000 CONTINUE

A=SUM*OCOST

RETURN
REAL FUNCTION B(I,T,DT,TNO)
REAL DT(12,24)
COMMON /ONE/ P(12),S(12)
INTEGER T,TNO
IF (T.EQ.TNO) THEN
  DEL=0
  GO TO 5100
ENDIF
IF (DT(I,T+1).EQ.0) THEN
  DEL=1
ELSE
  DEL=0
ENDIF
5100  B=P(I)*DT(I,T)+DEL*S(I)
RETURN
END

REAL FUNCTION C(I,JD,T,WAIT,DT)
COMMON /ONE/ P(12),S(12)
REAL WAIT(12,24),DT(12,24)
INTEGER T,TMIA1
SUM=0
DO 5200 IA=1,JD
  TMIA1=T-IA+1
  WRITE(6,5300) T,IA,JD
  5300  FORMAT(2X,' T,IA,JD',3IS)
  SUM=SUM+WAIT(I,TMIA1)*IA*P(I)
5200 CONTINUE
IF (DT(I,T).GT.0) THEN
  ELSE SUM=SUM+S(I)
END IF
C=SUM
RETURN
END

SUBROUTINE DEMAND (IC,MIYOU,SIGMA,AA,BB,DT,TNO)
INTEGER TNO,SIGMA,AA,BB
DOUBLE PRECISION DSEED,NDSEED
COMMON /SIX/WDT(12,24),DSEED,NDSEED,SUMD
REAL DT(12,24),ITEM(24)
DSEED = NDSEED
SUMD=0
PHI=3.14159
DO 5400 I=1,TNO
Y=GGNQF(DSEED)
W1=SIGMA*Y
W2=(2*PHI/BB)*(I+BB/4.)
ITEM(I)=MIYOU + W1 +AA*SIN(W2)
IF (ITEM(I).LT.O) THEN
ITEM(I)=0
ENDIF
C CALCULATE THE RATIO OF ZERO
DT(IC,I)=ITEM(I)
WDT(IC,I)=ITEM(I)
SUMD=SUMD+DT(IC,I)
5400 CONTINUE
NDSEED=DSEED
WRITE(6,5500) NDSEED
5500 FORMAT(' NEW SEED FOR DEMAND',F20.7)
RETURN
END
C ********************************************************
SUBROUTINE UNI(CT,INO,TNO)
REAL LP,RQRES(1,3)
INTEGER T,T1,CT,CT1,TN0,TT,TM1
COMMON /ONE/ P(12),S(12)
COMMON /TWO/ DT(12,24),H(12),U(12,24),SWDT(12,3)
COMMON /THREE/ LP(12,1,3),SKD(12,24),AVARES(1,26)
COMMON/FIVE/CHECK(12)
CALL CLOCK(IE)
KN0=3
J=1
DO 6010 LL=CT,TNO
DO 6010 11=1,INO
U(II,LL)=-9E10
C WRITE(6,6030) CT,INO,TNO
6030 FORMAT(2X,'CT,INO,TNO',315)
C WRITE(6,20) ((DT(I,T),T=1,TN0),1=1,INO)
20 FORMAT(2(4X,6F10.2/))
C WRITE(6,20) ((SKD(I,T),T=1,TN0),1=1,INO)
DO 6070 I=1,INO
C WRITE(6,6090) DT(I,CT)
6090 FORMAT(2X,'DT(I,CT)',F16.2)
IF (CHECK(I).EQ.0) GO TO 6070
CT1=CT+1
DO 6110 T1=CT1,TNO
SUM=0
TM1=T1-CT
DO 6130 TT=1,TM1
ITT1=CT+TT-1
SUM=SUM+(TT-1)*DT(I,ITT1)*H(I)
WRITE(6,6150) SUM,DT(I,ITT1),H(I)
6150 FORMAT(2X,3F16.2)
CONTINUE
A1=S(I)+SUM-H(I)*((TM1+1-1)**2)*DT(I, T1)
WRITE(6,6170) A1,SUM,DT(I, T1),I,T1,T1

FORMAT(2X,3F16.2,3I6)
IF (A1.LE.0) GO TO 6070
B1=(TM1+1)*(TM1+1-1)*DT(I, T1)
IF (B1.EQ.0) THEN
  U(I, T1)=9E10
ELSE
  U(I, T1)=A1/B1
ENDIF
WRITE(6,6210) CT,I,T1,U(I, T1)

6210 FORMAT(2X,'CT,I,T1,U(I,T1)',315,F16.8)
6110 CONTINUE
6070 CONTINUE
DO 6230 I=1,INO
SWDT(I, 1)=U(I,CT1)
SWDT(I, 2)=I
SWDT(I, 3)=CT1
6230 CONTINUE

CALL SRT(SWDT,INO,2)
DO 6250 I1=1,INO
I=SWDT(I1,2)
J0=SWDT(I1,3)
IF (CHECK(I).EQ.0) GO TO 6250
IF ((U(I,J0)+9E10).LT.0.00001) GO TO 6250
DST=DT(I,J0)
DO 6280 K=1,KNO
  RQRES(J,K)=LP(I,1,K)*DST
  T1=CT+K-1
  TEMP1=AVARES(J,T1)-RQRES(J, K)
  IF (TEMP1.LT.0) THEN
    RETURN
  ENDIF
6280 CONTINUE
SKD(I, CT)=SKD(I, CT)+DST
DT(I,J0)=0
DO 6290 K=1,KNO
  T1=CT+K-1
  AVARES(J, T1)=AVARES(J, T1)-RQRES(J, K)
6290 CONTINUE
IF (J0.EQ.TNO) THEN
  GO TO 6250
ENDIF
SWDT(I1, 1)=U(I, J0+1)
SWDT(I1, 3)=SWDT(I1,3)+1
IF (SWDT(I1,1).GT.0) THEN
  GO TO 6270
ELSE
  GO TO 6250
```fortran
ENDIF
6250 CONTINUE
RETURN
END

C *****************************************************
SUBROUTINE CLEARW(I, CT)
INTEGER TT, CT, CTT
INTEGER WORK
COMMON/FOUR/WORK(12,3), WAIT(12,24)
CTT = CT - WORK(I, 3)
DO 7010 TT = CTT, CT
    WAIT(I, TT) = 0
SWAIT = 0
7010 CONTINUE
C
WORK(I, 1) = 0
WORK(I, 2) = 0
WORK(I, 3) = 0
SWAIT = 0
RETURN
END

C *****************************************************
SUBROUTINE SRT(SWDT, INO, CHK)
INTEGER CHK
REAL SWDT(12,3)
INO M1 = INO - 1
DO 7030 NPASS = 1, INOM1
    INOMN = INO - NPASS
    DO 7050 I = 1, INOMN
        IF (SWDT(I, 1).LT.SWDT(I+1, 1)) THEN
            TEMPO = SWDT(I, 1)
            SWDT(I, 1) = SWDT(I+1, 1)
            SWDT(I+1, 1) = TEMPO
        ELSE IF (CHK.EQ.2) THEN
            TEMPO = SWDT(I, 2)
            SWDT(I, 2) = SWDT(I+1, 2)
            SWDT(I+1, 2) = TEMPO
        ENDIF
    7050 CONTINUE
C
TEMP0 = SWDT(I, 2)
SWDT(I, 2) = SWDT(I+1, 2)
SWDT(I+1, 2) = TEMPO
C
    IF (CHK.EQ.2) THEN
        TEMPO = SWDT(I, 3)
        SWDT(I, 3) = SWDT(I+1, 3)
        SWDT(I+1, 3) = TEMPO
    ENDIF
7050 CONTINUE
```
SUBROUTINE SKDING(SKD, I, T, DT, QTY, AVARES, RQRES, LP, CHK)
INTEGER T, CHK
REAL SKD(12, 24), DT(12, 24), RQRES(1, 3), AVARES(1, 26)
REAL LP(12, 1, 3)
J = 1
KNO = 3
SKD(I, T) = SKD(I, T) + QTY
IF (CHK.EQ.0) THEN
   DT(I, T) = 0
ENDIF
DO 7070 K = 1, KNO
   T1 = T + K - 1
   RQRES(J, K) = LP(I, 1, K) * QTY
   AVARES(J, T1) = AVARES(J, T1) - RQRES(J, K)
7070
RETURN
CONTINUE
END
Method B

$JOB 'KIM', TIME=(2,00), PAGES=100

* I/O FILE SUMMARY ******************************************

 DD NAME        DSN
 1. INPUT FT20F001 K.I6467.DATA
 2. OUTPUT FT40F001 K.I6467.RESB
     FT60F001 K.I6467.MINB

******** FILE DESCRIPTION ************************************

 1. K.I6467.DATA
     REFER TO METHOD A
 2. K.I6467.RESB
     SAME AS K.I6467.RESA
 3. K.I6467.MINB
     SAME AS K.I6467.MINA

** ARRAY DESCRIPTION ***************************************

ITEM(T): PRODUCTION REQUIREMENT AT TIME T, T=1,2,...,TNO
DT(I,T): PRODUCTION REQUIREMENT OF END ITEM I AT TIME T,
           I=1,2,...,INO  T=1,2,...,TNO
RESLIM(J,T): CAPACITY LIMIT, J=1  T=1,2,...,TNO+2
LP(I,J,K): LOAD PROFILE, I=1,2,...,INO  J=1  K=1,2,3
P(I): PENALTY COST PER UNIT OF THE ITEM I
      PER PERIOD CARRIED.
S(I): SET UP COST OF THE ITEM I
H(I): CARRYING COST PER UNIT OF THE ITEM I
      PER PERIOD CARRIED.
OCOST:  COST PER MAN PERIOD OR MACHINE PERIOD
OF OVER TIME LABOR OR MACHINE.

