WORKING PAPER
ALFRED P. SLOAN SCHOOL OF MANAGEMENT

JOB-SHOP SCHEDULING IN TEXTILE MANUFACTURING

A STUDY OF DECISION MAKING

Paper Number 163 - 66

ERNEST G. HURST JR. and AIDAN B. MC NAMARA

MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
50 MEMORIAL DRIVE
CAMBRIDGE, MASSACHUSETTS 02139
JOB-SHOP SCHEDULING IN TEXTILE MANUFACTURING

A STUDY OF DECISION MAKING

Paper Number 163 - 66

ERNEST G. HURST JR. and AIDAN B. MC NAMARA

This paper was originally presented at the 36th Annual Meeting of the Textile Research Institute, New York City, March 30, 1966. It is not to be cited, quoted, or reproduced prior to publication.
ABSTRACT

The scheduling procedure of a particular production planner in a woolen mill is investigated. A model is developed which attempts to describe the planner's average behavior. Schedules are generated by this model and are compared with the corresponding schedules of the planner. Discrepancies between the planner's and the model's schedules are interpreted with respect to both the adequacy of the model and the consistency of the planner. Suggestions are made for application of the technique to real-time scheduling.
INTRODUCTION: The operation of planning production and of deciding on production schedules in manufacturing is one which the management of manufacturing organizations regards and accepts as being a part of its everyday and continuing responsibility. The ability of a company to deliver to its customers goods of acceptable quality on a specified date is held to be a prerequisite of doing business in a competitive situation and the resources of manufacturing companies are directed towards fulfilling this requirement. Among the various manufacturing industries a great diversity of techniques has evolved and been devised to control the flow of goods through the plant. In general, these variations in production technique reflect the character of individual industries or of individual companies within one industry; the nature of the products they produce; and the market situation which they face.

The involvement of company management on a day-to-day basis in the production scheduling process and the importance it attributes to its function in this regard is reflected in the extensive coverage of the topic in the management literature. The production scheduling problem has attracted the attention and has engaged the interest of many investigators in this field and very many studies of the topic have been reported. The early work on the subject was frequently concerned with finding exact or optimal solutions to simplified versions of the problems being investigated. More recent studies have attempted to discover
approximate methods for solving real, full-scale problems which have proved to be insoluble by exact methods even with the aid of high speed computers. These latter developments have recently been discussed by Carroll [2] in a comprehensive review which provides a particularly appropriate context for the investigation reported here.

A typical job-shop production scheduling problem was investigated in the present study. The simplest statement of the problem with which the job-shop scheduling decision is involved is as follows: given a plant where the number of machines engaged on different stages of the process is fixed and given a job file of firm orders where each order has an associated due delivery date; then in what sequence or on which machines should each order be processed to satisfy some performance criterion. This statement describes the job-shop scheduling decision problem in a general manufacturing context. The purpose of the study reported here was to consider the question with regard to the unique character of wool textile manufacture.

The study was concerned specifically with the problem of scheduling production in a mill producing good quality woolen fabrics for the ladies dress trade. This is a fashion-sensitive segment of the textile market where goods are manufactured to order rather than for inventory and where production lots are typically small. By virtue of the market situation, an individual mill is obliged to carry very many fabric styles
in the course of a single season. In such a context, the planning of raw material requirements; the control of in-process inventory; the preservation of production flexibility; and the requirement of meeting due delivery dates, all of which bear on the production scheduling decision under consideration, require particular attention.