RQRES(J,T):  REQUIRED RESOURCE,  J=1  T=1,2,3

AVARES(J,T):  AVAILABLE RESOURCE,  J=1  T=1,2,...,TNO+2

SKD(I,T): SCHEDULE OF END ITEM I,  I=1,2,...,INO
          T=1,2,...,TNO

VARIABLE DECLARATION

INTEGER INO,CT,T,TNO,TNO1,TT,T1,T2,T3,TA,CTMT2
INTEGER TEMP1,TEMP2,TFROM,TFROM1,TTO,TNO2
INTEGER SIGMA,A,B,IPRD(12),MEAN(12)
INTEGER ST,TN0M1
INTEGER SWA,STFROM,STTO,COUNT
REAL IRA(5),E(12,26),VAL(12),H,MINVAL,MAXVAL
REAL GCNFQ,Y,LP,LSQ,LSQ1,LSQ2,MAABB
REAL ITEM(24),RESLIM(1,26),SKD(12,24),EOQ(12)
REAL P(12),COST(24,24),OCOST,HCOIST,AVADMD(12),TALP(12)
REAL RQRES(1,3),AVARES(1,26),SWDT(12,2),TEMP(12,1,3)
DOUBLE PRECISION DSEED,NDSEED
COMMON /ONE/ H(12),DT(12,24),LP(12,1,3),S(12)
COMMON /TWO/ TARES(1,25),ELSN(25),PRED(25)
COMMON /THREE/ DSEED,NDSEED,SUMD
COMMON /FOUR/ TN0,TN02
DO 12345 IJKL=1,5.

INITIALIZATION
CALL CLOCK(IC)
STRES=0
I=1
J=1
K=1
READ(20,10) INO,TNO,DSEED,OCOST
10 FORMAT(2I2,F20.7,F7.2)
IF (TNO.GE.12) THEN
   NTNO=12
ELSE
   NTNO=TNO
ENDIF

GENERATE LOAD PROFILE
READ(20,30) IX
30 FORMAT(I12)
WRITE(6,50) IX
50 FORMAT(' OLD SEED FOR LP',I12)
DO 70 III=1,INO
CALL RANDU(IX,IY,R)
IX=IY
R=R*1000
IR=INT(R)
WRITE(6,90) IR
90 FORMAT(2X,'RANDOM NUMBER',I6)
DO 70 IB=1,3
RA=IR/((10)**(3-IB))
LP(III,1,IB)=INT(RA)
IR=IR-INT(RA)*((10)**(3-IB))
70 CONTINUE
WRITE(6,110) IX
110 FORMAT('NEW SEED FOR LOAD PROFILE',I12)
DO 130 I1=1,INO
   SUM=0
   DO 150 I2=1,3
      SUM=SUM+LP(I1,1,I2)
   150 CONTINUE
   TALP(I1)=SUM
130 CONTINUE
NDSEED=DSEED
WRITE(6,170) INO,TNO,DSEED,OCOST
170 FORMAT('INO,TNO,DSEED,OCOST',212,F20.7,F7.2)
KNO=3
WRITE(6,190) NF,NTEMP1,NTEMP2,TEMPO
190 FORMAT(2X,'NF,NTEMP1,2,TEMPO',3I5,F15.2)
TN01=TNO+1
TN02=TNO+2
JP1=J+1
DO 210 I=1,INO
   STLP=0
   DO 230 IT=1,3
      STLP=STLP+LP(I,1,IT)
   230 CONTINUE
   READ(20,250) MEAN(I),MVAR,MAMP
250 FORMAT(3I3)
   CALL DEMAND(I,MEAN(I),MVAR,MAMP,NTNO,DT,TNO)
   AVADMD(I)=SUMD/TNO
270 FORMAT('TOTAL SUM& AVA DMD',2F15.2)
   STRES=STRES+STLP*SUMD
   WRITE(6,290) MEAN(I),MVAR,MAMP
290 FORMAT('MEAN(I),MVAR,MAMP',315)
   WRITE(6,310) (DT(I,T),T=1,TN0)
310 FORMAT(2X,12F10.2/)
210 CONTINUE
   UNIRES=STRES/TNO
   READ(20,330) RATIO,NCT
330 FORMAT(F7.2,I2)
   SRATIO=RATIO
   DO 10000 III=1,3
      RATIO=SRATIO
   10000 CONTINUE
   WRITE(6,350) I=1,INO
350 FORMAT(2X,12F10.2/)
READ(20,370) P(I),S(I),H(I)
370 FORMAT(3F7.2)
   EOQ(I)=SQRT(2*MEAN(I)*S(I)/H(I))
   TMP=EOQ(I)/MEAN(I)
   IPRD(I)=INT(TMP)
WRITE(6,390) I,P(I),S(I),H(I)
390 FORMAT(' I,P(I),S(I),H(I)',13,3F10.2)
350 CONTINUE
   DO 9999 IJK=1,NCT
      I=1
      J=1
      K=1
      DO 410 I=1,INO
         DO 410 T=1,TN0
            SKD(I,T)=0
            PHI=3.14159
            C WRITE(6,430) INO
               FORMAT(IX,15)
            DO 450 I=1,INO
               DO 450 T=1,TN0
                  SKD(I,T)=0
                  DO 470 K=1,3
                     RQRES(1,K)=0
                  DO 490 J=1,TN0
                     DO 490 K=J,TN0
                        COST(J,K)=9E10
                  CONTINUE
                  WRITE(6,510) RATIO, UK
                     FORMAT('1RATIO,NCT',F7.2,12)
                  RC=UNIRES*RATIO
                  WRITE(6,530) RC,UNIRES
                     FORMAT(' RC,UNIRES',2F15.2)
                  C CAPACITY LIMIT
                     DO 550 I=1,TN02
                        AVARES(1,I)=RC
                     CONTINUE
                     RATIO=RATIO+0.1
                     DO 1000 I=1,INO
                        IF (I.LT.INO) THEN
                           RCC=AVADMD(I)*TALP(I)
                        DO 570 T=1,TN02
                           TARES(1,T)=RCC
                        ELSE
                           DO 590 T=1,TN02
                              TARES(1,T)=AVARES(1,T)
                        END IF
                        DO 510 J=1,TN0
                           JP1=J+1
                           DO 530 K=JP1,TN01
                              SUM=0
DO 650 T=JP1,K
SUM=SUM+H(I)*(T-JP1)*DT(I,T-1)
650 CONTINUE
TEMP1=S(I)-SUM
IF (TEMP1.GT.0) THEN
KM1=K-1
COST(J,KM1)=CALC(I,J,KM1,AVARES,TARES,OCOST)
ELSE
GO TO 670
ENDIF
630 CONTINUE
670 CONTINUE
IF (J.EQ.TNO) THEN
GO TO 690
ELSE
GO TO 710
ENDIF
710 CONTINUE
IF (J.GE.2) THEN
CALL SPATH(JP1,ELSN,COST)
ENDIF
CALL UPRES(I,JP1,1,DT,LP,AVARES,SKD,COST)
WRITE(6,370) (TARES(1,LT),LT=1,TN02)
100 CONTINUE
690 CALL SPATH(TNO1,ELSN,COST)
CALL UPRES(I,TNO1,2,DT,LP,AVARES,SKD,COST)
1000 CONTINUE
CALL CLOCK(ID)
ICPU=IC-ID
WRITE(6,730) IC,ID,ICPU
730 FORMAT(' IC,ID,ICPU',3 IS)
C
WRITE(6,310) ((SKD(I,T),T=1,TN0),I=1,INO)
WRITE(6,750) (AVARES(1,LT),LT=1,TN02)
750 FORMAT(2X,8F16.2)
CALL CCOST(INO,TNO,SKD,AVARES,OCOST,RC,1)
WRITE(40,770) ((DT(I,T),T=1,TN0),I=1,INO)
WRITE(40,770) ((SKD(I,T),T=1,TN0),I=1,INO)
770 FORMAT(F10.2)
WRITE(40,790) (AVARES(1,LT),LT=1,TN02)
790 FORMAT(F16.2)
9999 CONTINUE
10000 CONTINUE
C2345 CONTINUE
STOP
END
C*************************************************************
SUBROUTINE DEMAND (IC,MIYOU,SIGMA,A,B,DT,TNO)
INTEGER TNO,SIGMA,A,B
REAL DT(12,24),ITEM(24),PHI
DOUBLE PRECISION DSEED, NDSEED
COMMON /THREE/ DSEED, NDSEED, SUMD
SUMD=0
PHI=3.14159
DSEED = NDSEED
DO 1500 I=1, TNO
Y=GGNQF(DSEED)
W1=SIGMA*Y
W2= (2*PHI/B)*(I+B/4.)
ITEM(I)=MIYOU + W1 + A*SIN(W2)
IF (ITEM(I).LT.0) THEN
   ITEM(I)=0
ENDIF
C CALCULATE THE RATIO OF ZERO
DT(IC,I)=ITEM(I)
SUMD=SUMD+DT(IC,I)
1500 CONTINUE
NDSEED=DSEED
WRITE(6,1510) DSEED
1510 FORMAT(2X,'NEW DSEED',F20.7)
RETURN
END
C ************************************************************
SUBROUTINE SPATH(J, ELSN, COST)
REAL COST(24, 24), TCOST(25), TEST(25)
REAL ELSN(25)
WRITE(6,1530) ((COST(JJ,KK), KK=1, 6), JJ=1, 6)
1530 FORMAT(6(2X,6F16.1/))
DO 1550 1=1, J
TCOST(I)=9E10
TEST(I)=0
ELSN(I)=0
1550 CONTINUE
TCOST(1)=0
TEST(1)=1
1590 CONTINUE
DO 1600 I=1, J
IF (TEST(I).EQ.1) THEN
   JM1=J-1
   NUM=0
   DO 1610 JJ=1, JM1
      DO 1620 KK=JJ, JM1
         NUM=NUM+1
         SERN=NUM
         KKP1=KK+1
         IF (JJ.EQ.I) THEN
            IF ((TCOST(I)+COST(JJ,KK)).LT.TCOST(KKP1)) THEN
               TCOST(KKP1)=TCOST(I)+COST(JJ,KK)
               ELSN(KKP1)=SERN
               TEST(KKP1)=1
            ENDIF
          ENDIF
        ENDIF
      ENDIF
   ENDIF
1610 CONTINUE
1620 CONTINUE
1600 CONTINUE
C **********