From a scheduling point of view, wool textile manufacture is regarded as a batch process in which more than one operation is performed on material from each batch, but in which the sequence of operations on material from successive batches is determined. The sequence of key operations in a typical wool textile process is shown schematically in Figure 1. The raw wool (or stock) as received at the mill is first washed (or scoured) and is then submitted to a picking operation to break up entanglements and remove any remaining dirt, trash, etc. The picked stock is then put through a carding operation to further subdivide the groups of fibers, produce a homogeneous mix and convert from a three-dimensional bale to a continuous, two-dimensional, thin web of fibers. This web is then split longitudinally into thin, continuous, one dimensional strands (or slivers) which are given a transverse, reciprocating rub to give the cohesion necessary to wind them onto a wide bobbin. This bobbin (the condenser bobbin) is next transferred to the input end of the spinning frame on which the slivers are drawn out (or drafted) to a weight per unit length (or count) appropriate to the yarn
FIG. 1 = WOOL TEXTILE PRODUCTION - FLOW CHART
being produced and are also twisted to give them a strength sufficient to withstand the tensions which they will experience in later operations. The output from the spinning operation is designated as yarn and each spun yarn is wound onto a separate bobbin. The processes to which a particular yarn is subjected following spinning depend on whether it is destined for use as warp yarn (longitudinal) or filling yarn (transverse) in the woven fabric. Warp yarns are wound onto a large drum (or beam) which supplies a "sheet" of yarns to the loom. Filling yarns are wound onto a small bobbin (or quill) which in the loom is carried by the shuttle across the full width of the sheet of warp yarns interlacing with each of the warp elements in a pattern dictated by the fabric design. In this manner the two-dimensional woven fabric is produced.

The machinery used to handle these fibers and yarns is somewhat cumbersome and before a new lot of material is processed extensive cleaning and readjustment of the equipment is required. Thus, characteristically, a long stoppage time or down time is involved in changing over from one batch of material to the next. For this reason, a desirable objective in scheduling production is to effect a smooth batch-to-batch transition while recognizing the cost considerations involved and the need to meet due date requirements for each batch.

Scheduling of production in the mill under investigation is done by a production planner who draws up a schedule for the plant each week.
Although orders for goods are being received by the mill each day, the planner assumes a fixed job file on the day on which the schedule is prepared. He plans a week's production on the basis of this file and any orders which he receives within the week thus planned, but subsequent to preparing his schedule, are considered when the following week's schedule is being drawn up.

In this mill the planner prepares a formal carding schedule, copies of which are distributed to key points in the production line. The flow of goods through the other stages of the process (picking, spinning, twisting, winding, weaving, etc.) is dictated by the card schedule and the operations other than carding are not formally scheduled. Once the weekly card schedule is prepared, the planner devotes a major portion of his time to implementing this schedule with respect to these other operations.

In general, the scheduling procedure devised by this particular production planner is very satisfactory. Due dates on finished piece goods are invariably met; the quality of the goods produced is excellent; little overtime working is required and scheduling efficiency, as measured qualitatively by in-process inventory, is high. This describes the context in which the investigation was conducted. In the following sections we shall describe the specific approach which was taken in studying the problem.
OPTIMAL, SATISFACTORY AND CONSISTENT DECISION MAKING: As has been suggested earlier, many scheduling decision studies reported in the literature have been concerned with finding an optimal solution to the problem (See for example Manne [5], Smith [8]). In the present case, the generation of an optimum schedule for a set of jobs on a group of machines resolves to the problem of choosing among alternatives, where each alternative represents a set of job-machine combinations. For any real problem the number of possible job-machine alternatives will be very large. If now some criterion of comparative efficiency among alternatives can be obtained and if the functional relationship of this criterion to the relevant characteristics of each job-machine combination can be determined; then that alternative is optimal which is preferred in terms of this criterion to all other alternatives.

This optimization procedure appears to be straightforward in principle but serious difficulties arise when one attempts to apply it in practice. Firstly, the size of real problems renders them inherently complex from a practical point of view. However, this very aspect of size which makes an optimal solution elusive frequently provides an abundance of acceptable solutions. Among the very many alternate possibilities there are generally a sizeable number which provide efficiencies close to the optimum or which at least provide acceptable solutions to real problems. Furthermore, these acceptable solutions are in general also more
March and Simon [6] suggest that "most human decision making, whether individual or organizational, is concerned with the discovery and selection of satisfactory alternatives; only in exceptional cases is it concerned with the discovery and selection of optimal alternatives. To optimize requires processes several orders of magnitude more complex than those required to satisfice (sic). An example is the difference between searching a haystack to find the sharpest needle in it, and searching the haystack to find a needle sharp enough to sew with".

Having accepted the desirability of seeking out satisfactory solutions, Simon and his co-workers further assert that the discovery of such solutions is at the present time most efficiently done by human decision makers. Simon [7] proposes "several conceivable ways in which the limitations of the new approaches to programmed decision making might be transcended. One of these would be to discover how to increase substantially the problem-solving capabilities of humans in nonprogrammed situations. Another way would be to discover how to use computers to aid humans in problem solving without first reducing the problems to mathematical or numerical form. Both of these possibilities hinge on our deepening our understanding of human problem-solving processes".
This acknowledgement of the decision making skills of human managers has prompted several workers to investigate the structure of human decision rules by modeling the decision process of a particular manager in detail. In an extensive study of this kind Clarkson [3] has constructed a model which simulates the decision making process of a trust investment officer. Having distilled the behavior patterns of the trust officer while the latter was choosing several portfolios and having incorporated these patterns in the simulation, Clarkson then uses the model to select portfolios. His choices via the model are in remarkably good agreement with those portfolios selected by the officer. Statistical tests of the selected portfolios against a selection chosen at random provide highly significant indications that the trust officer's behavior has been duplicated. Furthermore, examination of the detailed procedure of selecting portfolios establishes that the decision process itself is duplicated in the simulation.

No attempt is made in Clarkson's study to compare the relative efficiencies of the model and of the trust officer in terms of some objective criterion; the goodness of fit between the model's prediction and the trust officer's practice is accepted as an appropriate yardstick of performance. In fact, an objective function was not required for the purposes of this study, which attempted only to describe the trust
officer's behavior. To prescribe behavior, as is required of an optimal solution, it is necessary to propose an objective function in terms of which a comparison can be made among alternatives.

The appropriate objective function is not always readily obtained. This is a further difficulty which must be faced in seeking optimal solutions. It may be that no simple criterion (such as a minimum percentage of late deliveries or a minimum completion time) is suitable in the particular situation and moreover a simple combination of objectives may not be appropriate. Even if some criterion is recognizable, its relationship to a particular process may not be easily separable from the larger context in which the decision situation is embedded. For example, for a given production line in a plant within a larger company it may not be possible to select that criterion which when applied to the scheduling decision on that line ranks the alternatives in an order which reflects their economic desirability to the company as a whole. The difficulty is that of defining such intangible costs as run-out and delay penalties. With respect to these costs, assumptions must frequently be made on an intuitive basis and the validity or invalidity of these assumptions can have a very significant influence on the outcome.

Bowman [1] proposes a method of investigation which circumvents this difficulty. He recognizes that the method "is pragmatic rather than
utopian in that it offers one way of starting with the manager's actual decisions and building on them to reach a better system." Bowman submits that experienced managers in an actual decision situation are aware of and sensitive to the criteria and the variables which affect their performance. They are also sensitive to the implicit values of the parameters which relate the variables to the decision consequences. The problem is that in operating intuitively they relate the variables to the criteria imperfectly. They tend on occasions to overrespond to certain stimuli which is reflected in their inconsistency when faced with comparable decisions at different points in time. Bowman therefore suggests that the average decision performance of experienced managers is close to the optimum but that they are erratic about this mean. Assuming that the criteria surface in the region of the optimum is rather flat, a slight bias in their judgements is not particularly harmful. Erratic decisions on the other hand may prove considerably more expensive by placing the particular decision point on the curved portion of the criteria surface.

To take advantage of the experienced manager's grasp of the overall context while not being committed to the erratic nature of his particular decisions, Bowman proposes the derivation of decision rules from the average behavior of the manager. He studied various decision contexts, having assumed a structure for his decision rule
with the appropriate variables incorporated. This decision rule was investigated relative to actual performance using an assumed objective function. A comparison between the economic consequences of actual decisions made by a manager and those decisions made using a rule based on the manager's average behavior over the same time period revealed that with one exception the decision rule provided a better performance than the manager's aggregate behavior.