ENDIF

ENDIF

1620  CONTINUE

1610  CONTINUE

TEST(I)=0

ENDIF

1600  CONTINUE

DO 1650  I=1,J

1650  CONTINUE

IF (TEST(I).EQ.1) GO TO 1590

IF (J.EQ.5) THEN

DO 1660  M=1,J

1660  CONTINUE

ENDIF

RETURN

END

SUBROUTINE UPRES(I,JNO,CHK,DT,LP,AVARES,SKD,COST)

COMMON /TWO/ TARES(1,26),ELSN(25),PRED(25)

COMMON /FOUR/ TN0,TN02

REAL RQRES(1,3),AVARES(1,26),LP(12,1,3),DT(12,24)

REAL COST(24,24),SKD(12,24)

INTEGER S,S1,F,T,TN0,TN02,CHK

IF (JNO.EQ.2) THEN

TDMD=DT(I,1)

DO 1670  K=1,3

WRITE(6,1665) TDMD,LP(I,1,K)

1665  FORMAT(2X,2F10.3)

RQRES(1,K)=TDMD*LP(1,1,K)

TARES(1,K)=TARES(1,K)-RQRES(1,K)

CONTINUE

RETURN

ENDIF

PRED(1)=JNO

J=1

N=1

WHILE(PRED(N).NE.1)

WRITE(6,1690) N,PRED(N)

1690  FORMAT(5X,'PRED',15,'=',F10.3)

N=N+1

SERN=ELSN(PRED(N-1))

JTEMP=JNO-1

JNOM1=JNO-1

DO 1750  L=1,JTEMP

T=SERN-JNOM1

IF (T.LE.0) THEN

PRED(N)=L

GO TO 1770

ENDIF

ENDIF

RETURN

END
ELSE
SERN=SERN-JN0M1
JNOM1=JNOM1-1
ENDIF
1750 CONTINUE
1770 CONTINUE
   WRITE(6,1690) N,PRED(N)
END WHILE
IF (CHK.EQ.2) GO TO 2000
JN01=JNO
NM1=N-1
DO 1800 KA=1,NM1
   TDMD=0
   F=JN01
   C PRED(1) IS THE DESTINATION
   KA1=KA+1
   S=PRED(KA1)+1
   S1=S-1
   DO 1850 K1=S,F
      TDMD=TDMD+DT(I,K1-1)
   1850 CONTINUE
   DO 1900 K=1,3
      RQRES(J,K)=TDMD*LP(I,J,K)
      T1=S1-1+K
      TARES(J,T1)=TARES(J,T1)-RQRES(J,K)
   1900 CONTINUE
   JN01=PRED(KA1)
   WRITE(5,1950) JN01,KA
   1950 FORMAT(2X,215/)
   1800 CONTINUE
RETURN
2000 CONTINUE
JN01=JNO
WRITE(6,2040) N
2040 FORMAT(2X,15/)
NM1=N-1
DO 2050 KA=1,NM1
   TDMD=0
   F=JN01
   KA1=KA+1
   S=PRED(KA1)+1
   S1=S-1
   DO 2100 K1=S,F
      TDMD=TDMD+DT(I,K1-1)
   2100 CONTINUE
   SKD(I,S1)=TDMD
   WRITE(6,1950) S,F
   DO 2200 K=1,3
      T1=S1-1+K
      RQRES(J,K)=TDMD*LP(I,J,K)
AVARES(J,T1) = AVARES(J,T1) - RQRES(J,K)

CONTINUE

JNO1 = PRED(KA1)

CONTINUE

WRITE(6,370) (TARES(1,LT),LT=1,TN02)

FORMAT(2X,8F16.2)

DO 2270 KKK=1,TN0

DO 2270 JJJ=KKK,TNO

COST(JJJ,KKK) = 9E10

CONTINUE

RETURN

END

C **************************************************

SUBROUTINE CCOST(INO,TNO,SKD,AVARES,OCOST,RC,III)

REAL LP

COMMON /ONE/ H(12),DT(12,24),LP(12,1,3),S(12)

REAL E(12,26),AVARES(1,26),SKD(12,24),P(12)

REAL RQRES(1,3)

INTEGER TN0,T,T1,CT,TN02

WRITE(6,4000) ((SKD(I,T),T=1,TN0),I=1,INO)

FORMAT(2X,12F10.2/)

C TOTAL SETUP COST

C

TN02 = TN0 + 2

DO 4005 II=1,12

P(II) = 0

SETN = 0

SUMS = 0

DO 4020 I=1,INO

NSETUP = 0

DO 4010 T=1,TNO

IF (SKD(I,T),CT.0) THEN

NSETUP = NSETUP + 1

ENDIF

SETN = SETN + NSETUP

SUMS = SUMS + NSETUP * S(I)

C CALCULATE HOLDING/PENALTY COST

C

SUMH = 0

SUMP = 0

TSUMH = 0

TSUMP = 0

DO 4035 I=1,INO

DO 4030 CT=1,TNO

SDT = 0

SX = 0

DO 4050 T=1,CT

2200

2050

370

2270

4000

4005

4010

4020

4035

4030

4050
SX = SX + SKD(I, T)  
SDT = SDT + DT(I, T)  
E(I, CT) = SX - SDT  
IF (E(I, CT) > 0) THEN  
  SUMH = SUMH + E(I, CT) * H(I)  
  TSUMH = TSUMH + E(I, CT)  
ELSE  
  SUMP = SUMP - E(I, CT) * P(I)  
  TSUMP = TSUMP - E(I, CT)  
ENDIF  
CONTINUE  
WRITE(6, 4036) SUMH, SUMP  
4036 FORMAT(' SUMH, SUMP', 2F16.2)  
CONTINUE  

C  
C CALCULATE OVERLOAD COST  
C  
SUMOC = 0  
DO 5000 II = 1, TNO  
5000 AVARES(1, II) = RC  
DO 5010 I = 1, INO  
DO 5010 IT = 1, TNO  
DO 5010 K = 1, 3  
  T1 = IT + K - 1  
  RQRES(1, K) = LP(I, 1, K) * SKD(I, IT)  
  AVARES(1, T1) = AVARES(1, T1) - RQRES(1, K)  
CONTINUE  
WRITE(6, 5020) (AVARES(1, LT), LT = 1, TNO)  
5020 FORMAT(2X, 2(7F15.2/))  
DO 4070 T = 1, TNO  
  IF (AVARES(1, T) < 0) THEN  
    SUMOC = SUMOC - AVARES(1, T)  
  ENDIF  
CONTINUE  
TSUMOC = SUMOC  
WRITE(6, 4071) SUMOC  
4071 FORMAT(' OVARES', F15.2)  
SUMOC = SUMOC * OCOST  

C  
C CALCULATE TOTAL COST  
C  
SUMTC = SUMS + SUMH + SUMP + SUMOC  
WRITE(60, 4077) SUMTC, SUMS, SUMH, SUMP, SUMOC  
WRITE(60, 4077) SUMTC, SETN, TSUMH, TSUMP, TSUMOC  
40570 FORMAT(5F16.2)  
WRITE(65, 5090) SUMTC, SUMS, SUMH, SUMP, SUMOC  
5090 FORMAT(2X, 'SUMTC, SUMS, SUMH, SUMP, SUMOC', 5F16.2)  
IF (III.EQ.1) THEN  
  WRITE(40, 5093) SUMTC  
ENDIF
REAL FUNCTION AMIN(AM,BM)
REAL AM,BM
IF (AM.LT.BM) THEN
  AMIN=AM
ELSE
  AMIN=BM
ENDIF
RETURN
END

REAL FUNCTION CALC(I,JN,KN,AVARES,TARES,OC)
REAL AVARES(1,26),TARES(1,26),TEMP(12,1,3),LP
INTEGER T,TNO
J=1
COMMON /ONE/ H(12),DT(12,24),LP(12,1,3),S(12)
COMMON /FOUR/ TNO,TNO2
C SET UP COST
A=S(I)
C HOLDING COST/PRODUCTION QUANTITY
B=0
PQ=0
  DO 6000 T=JN,KN
    B=B+H(I)*(T-JN)*DT(I,T)
    PQ=PQ+DT(I,T)
  ENDIN
  DO 6000 T=JN,KN
    B=B+H(I)*(T-JN)*DT(I,T)
    PQ=PQ+DT(I,T)
6000 CONTINUE
C OVERLOAD COST
SUM=0
  DO 6010 K=1,3
    TEMP(I,J,K)=LP(I,J,K)*PQ
    T1=JN+K-1
    IF (T1.GT.TNO) GO TO 6010
    IF (TARES(J,T1).LT.O) THEN
      SUM=SUM+TEMP(I,J,K)
    ELSE
      WK=TEMP(I,J,K)-TARES(J,T1)
      IF (WK.GT.O) THEN
        SUM=SUM+WK
      ENDIF
    WRITE(5,5030) K,TARES(J,T1),PQ,TEMP(1,1,K)
  ENDIF
  WRITE(6,6030) K,TARES(J,T1),PQ,TEMP(I,1,K)
6010 CONTINUE
C OVERLOAD COST
WRITE(6,6050) SUM
C=SUM*OC
IF (JN.EQ.3) THEN
WRITE(6,6070) A,B,C
6070 FORMAT(2X,'A,B,C=',3F12.2)
ENDIF
CALC=A+B+C
RETURN
END
C$ENTRY
Method C

$JOB 'KIM',TIME=(2,30),PAGES=100,NOWARN

C * I/O FILE SUMMARY ****************************************

C DD NAME DSN

C 1. INPUT FT20F001 K.I6467.DATA
   FT30F001 K.I6467.RESA
   FT40F001 K.I6467.RESB

C 2. OUTPUT FT70F001 K.I6467.MINC

********* FILE DESCRIPTION **********************************

1. K.I6467.DATA
   REFER TO METHODA

2. K.I6467.RESA
   REFER TO METHODA

3. K.I6467.RESB
   REFER TO METHODB

4. K.I6467.MINC
   1) BOUNDL: COST C FROM METHOD C (TREE SEARCH METHOD)

VARIABLE DEFINITION ****************************************

INTEGER INO,CT,T,TNO,TNO1,TT,T1,T2,T3,TA,CTMT2
INTEGER TEMP1,TEMP2,TFROM,TFROM1,TTO,TNO2
INTEGER ST,TNOM1,CT1,KSAVE(12),TABLE(20,4)
INTEGER SWA,STFROM,STTO,COUNT,ITBL(300,4)
REAL TEMP(12,1,3),LP(12,1,3),E(12,24)
REAL SIGN(20,3),IRA(5),TARES(1,26)
REAL S(12),P(12),H(12),VAL(10)
REAL LSQ,LSQ1,LSQ2,MAABB
REAL MINVAL,MAXVAL
DOUBLEPRECISION DENOM,DNUMER
COMMON/ONE/DT(12,24),SKD(12,24),AVARES(1,26)
COMMON/TWO/VAL10(10),UVAL

DO 12345 IJKL=1,5
KNO=3
READ(20,50) INO,TNO,DSEED,OCOST
50 FORMAT(2I2,F20.7,F7.2)
WRITE(6,100) INO,TNO,DSEED,OCOST
100 FORMAT(' INO,TNO,DSEED,OCOST',2I2,F20.7,F7.2)

TNO2=INO+2

C GENERATE LOAD PROFILE
READ(20,150) IX,ICT
150 FORMAT(I12,I4)
WRITE(6,200) IX,ICT
200 FORMAT(' OLD SEED FOR LP & TOTAL COUNT',I12,I4)
DO 250 III=1,INO
CALL RANDU(IX,IY,R)
IX=IY
R=R*1000
IR=INT(R)
WRITE(6,300) IR
300 FORMAT(2X,'RANDOM NUMBER',15)
DO 250 IB=1,3
RA=IR/((10)**(3-IB))
LP(III,1,IB)=INT(RA)
IR=IR-INT(RA)*((10)**(3-IB))
250 CONTINUE
WRITE(6,350) IX
350 FORMAT(' NEW SEED FOR LOAD PROFILE',112)
DO 400 II=1,INO
READ(20,450) MEAN,MVAR,MAMP
450 FORMAT(3I3)
400 CONTINUE
READ(20,500) RATIO,NCT
500 FORMAT(F7.2,I2)
SRATIO=RATIO
DO 550 INUM=1,INO
SLP=0
DO 600 K=1,3
IF (LP(INUM,1,K).GT.SLP) THEN
SLP=LP(INUM,1,K)
KSAVE(INUM)=K
ENDIF
550 CONTINUE
500 CONTINUE
READ(20,700) P(I),S(I),H(I)
700 FORMAT(3F7.2)
WRITE(6,750) P(I),S(I),H(I)
750 FORMAT(' P(I),S(I),H(I)',3F7.2)
650 CONTINUE
DO 9999 IJK=1,NCT
IBRCH=0
COUNT=0
BOUNDL=9E11
ILEVEL=1
CALL CLOCK(IC)
SWA=0
STFROM=0.
STTO=0
WRITE(6,800) RATIO, IJK
800 FORMAT('IRATIO, IJK',F16.2,I3)
RATIO=RATIO+0.1
READ(30,850) STCA
850 FORMAT(F16.2)
WRITE(6,900) STCA
900 FORMAT(' ORIGINAL TOTAL COST OF RESA',F16.2)
READ(40,850) STCB
WRITE(6,900) STCB
900 FORMAT(' ORIGINAL TOTAL COST OF RESB',F16.2)
IF (STCA.LE.STCB) THEN
  IUNIT=30
  SUMTC=STCA
ELSE
  IUNIT=40
  SUMTC=STCB
ENDIF
VAL(1)=SUMTC
SMALLV=SUMTC
NCOL=2
CALL READ(IUNIT,INO,TNO)
950 CONTINUE
DO 1050 LT=1,TNO2
1050 TARES(1,LT)=AVARES(1,LT)
IF (SMALLV.LT.BOUNDL) THEN
  BOUNDL=SMALLV
ENDIF
IF (ILEVEL.GT.4) THEN
  GO TO 1100
ENDIF
DO 3010 T=1,TNO
  IF (AVARES(1,T).GT.O) THEN
    ST=T
  GO TO 3030
3010 CONTINUE
WRITE(6,3015)
3015 FORMAT(2X,'ALL AVARES IS NEGA')
GO TO 3950
C *************************************************************
3030 TNOM1=TNO-1
N=1
SIGN(N,1)=ST
TAVA=0
DO 3050 T=ST,TNOM1
   IF (((AVARES(1,T).LT.0).AND.(AVARES(1,T+1).GT.0)).OR.
      ((AVARES(1,T).GT.0).AND.(AVARES(1,T+1).LT.0))) THEN
      SIGN(N,2)=T
      SIGN(N,3)=TAVA+AVARES(1,T)
      TAVA=0
      N=N+1
      SIGN(N,1)=T+1
   ELSE
      TAVA=TAVA+AVARES(1,T)
      IF (T.EQ.TNOM1) THEN
         SIGN(N,2)=TNOM
         SIGN(N,3)=TAVA+AVARES(1,T+1)
      ENDIF
   ENDIF
3050 CONTINUE
   NT=MOD(N,2)
   IF (NT.EQ.0) THEN
      NT=N
   ELSE
      NT=N-1
   ENDIF
WRITE(6,3070) NT
3070 FORMAT(2X, 15)
   IF (NT.LT.2) THEN
      WRITE(6,3075) NT
      GO TO 3950
   ENDIF
   NT IS THE TOTAL NUMBER OF ROWS
C *******************************************************
IX=12357
3800 CONTINUE
COUNT=COUNT+1
   IF (COUNT.GT.ICT) THEN
      WRITE(6,3701)
3701 FORMAT(2X, 'INCREASE COUNT')
   GO TO 1100
   ENDIF
   CALL RANDU(IX,IY,R)
IX=IY
R=R*100000
IR=INT(R)
C WRITE(5,3090) IR
3090 FORMAT(2X,'RANDOM NUMBER',I6)
DO 3110 IB=1,5
RA=IR/((10)**(5-IB))
IRA(IB)=INT(RA)/10.
IR=IR-INT(RA)*((10)**(5-IB))
3110 CONTINUE
C WRITE(6,3000) (IRA(IB),IB=1,5)
3000 FORMAT(2X,5F10.2)
TEMP0=NT*IRA(1)
NTEMP1=INT(TEMP0+01.000)
NTEMP2=MOD(NTEMP1,2)
IF (NTEMP2.EQ.0) THEN
   NF=NTEMP1
ELSE
   NF=NTEMP1+1
ENDIF
C FIND ITEM NUMBER
TEMPO=INO*IRA(2)
INUM=INT(TEMPO+01.000)
C FIND THE ORIGIN PERIOD
TEMP1=SIGN(NF,1)
TEMP2=SIGN(NF,2)
TEMPO=(TEMP2-TEMP1)*IRA(3)
IF (TEMPO.EQ.0) THEN
   TEMPO=-0.001
ENDIF
TFROM=INT(TEMPO+01.000)+TEMP1
C WRITE(6,3145) NF,TEMP1,TEMP2,TFROM,TEMPO
3145 FORMAT(2X,'NF,TEMP1,2,TFROM,TEMPO',4I5,F16.2)
IF (SKD(INUM,TFROM).EQ.0) THEN
   DO 3150 II=TEMP1,TEMP2
      IF (SKD(INUM,II).GT.0) THEN
         TFROM=II
         GO TO 3156
      ENDIF
   3150 CONTINUE
C ORIGIN PERIOD IS EMPTY
   DO 3175 III=TEMP1,TEMP2
      DO 3175 JJJ=1,INO
         IF (SKD(JJJ,III).GT.0) THEN
            TFROM=III
            INUM=JJJ
            LSQ=IRA(5)*SKD(JJJ,III)
         ENDIF
      3175 CONTINUE
C FIND THE TO PERIOD
NF1=NF-1
TMP1=SIGN(NF1,1)
TMP2=SIGN(NF1,2)
TMP0=(TMP2-TMP1)*IRA(4)
IF (TMP0.EQ.0) THEN
TMPO=-0.001
ENDIF
TTO=INT(TMPO+O.000)+TMP1
    GO TO 3180
ENDIF
C C
C FIND THE DESTINATION PERIOD
C
3156 NFM1=NF-1
    TEMP1=SIGN(NFM1,1)
    TEMP2=SIGN(NFM1,2)
    TEMPO=(TEMP2-TEMP1)*IRA(4)
    IF (TEMPO.EQ.0) THEN
       TEMPO=-0.001
    ENDIF
    TTO=INT(TEMPO+O.000)+TEMP1
C
3157 FORMAT(2X,'AVA,LSQ1,2,TTO',3F16.2,15)
3180 CONTINUE
C C
C MINUS OCOST
C
SUM=0
DO 3200 K=1,3
    TEMP(INUM,1,K)=LSQ*LP(INUM,1,K)
    T1=TFROM+K-1
    IF (TARES(1,T1).LT.0) THEN
       AAA=(-1)*TARES(1,T1)
       BBB=TEMP(INUM,1,K)
       WRITE(6,3205) AAA,BBB,TARES(1,T1),T1
    ENDIF
3205 FORMAT(2X,'AAA,BBB,AVA,T1',3F16.2,15)
    IF (AAA.LT.BBB) THEN
       MAABB=AAA
    ELSE