The study reported in the present paper presents a technique which is in a sense a marriage of the Clarkson and Bowman approaches. A rather simple decision function is derived which is in fact a priority rule for sequencing jobs on machines. This function is fit to the manager's actual behavior as represented by scheduling information generated by him over a six month time period. However, the independent variables in the decision rule and the heuristic with which the priority function is applied are derived from qualitative verbal interaction with the manager during the course of the investigation. In describing the manager's behavior simplifications are made in the interests of averaging rather than duplicating his behavior. However, the heuristic is faithful in a simple way to the procedures he adopted when planning his schedules.

No specific economic criterion is used to compare the manager's decisions in this case with those proposed by the model, as no such
criterion was available. In its place, the discrepancies between the manager's practice and the model's predictions are discussed in detail with a view to evaluating the procedure and its assumptions.

MODELING THE PRODUCTION PLANNER'S AVERAGE BEHAVIOR:

Five phases can be distinguished in the development of the scheduling decision model:

1. Structuring the planner's decision process.

2. Determining the variables which enter into this decision process.

3. Relating the dependent variable(s) of the decision process to the independent variables in a functional form.

4. Fitting this function to the planner's actual behavior thus evaluating the weighting coefficients of the decision variables.

5. Validation and refinement of the model.

The five phases of this development proceeded more or less simultaneously. For example, the functional form of the decision rule was not selected independently of the structure in which it was embedded, nor were the relevant variables selected without regard to both the decision function and its structure. However, for obvious reasons the phases of development are reported sequentially.
1. THE DECISION STRUCTURE:

In deciding on both the decision structure and the decision variables which influenced the planner's decision behavior, it was necessary to obtain information from conversations with him and from close inspection of his card schedules as to why he scheduled particular batches of material in a given sequence and on particular machines. Thus, the early stages of the study involved extensive discussions with the production planner on the scheduling process; detailed examination of his card schedules while they were being prepared and subsequently; and continual probing by the study group to discover the reasoning behind specific decisions.

Considering the complex nature of human decision making it seems unlikely that preliminary investigation of this type will reveal all the pertinent parameters which influence the planner's decision process. The planner himself will undoubtedly be unaware of all the factors which influenced his behavior at the point of decision and his response to requests for justification of his procedures might variously be cautious, defensive or even erratic.

The purpose of this preliminary inquisition was to establish the major determinants of the planner's decisions. If rules or variables other than those brought to light by discussion proved to be significant, it was felt that these would be revealed by the validation phase of the
study. Discrepancies between the model's predictions and the planner's practice determined by validation would provide the basis for further diagnosis and discussion with the planner. The model could then be refined by feedback from that phase.

It was quickly established that the planner responded to different scheduling situations in somewhat different ways depending on the values of the independent factors in the decision. However, in spite of slight variations observed two main modes of decision making were distinguished:

First Decision Mode: In this mode the planner inspects his job file per se without reference to the machine openings occurring in the week under consideration and selects a job which ought to be scheduled in that week on the basis of due date and process time. From among the machine openings which occur during the week under consideration an appropriate match is made with the selected job. Thus, in this mode a machine is chosen for a selected job.

Second Decision Mode: In this mode the planner examines the schedule and recognizes the next available machine opening. From among the jobs on the job file an appropriate selection is made to fill the available machine opening. Thus, in this mode a job is chosen for a selected machine opening.

From observation of the production planner when drafting his
schedule and from subsequent discussions with him, it was evident that he actually operated with some combination of these decision modes. He preselected some jobs from the file which he considered ought to be scheduled without explicit reference to compatibility; he attempted to get the best job-machine fit for the jobs so selected; he proceeded to identify remaining machine openings scanning the other jobs on his file for suitable jobs for these openings; and he then repeated the cycle where necessary.