MAABB = BBB
ENDIF
SUM = SUM + MAABB
ENDIF
TARES(1, T1) = TARES(1, T1) - TEMP(INUM, 1, K)
3200 CONTINUE
OTCOST = SUM * OCOST
C WRITE(6, 3210) OTCOST, SUM, OCOST
3210 FORMAT(2X, 'OTCOST, SUM, OCOST', 3F16.2)
C C C PLUS OCOST C C OVERLOAD COST
J = 1
SUM1 = 0
DO 3300 K = 1, 3
TEMP(INUM, J, K) = LP(INUM, J, K) * LSQ
T1 = TTO + K - 1
IF (TARES(J, T1).LT.O) THEN
SUM1 = SUM1 + TEMP(INUM, J, K)
ELSE
WK = TEMP(INUM, J, K) - TARES(J, T1)
IF (WK.GT.O) THEN
SUM1 = SUM1 + WK
ENDIF
C WRITE(6, 3350) K, TARES(1, TL), PQ, TEMP(INUM, 1, K)
3350 FORMAT(2X, 'K, TARES, PQ, TEMP', I3, 3F16.2)
ENDIF
3300 CONTINUE
C WRITE(6, 3400) SUM1
3400 FORMAT(2X, 'SUM1=', F16.2)
OMCOST = SUM1 * OCOST
DO 3450 LT = 1, TNO2
3450 FORMAT(2X, 'SUM1=', F16.2, 2I6)
WRITE(6, 3500) HCOST, H(INUM), TFROM, TTO
3500 FORMAT(2X, 2F16.2, 2I6)
C ADD SETUP COST
C TEMPO = SKD(INUM, TTO)
IF (TEMPO.EQ.O.) THEN
SCOST = S(INUM)
ELSE
SCOST = 0
ENDIF
C ADD HOLDING COST
HCOST = (TFROM - TTO) * H(INUM) * LSQ
C WRITE(6, 3550) HCOST, H(INUM), TFROM, TTO
3550 FORMAT(2X, 'HCOST, H(INUM), TFROM, TTO', 2F16.2, 2I6)
160

3550 FORMAT(2X,'HCOST',F16.2)
C ADD ALL ADDITIONAL COST
C
TOTCOST=OTCOST+OMCOST+SCOST+HCOST
C
3600 CONTINUE
IF (NCOL.LT.10) THEN
ENDIF
VAL(NCOL)=TOTCOST+BOUNDL
TABLE(NCOL,1)=TTO
TABLE(NCOL,2)=TFROM
TABLE(NCOL,3)=INUM
IF (IBRCH.EQ.0) THEN
TABLE(NCOL,4)=INT(LSQ)
ELSE
TABLE(NCOL,4)=INT(RSQ)
ENDIF
NCOL=NCOL+1
C
IF (NCOL.GE.5) THEN
SMALLV=9E10
DO 3650 I=1,4
   IF (SMALLV.GT.VAL(I)) THEN
      ISAVE=I
      SMALLV=VAL(I)
   ENDIF
3650 CONTINUE
IF (IBRCH.EQ.1) THEN
WRITE(6,3700) (VAL(I),I=1,4)
3700 FORMAT(' **VAL10**',9F10.2/)
ENDIF
VAL(1)=VAL(ISAVE)
IF (ISAVE.EQ.1) THEN
   NCOL=2
   ILEVEL=ILEVEL+1
   GO TO 950
ENDIF
INUM=TABLE(ISAVE,3)
TTO=TABLE(ISAVE,1)
TFROM=TABLE(ISAVE,2)
LSQT=TABLE(ISAVE,4)
RLSQ=FLOAT(LSQ)
DO 3750 K=1,3
   TEMP(INUM,1,K)=RLSQ*LP(INUM,1,K)
   K1=TFROM+K-1
   K2=TTO+K-1
   AVARES(1,K1)=AVARES(1,K1)+TEMP(INUM,1,K)
   AVARES(1,K2)=AVARES(1,K2)-TEMP(INUM,1,K)
3750 CONTINUE
C UPDATE SCHEDULE
161

\[ \text{SKD(INUM,TFROM)} = \text{SKD(INUM,TFROM)} - \text{RLSQ} \]
\[ \text{SKD(INUM,TTO)} = \text{SKD(INUM,TTO)} + \text{RLSQ} \]
\[ \text{ILEVEL} = \text{ILEVEL} + 1 \]
\[ \text{NCOL} = 2 \]
\[ \text{GO TO 950} \]

ELSE
\[ \text{IF (IBRCH.EQ.0) THEN} \]
\[ \text{GO TO 3800} \]

GO TO 3900

ENDIF

3950 CONTINUE

IBRCH = 1
ISER = 1
\[ \text{DO 4035 I=1,INO} \]
\[ \text{DO 4030 CT=1,TNO} \]
SDT = 0
SX = 0
\[ \text{DO 4050 T=1,CT} \]
SX = SX + SKD(I,T)
SDT = SDT + DT(I,T)
\[ \text{E(I,CT)} = SX - SDT \]
\[ \text{IF (E(I,CT).GT.0) THEN} \]
\[ \text{ITBL(ISER,1)} = I \]
\[ \text{ITBL(ISER,2)} = CT \]
\[ \text{ITBL(ISER,3)} = \text{INT(E(I,CT))} \]
\[ \text{SUME} = E(I,CT) \]
\[ \text{IF (CT.EQ.TNO) THEN} \]
\[ \text{ITBL(ISER,4)} = 0 \]
ELSE
CT1 = CT + 1
\[ \text{DO 4055 T=CT,TNO} \]
SUME = SUME - DT(I,T)
\[ \text{IF (SUME.LE.0) THEN} \]
\[ \text{ITBL(ISER,4)} = T - CT - 1 \]
\[ \text{GO TO 4056} \]
ENDIF

4055 CONTINUE
\[ \text{ITBL(ISER,4)} = 0 \]
4056 CONTINUE
ENDIF
ISER = ISER + 1
ENDIF

4030 CONTINUE
4035 CONTINUE
3900 CONTINUE

C GENERATE RANDOM VARIABLE AND INUM AND TFROM
CALL RANDU(IX,IY,R)
IX = IY
R = R * 100
IR = INT(R)
WRITE(6, 3090) IR
DO 4100 IB = 1, 2
RA = IR / ((10) ** (2 - IB))
IRA(IB) = INT(RA) / 10.
IR = IR - INT(RA) * ((10) ** (2 - IB))
CONTINUE
TEMP0 = (ISER - 1) * IRA(1)
ISERC = INT(TEMP0 + 1.0)
TEMP0 = ITBL(ISERC, 4) * IRA(2)
IRSP = INT(TEMP0 + 1.0)
INUM = ITBL(ISERC, 1)
TFROM = ITBL(ISERC, 2)
TTO = ITBL(ISERC, 2) + IRSP
IF (TTO .GT. TNO) THEN
TTO = TNO
ENDIF
ITEMP = ITBL(ISERC, 3)
TEMP11 = FLOAT(ITEMP)
RSQ1 = AMIN(SKD(INUM, TFROM), TEMP11)
TTOS = TTO + KSAVE(INUM) - 1
TLP = LP(INUM, 1, KSAVE(INUM))
IF (TLP .EQ. 0) THEN
TLP = 1.
ENDIF
RSQ2 = AVARES(1, TTOS) / TLP
RSQ = AMIN(RSQ1, RSQ2)
C DECREASE THE HOLDING COST
DHC0ST = H(INUM) * (TTO - TFROM) * RSQ
C ADD THE SET UP COST
IF (SKD(INUM, TTO) .EQ. 0) THEN
ASC0ST = S(INUM)
ELSE
ASC0ST = 0
ENDIF
TOTCOST = - DHC0ST + ASC0ST
GO TO 3600
CONTINUE
WRITE(70, 4250) BOUNDL
WRITE(6, 4300) NCOL, ILEVEL, BOUNDL
FORMAT('NCOL, ILEVEL, * BOUNDL *,', 215, F16.2)
CALL CLOCK(ID)
ICPU = IC - ID
WRITE(6, 4350) IC, ID, ICPU
FORMAT('IC, ID, ICPU', 315)
WRITE(6, 4400) ((SKD(TT, IT), IT = 1, TNO), II = 1, INO)
FORMAT(6, 4450) (AVARES(1, IT), IT = 1, TNO2)
C **********************************************************
SUBROUTINE READ(IUNIT,INO,TNO)
   INTEGER TNO,T,TN02
   COMMON/ONE/DT(12,24),SKD(12,24),AVARES(1,26)
   TN02=TNO+2
   DO 6000 I=1,INO
   DO 6000 T=1,TNO
   READ(IUNIT,70) DT(I,T)
   5000 CONTINUE
   WRITE(6,6050) ((DT(11, IT),IT=1,TNO),11=1,INO)
   6050 FORMAT(5(2X,5F10.2/))
   DO 5100 1=1,INO
   DO 6100 T=1,TN0
   READ(IUNIT,6125) SKD(I,T)
   6125 FORMAT(F10.2)
   6100 CONTINUE
   WRITE(6,6150) ((SKD(II,IT),IT=1,TNO),I1=1,INO)
   6150 FORMAT(6(2X,6F10.2/))
   DO 6200 T=1,TN02
   READ(IUNIT,6250) AVARES(1,T)
   6250 FORMAT(F16.2)
   6200 CONTINUE
   WRITE(6,6300) (AVARES(1, IT),IT=1,TN02)
   6300 FORMAT(2(2X,7F16.2/))
   IF (IUNIT.EQ.30) THEN
      IDUM=40
   ELSE
      IDUM=30
   ENDIF
   IT=2*INO*TN0+TN0+2
   DO 6350 II=1,IT
      READ(IDUM,6400) DUMMY
   6350 CONTINUE
   RETURN
END

C **********************************************************
REAL FUNCTION AMIN(AM,BM)
   REAL AM,BM
   IF (AM.LT.BM) THEN
      AMIN=AM
   ELSE
      AMIN=BM
   ENDIF

REAL FUNCTION AMIN(AM,BM)
   REAL AM,BM
   IF (AM.LT.BM) THEN
      AMIN=AM
   ELSE
      AMIN=BM
   ENDIF
RETURN
END
C **********************************************************************************************************
SUBROUTINE SORT(VAL,INO)
C
REAL VAL(100)
INOM1=INO-1
DO 6450 NPASS=1,INOM1
    INOMN=INO-NPASS
    DO 5500 I=1,INOMN
        IF (VAL(I).GT.VAL(I+1)) THEN
            TEMPO=VAL(I)
            VAL(I)=VAL(I+1)
            VAL(I+1)=TEMPO
        ENDIF
    ENDIF
5450 CONTINUE
5500 CONTINUE
6450 CONTINUE
RETURN
END
C$ENTRY
Solution standard

$JOB 'KIM',TIME=(2,00),PAGES=100

C
C * I/O FILE SUMMARY *****************************************

C DD NAME DSN

C 1. INPUT FT20F001 K.16467.DATA
   FT30F001 K.16467.RESA
   FT40F001 K.16467.RESB

C 2. OUTPUT FT90F001 K.16467.EXT

C ********* FILE DESCRIPTION *****************************

C 1. K.16467.DATA
   REFER TO METHOD A

C 2. K.16467.RESA
   REFER TO METHOD A

C 3. K.16467.RESB
   REFER TO METHOD B

C 4. K.16467.EXT

C 1) VAL(1): VAL10(1): BOUNDL: SOLUTION STANDARD

C *** VARIABLE DEFINITION **********************************

INTEGER INO,CT,T,TNO1,TT,T1,T2,T3,TA,CTMT2
INTEGER TEMP1,TEMP2,TFROM,TFROM1,TTO,TNO2
INTEGER ST,TNOM1,CT1,KSAVE(12)
INTEGER SWA,STFROM,STTO,COUNT,ITBL(300,4)
REAL TEMP(12,1,3),LP(12,1,3),E(12,24)
REAL SIGN(20,3),IRA(5),TARES(1,26)
REAL S(12),P(12),H(12),VAL(300)
REAL LSQ,LSQ1,LSQ2,MAABB
REAL MINVAL,MAXVAL
DOUBLEPRECISION DENOM,DNUMER, DB,ALPHA
COMMON/ONE/DT(12,24),SKD(12,24),AVARES(1,26)
COMMON/TWO/VAL10(10),UVAL

DO 12345 IJKL=1,5
KNO=3
READ(20,50) INO,TNO,DSEED,OCOST
50 FORMAT(2I2,F20.7,F7.2)
WRITE(6,100) INO,TNO,DSEED,OCOST
100 FORMAT(INO,TNO,DSEED,OCOST',2I2,F20.7,F7.2)
TNO2=TNO+2

C GENERATE LOAD PROFILE
READ(20,150) IX,ICT
150 FORMAT(I12,I4)
WRITE(6,200) IX,ICT
200 FORMAT(' OLD SEED FOR LP & TOTAL COUNT',I12,I4)
DO 250 III=1,INO
CALL RANDU(IX,IY,R)
IX=IY
R=R*1000
IR=INT(R)
WRITE(6,300) IR
300 FORMAT(2X,'RANDOM NUMBER',I6)
DO 250 IB=1,3
RA=IR/((10)**(3-IB))
LP(III,1,IB)=INT(RA)
IR=IR-INT(RA)*((10)**(3-IB))
250 CONTINUE
WRITE(6,400) IX
400 FORMAT(' NEW SEED FOR LOAD PROFILE',I12)
DO 450 II=1,INO
READ(20,500) MEAN,MVAR,MAMP
500 FORMAT(3F7.2)
450 CONTINUE
READ(20,550) RATIO,NCT
550 FORMAT(F7.2,I2)
SRATIO=RATIO
DO 600 INUM=1,INO
SLP=0
DO 650 K=1,3
IF (LP(INUM,1,K).GT.SLP) THEN
SLP=LP(INUM,1,K)
KSAVE(INUM)=K
ENDIF
650 CONTINUE
DO 10000 IIII=1,3
RATIO=SRATIO
DO 700 I=1,INO
READ(20,750) P(I),S(I),H(I)
750 FORMAT(3F7.2)
WRITE(6,800) P(I),S(I),H(I)
800 FORMAT( P(I),S(I),H(I)',3F7.2)
700 CONTINUE
DO 9999 IJK=1,NCT
IBRCH=0
COUNT=0
    CALL CLOCK(IC)
SWA=0
STFROM=0
STTO=0
    WRITE(6,850) RATIO, IJK
850 FORMAT (' 1RATIO,IJK', F16.2, I3)
RATIO=RATIO+0.1
READ(30,900) STCA
900 FORMAT(F16.2)
WRITE(6,950) STCA
950 FORMAT (' ORIGINAL TOTAL COST OF RESA', F16.2)
READ(40,900) STCB
WRITE(6,1050) STCB
1050 FORMAT (' ORIGINAL TOTAL COST OF RESB', F16.2)
IF (STCA.LE.STCB) THEN
    IUNIT=30
    SUMTC=STCA
ELSE
    IUNIT=40
    SUMTC=STCB
ENDIF
VAL(1)=SUMTC
NCOL=2
CALL READ(IUNIT,INO,TNO)
DO 1100 LT=1,TNO2
1100 TARES(1,LT)=AVARES(1,LT)
DO 1150 T=1,TNO
    IF (AVARES(1,T).GT.O) THEN
        ST=T
        GO TO 3030
    ENDIF
1150 CONTINUE
    WRITE(6,1200)
1200 FORMAT(2X,'ALL AVARES IS NEGA')
    GO TO 9997
C *******************************************************
3030 TNOM1=TNO-1
N=1
    SIGN(N,1)=ST
TAVA=0
DO 3050 T=ST,TNOM1
    IF (((AVARES(1,T).LT.O).AND.(AVARES(1,T+1).GT.O)) .OR. 
1 ((AVARES(1,T).GT.O).AND.(AVARES(1,T+1).LT.O))) THEN
        SIGN(N,2)=T
        SIGN(N,3)=TAVA+AVARES(1,T)
        TAVA=0
        N=N+1
        SIGN(N,1)=T+1
    ENDIF
3050 CONTINUE
C
IF (T.EQ.TNOM1) THEN
  SIGN(N,2)=T+1
  SIGN(N,3)=TAVA+AVARES(1,T+1)
ENDIF
ELSE
  TAVA=TAVA+AVARES(1,T)
  IF (T.EQ.TNOM1) THEN
    SIGN(N,2)=TNO
    SIGN(N,3)=TAVA+AVARES(1,T+1)
  ENDIF
ENDIF
3050 CONTINUE
C
WRITE(6,3020) T,N,((SIGN(N,JJ),JJ=1,3), N=1, 4)
3020 FORMAT(2X,'T,N,SIGN123',215,4(3F16.2/))
NT=MOD(N,2)
IF (NT.EQ.0) THEN
  NT=N
ELSE
  NT=N-1
ENDIF
C
WRITE(6,3070) NT
3070 FORMAT(2X,15)
IF (NT.LT.2) THEN
  WRITE(6,3075) NT
3075 FORMAT(2X,15,'NT IS LESS THAN 2')
  GO TO 9997
ENDIF
C NT IS THE TOTAL NUMBER OF ROWS
C ******************************************************
IX=12357
3700 CONTINUE
COUNT=COUNT+1
IF (COUNT.GT.ICT) THEN
  WRITE(6,3701)
3701 FORMAT(2X,' INCREASE COUNT')
NCOLM1=NCOL-1
IF (NCOLM1.GT.1) THEN
  CALL SORT(VAL,NCOLM1)
ENDIF
C
WRITE(80,4450) VAL(1)
WRITE(90,4450) VAL(1)
WRITE(6,3778) VAL(1)
3778 FORMAT(' VAL(1)',F16.2)
  GO TO 9999
ENDIF
C
CALL RANDU(IX,IY,R)
IX=IY
R=R*100000
IR=INT(R)
C WRITE(6,3090) IR
3090 FORMAT(2X,'RANDOM NUMBER',I6)
DO 3110 IB=1,5
RA=IR/((10)**(5-IB))
IRA(IB)=INT(RA)/10.
IR=IR-INT(RA)*((10)**(5-IB))
CONTINUE
C WRITE(6,3000) (IRA(IB),IB=1,5)
3000 FORMAT(2X,5F10.2)
TEMP0=NT*IRA(1)
NTEMP1=INT(TEMP0+01.000)
NTEMP2=MOD(NTEMP1,2)
IF (NTEMP2.EQ.0) THEN
   NF=NTEMP1
   ELSE
   NF=NTEMP1+1
ENDIF
C FIND ITEM NUMBER
TEMPO=INO*IRA(2)
INUM=INT(TEMPO+01.000)
C FIND THE FROM PERIOD
TEMP1=SIGN(NF,1)
TEMP2=SIGN(NF,2)
TEMPO=(TEMP2-TEMP1)*IRA(3)
IF (TEMPO.EQ.0) THEN
   TEMPO=-0.001
ENDIF
TFROM=INT(TEMPO+01.000)+TEMP1
C WRITE(6,3145) NF,TEMP1,TEMP2,TFROM,TEMPO
3145 FORMAT(2X,'NF,TEMP1,2,TFROM,TEMPO',415,F16.2)
IF (SKD(INUM,TFROM).EQ.O) THEN
   DO 3150 II=TEMP1,TEMP2
      IF (SKD(INUM,II).GT.O) THEN
         TFROM=II
         GO TO 3156
      END IF
   3150 CONTINUE
C FROM PERIOD IS EMPTY
   DO 3175 III=TEMP1,TEMP2
      DO 3175 JJJ=1,INO
         IF (SKD(JJJ,III).GT.O) THEN
            TFROM=III
            INUM=JJJ
            LSQ=IRA(5)*SKD(JJJ,III)
            END IF
   3175 CONTINUE
C FIND THE TO PERIOD
NFM1=NF-1
TMP1=SIGN(NFM1,1)
TMP2=SIGN(NFM1,2)
TMPO=(TMP2-TMP1)*IRA(4)
IF (TMPO.EQ.0) THEN
TMP0=-0.001
ENDIF
TTO=INT(TMP0+0.000)+TMP1
GO TO 3180
ENDIF
3175 CONTINUE
GO TO 3700
ELSE
ENDIF
C
C FIND THE DESTINATION PERIOD
C
3156 NFM1=NF-1
TEMPO=SIGN(NFM1,1)
TEMP2=SIGN(NFM1,2)
TEMPO=(TEMP2-TEMPO)*IRA(4)
IF (TEMPO.EQ.0) THEN
TEMPO=-0.001
ENDIF
TTO=INT(TEMPO+0.000)+TEMPO
C FIND LSQ
TEMPO=3*IRA(5)
JJJ=INT(TEMPO+1.000)
TLP=LP(INUM,1,JJJ)
IF (TLP.EQ.0) THEN
TLP=1
ENDIF
LSQ1=AVARES(1,TTO)/TLP
LSQ2=SKD(INUM,TFROM)
LSQ=AMIN(LSQ1,LSQ2)
C WRITE(5,3157) AVARES(1,TTO),LSQ1,LSQ2,TTO
3157 FORMAT(2X,'AVA,LSQ1,LSQ2,TTO',3F16.2,15)
3180 CONTINUE
C
C MINUS OCOST
C
SUM=0
DO 3200 K=1,3
TEMP(INUM,1,K)=LSQ*LP(INUM,1,K)
T1=TFROM+K-1
IF (TARES(1,T1).LT.0) THEN
AAA=(-1)*TARES(1,T1)
BBB=TEMP(INUM,1,K)
C WRITE(6,3205) AAA,BBB,TARES(1,T1),T1
3205 FORMAT(2X,'AAA,BBB,TARES(1,T1),T1',3F16.2,15)
IF (AAA.LT.BBB) THEN
MAABB=AAA
ELSE
MAABB=BBB
ENDIF
SUM=SUM+MAABB
ENDIF
TARES(1,T1)=TARES(1,T1)-TEMP(INUM,1,K)
3200 CONTINUE
OTCOST=SUM*OCOST
C WRITE(6,3210) OTCOST,SUM,OCOST
3210 FORMAT(2X,'OTCOST,SUM,OCOST',3F15.2)
C
C PLUS OCOST
C
C OVERLOAD COST
J=1
SUM1=0
DO 3300 K=1,3
TEMP(INUM,J,K)=LP(INUM,J,K)*LSQ
T1=TTO+K-1
IF (TARES(J,T1).LT.0) THEN
SUM1=SUM1+TEMP(INUM,J,K)
ELSE
WK=TEMP(INUM,J,K)-TARES(J,T1)
IF (WK.GT.0) THEN
SUM1=SUM1+WK
ENDIF
ENDIF
3300 CONTINUE
C WRITE(6,3350) K,TARES(1,T1),PQ,TEMP(INUM,1,K)
3350 FORMAT(2X,'K,TARES,PQ,TEMP',I3,3F16.2)
ENDIF
3300 CONTINUE
C WRITE(6,3400) SUM1
3400 FORMAT(2X,'SUM1=',F16.2)
OMCOST=SUM1*OCOST
DO 3450 LT=1,TNO2
3450 TARES(1,LT)=AVARES(1,LT)
C ADD SETUP COST
C
TEMP0=SKD(INUM,TTO)
IF (TEMP0.EQ.0.) THEN
SCOST=S(INUM)
ELSE
SCOST=0
ENDIF
C
C ADD HOLDING COST
HCOST=(TFROM-TTO)*H(INUM)*LSQ
C
C WRITE(6,3500) HCOST,H(INUM),TFROM TTO
3500 FORMAT(2X,2F16.2,2I6)
C
C WRITE(6,3550) HCOST
3550 FORMAT(2X,'HCOST',F16.2)
C ADD ALL ADDITIONAL COST
C
TOTCOST=OTCOST+OMCOST+SCOST+HCOST
C
IF (NCOL.LT.10) THEN
ENDIF
3600 VAL(NCOL)=TOTCOST+SUMTC
   NCOL=NCOL+1
C
IF (NCOL.GT.300) THEN
   CALL SORT(VAL,100)
   II=1
   SVAL=0.00
   DO 3650 I=1,100
      IF (SVAL.NE.VAL(I)) THEN
         IF (II.LE.10) THEN
            VAL10(II)=VAL(I)
            II=II+1
         ELSE
            GO TO 124
         END IF
      END IF
      SVAL=VAL(I)
   CONTINUE
   IF (II.LT.IO) THEN
      II1=II-1
      DO 3800 III=II1,10
         VAL10(III)=VAL10(II1)
      ENDF
   ENDIF
124 WRITE(5,3850) (VAL10(II),I1=1,10)
3850 FORMAT(' VAL10',lOFlO.1/)
   DBN=VAL10(4)-VAL10(1)
   IF (DEN.NE.O) THEN
      DB=(VAL10(10)-VAL10(1))/DBN
   ELSE
      WRITE(5,3900)
      GO TO 3960
   ENDIF
   IF (DL0G(DABS(DB)).NE.O) THEN
      ALPHA=DL0G(DFLOAT(3))/DLOG(DABS(DB))
      WRITE(5,3950) ALPHA
   ELSE
      WRITE(5,3900)
      GO TO 3960
   ENDIF
3950 FORMAT(' ALPHA',D16.7/)
   ELSE
3900 FORMAT(' ALPHA CAN NOT BE CALCULATED')
   GO TO 3960
ENDIF
ELSE
   IF (IBRCH.EQ.0) THEN
IF (ALPHA.GT.(DFLOAT(11)/DFLOAT(10))) THEN
    WRITE(6,4150)
  4150 FORMAT(' ALPHA IS LARGER THAN 1.1')
  GO TO 3960
ENDIF
UVAL=0.4266
B=VAL10(1)-1
IF (VAL10(1).GT.3000) THEN
  DICRT=1000
ELSE
  DICRT=100
ENDIF
A=B-1000.
DO 4200 I=1,40
IF (A.LT.0) THEN
  GO TO 4250
ENDIF
CALC=F(A)*F(B)
IF (CALC.LE.0) THEN
  GO TO 4560
ELSE
  A=B-1000.*(I+1)
ENDIF
  4200 CONTINUE
  4250 WRITE(6,4300)
  4300 FORMAT(' F(A)*F(B) IS POSITIVE')
  4350 FORMAT(' BOUNDL:: : : : :zNULL')
C3960 WRITE(80,4450) VAL10(1)
WRITE(90,4450) VAL10(1)
WRITE(6,4500) VAL10(1)
  4500 FORMAT(' SMALLEST VALUE AMONG SAMPLE',F16.
GO TO 9999
  4560 CONTINUE
  ICOUNT=50
  CALL ZBRENT(F,0.0,3,A,B,ICOUNT,IER)
  BOUNDL=(A+B)/2
  IBRCH=0
  GO TO 4570
9997 CONTINUE
  IBRCH=1
  ISER=1
  DO 4035 I=1,INO
  DO 4030 CT=1,TNO
  SDT=0

SX=0
DO 4050 T=1,CT
   SX=SX+SKD(I,T)
   SDT=SDT+DT(I,T)
   E(I,CT)=SX-SDT
   IF (E(I,CT).GT.0) THEN
      ITBL(ISER,1)=I
      ITBL(ISER,2)=CT
      ITBL(ISER,3)=INT(E(I,CT))
      SUME=E(I,CT)
      IF (CT.EQ.TNO) THEN
         ITBL(ISER,4)=0
      ELSE
         CT1=CT+1
         DO 4055 T=CT1,TNO
            SUME=SUME-DT(I,T)
            IF (SUME.LE.0) THEN
               ITBL(ISER,4)=T-CT-1
               GO TO 4056
            ENDIF
         CONTINUE
         ITBL(ISER,4)=0
      ENDIF
   ENDIF
4050 CONTINUE
4055 CONTINUE
4056 CONTINUE
ENDIF
ISER=ISER+1
4030 CONTINUE
4035 CONTINUE
3970 CONTINUE
C GENERATE RANDOM VARIABLE AND INUM AND TFROM
CALL RANDU(IX,IY,R)
   IX=IY
   R=R*100
   IR=INT(R)
C WRITE(6,3090) IR
   DO 4600 IB=1,2
      RA=IR/((10)**(2-IB))
      IRA(IB)=INT(RA)/10.
      IR=IR-INT(RA)*((10)**(2-IB))
   CONTINUE
   TEMPO=(ISER-1)*IRA(1)
   ISERC=INT(Tempo+1.0)
   TEMPO=ITBL(ISERC,4)*IRA(2)
   IRSP=INT(Tempo+1.0)
   INUM=ITBL(ISERC,1)
   TFROM=ITBL(ISERC,2)
   TTO=ITBL(ISERC,2)+IRSP
   IF (TTO.GT.TNO) THEN
      TTO=TNO
   ENDIF
4600 CONTINUE
ITEMP=ITBL(ISERC,3)
TEMP11=FLOAT(ITEMP)
RSQ1=AMIN(SKD(INUM,TFROM),TEMP11)
TTOS=TTO+KSAVE(INUM)-1
TLP=LP(INUM,1,KSAVE(INUM))
IF (TLP.EQ.0) THEN
  TLP=1
ENDIF
RSQ2=AVARES(1,TTOS)/TLP
RSQ=AMIN(RSQ1,RSQ2)
C DECREASE THE HOLDING COST
DHCOST=H(INUM)*(TTO-TFROM)*RSQ
C ADD THE SET UP COST
IF (SKD(INUM,TTO).EQ.0) THEN
  ASCOST=S(INUM)
ELSE
  ASCOST=0
ENDIF
TOTCOST=-DHCOST+ASCOST
GO TO 3600
4570 CONTINUE
WRITE(90,4450) BOUNDL
4450 FORMAT(F16.2)
WRITE(6,4750) BOUNDL
4750 FORMAT(' * BOUNDL *',F16.2)
CALL CLOCK(ID)
ICPU=IC-ID
WRITE(6,4800) IC,ID,ICPU
4800 FORMAT(' IC,ID,ICPU',315)
C WRITE(80,4450) VALI0(I)
9999 CONTINUE
10000 CONTINUE
C2345 CONTINUE
STOP
END
C *************************************************************************************************************
SUBROUTINE READ(IUNIT,INO,TNO)
  INTEGER TNO,T,TNO2
  COMMON/ONE/DT(12,24),SKD(12,24),AVARES(1,26)
TNO2=TNO+2
DO 6000 I=1,INO
  DO 6000 T=1,TNO
    READ(IUNIT,6150) DT(I,T)
6000 CONTINUE
C WRITE(6,6050) ((DT(II,IT),IT=1,TNO),II=1,INO)
6050 FORMAT(6(2X,6F10.2/))
DO 6160 I=1,INO
  DO 6160 T=1,TNO
    READ(IUNIT,6150) SKD(I,T)
6150 FORMAT(F10.2)
CONTINUE
WRITE(6,6200) ((SKD(II,IT),IT=1,TN0),II=1,INO)
6200 FORMAT(6(2X,6F10.2/))
DO 6250 T=1,TN02
READ(IUNIT,6300) AVARES(1,T)
6300 FORMAT(F16.2)
6250 CONTINUE
C WRITE(6,6350) (AVARES(1,IT),IT=1,TN02)
6350 FORMAT(2(2X,7F16.2/))
IF (IUNIT.EQ.30) THEN
  IDUM=40
ELSE
  IDUM=30
ENDIF
IT=2*INO*TNO+TNO+2
DO 6500 II=1,IT
  READ(IDUM,6400) DUMMY
6400 FORMAT(F16.2)
6500 CONTINUE
RETURN
END
C ************************************************************
REAL FUNCTION AMIN(AM,BM)
REAL AM,BM
IF (AM.LT.BM) THEN
  AMIN=AM
ELSE
  AMIN=BM
ENDIF
RETURN
END
C **********************************************************
SUBROUTINE SORT(VAL,INO)
C
REAL VAL(300)
INOM1=INO-1
DO 6600 NPASS=1,INOM1
  INOMN=INO-NPASS
  DO 6700 I=1,INOMN
    IF (VAL(I).GT.VAL(I+1)) THEN
      TEMPO=VAL(I)
      VAL(I)=VAL(I+1)
      VAL(I+1)=TEMPO
    ENDIF
  6700 CONTINUE
  6600 CONTINUE
RETURN
END
REAL FUNCTION F(U)
COMMON/TWO/VAL10(10), UVAL
DOUBLE PRECISION DENOM, DNUMER

DENOM=(VAL10(2)-U)*(VAL10(3)-U)*(VAL10(4)-U)*
(VAL10(5)-U)*(VAL10(6)-U)*(VAL10(7)-U)*
(VAL10(8)-U)*(VAL10(9)-U)

DNUMER=(VAL10(10)-U)**8

F=(DNUMER/DENOM)**UVAL-(VAL10(10)-U)/(VAL10(1)-U)
RETURN
END
C$ENTRY
APPENDIX C: SHORTEST PATH ALGORITHM

The shortest path algorithm (39) which is applied to the Method B can be described as follows:

Definition 1 (Data structure): A data structure \( B = (K, R) \) is a pair, where \( K \) is a finite set of nodes and \( R \) is a finite set of relations on \( K \). The value of a node \( k \in K \) is denoted by \( W_k \).

Definition 2 (Linear List): A linear list (of length \( n \)) is a data structure \( B = (K, R) \), where \( K \) consists of \( n \) nodes and \( R \) consists of exactly one relation \( N \) and where the nodes of \( K \) can be ordered so that \( N = \{ (K_{i-1}, K_i) \mid 2 \leq i \leq n \} \).

Definition 3 (Queue): A queue is a linear list in which nodes can be removed only at the beginning and nodes can be inserted only at the end of the list.

The problem is to find the shortest connection from node \( g \) to node \( j \). There is a linear array \( E \) of length \( n \) with nodes \( e_1, e_2, \ldots, e_n \), a queue \( S \), and a number \( U \) much larger than any possible distance occurring in the problem. The shortest path algorithm is processed as follows:

1. The value \( W_{e_1} \) assigns at each point in time the shortest connection from \( g \) to \( i \) yet found. Thus, \( W_{e_1} = u \) means that so far no connection from \( g \) to \( i \) has been found and \( W_{e_1} = 0 \) indicates that \( i \) is the
given city, i.e., that i=g. So at the beginning
\[ W_{i} = u \] for \( i = g \) and \( W_{g} \neq 0 \).

2. If a value \( i \) occurs in the queue \( S \), then \( i \) can be
reached from \( g \) by way of a connection of length
\( W_{i} \); it is then to be determined whether there are
possibly shorter connections than any yet found,
from \( g \) via node \( i \) to other nodes \( j \). The queue
\( S \) initially consists of exactly one node with
value \( g \).

3. If a connection of length \( h \), where \( 0 < h < W_{j} \), from
\( g \) to \( j \) is found, then \( W_{j} \) is replaced by this value
\( h \) and \( j \) is added to the queue \( S \), as long as \( j \) does
not already appear in \( S \).

4. For finding new or shorter connections to nodes
from \( g \), the value \( i \) of the first node of the queue
\( S \) is always used: since \( i \) appears in \( S \), there
is a connection from \( g \) to \( i \); each \( j \) that can be
reached directly from \( i \) is considered. Let
\( h = W_{i} + \text{direct distance from } i \text{ to } j \); if \( h < W_{j} \), then
proceed according to Step 3. After considering
all direct connections from \( i \), \( i \) is removed from
\( S \).

5. The process terminated as soon as the queue \( S \) is
empty. Each \( e_{i} \) with \( 0 < W_{i} < u \) means that at this
point in time the shortest distance from \( g \) to \( i \) is \( W_{e_i} \).