The possibility of modeling this observed scheduling behavior in detail was considered during the study and was rejected. The main reason for its rejection was the apparent complexity of the criterion by which the planner selected the proper decision mode for the next decision in sequence. Even if the choice of mode was based simply on the magnitude (in days) of due date less process time, this would involve the concept of a cut-off point on the planner's job file above which all jobs must be scheduled and below which jobs from the file would only be scheduled, depending both on their urgency and their compatibility with any machine openings remaining. The planner was not aware of any such dividing line in his procedure; the cut-off point established by his schedules varied between wide limits; and the selection of an average or upper limit for the division would have had to be done on an arbitrary basis not necessarily related to his criteria. Moreover, it
was difficult to establish that the production planner's preselection of jobs from the file did not relate in some way to his machine configuration, as he was familiar with the state of his machines when drafting his schedules. It even appeared that the planner's choice of decision mode in particular instances depended on what jobs had already been scheduled. For example, if the warp yarn for a particular fabric was completed this placed an urgency on completion of the complementary filling yarn. This question will be discussed in more detail in a later section.

All the foregoing considerations imply that a very complex criterion would need to be established to represent the planner's selection of particular decision modes. Because of the desire to utilize a simple decision rule, at least for the initial cycle of the model, the study group decided to base the quantitative analysis and the scheduling heuristic on one decision mode or the other rather than on a complex combination of the two. The choice between the two was influenced by the form of the data as is discussed in a later section. In the following sections the choice of the decision variables and of the priority function are discussed.

2. THE DECISION VARIABLES:

The relevant decision variables established in the preliminary discussions with the production planner are as follows:
(a) **Slack Time**: The slack time measure is defined as:

\[
\text{Slack Time} = \text{Due Date for the Condensed Slivers} - \text{Process Time for Carding} - \text{Date on which a Card becomes available.}
\]

This measure, to which the production planner is sensitive, establishes the time urgency on individual jobs. Jobs with high slack times can be deferred; jobs with zero slack time must be scheduled now, if a card is available; and jobs with negative slack time will not meet due date requirements.

To establish due date for the condensed slivers, or the completion of carding, the planner operates to a rule of thumb:

\[
\text{Due Date of the Condensed Slivers} = \text{Due Date of the Finished Goods} - \text{Constant Time period.}
\]

The constant time period is intended to provide for processes subsequent to carding. The slack time measure was incorporated in the functional relationship as a continuous variable.

(b) **Count Difference**: The count system used in the mill is American Run (defined as the number of hanks of length 1600 yards in one pound weight). The planner attempts wherever possible to maintain a constant condensed count on each card thus minimizing machine adjustments. He therefore favors scheduling a particular job on a machine which has just completed a job of equal or comparable
count. Thus, the difference in count (or $\Delta$ count) between a job on his file and the job just completed on an available card was recognized as a decision variable. Since it appeared that he responded only to the size and not to the direction of the count change, the absolute value of count difference was used in the analysis.

(c) **Blend Change:** The production planner attempts to minimize blend changes on any card to reduce the possibility of contamination and to avoid having to strip the cards after each job. The classification of blends was a difficult problem in a mill which processes a wide variety of blends. For simplicity, four blend categories were employed:

1. All Wool (including virgin wool, comb noils, worsted wool, waste wool)
2. Wool-Mohair
3. Wool-Rabbit
4. Wool-Other

Blend change was treated as a dichotomous variable in the analysis. These four blend categories therefore provide 16 different, mutually exclusive, binary variables.

(d) **Color:** The mill in which the study was conducted produces stock dyed and piece dyed fabrics and therefore processes white and colored stock. The production planner regards color changes
on a particular card in the same light as blend changes. However, certain cards in the mill are reserved exclusively for stock dyed material and the planner drafts a separate schedule for those cards. This study concerned itself only with the cards processing white stock and thus color was eliminated as a variable of the analysis.

(e) **Geography of the Card Room:** The question of card room geography arose in the initial discussions with the planner in connection with the possibility of contamination by fibers flying between adjacent cards. However, before the collection of data commenced, shields were erected between cards to avoid possible fly contamination. A trial run of the model on five weeks of production data suggested that the planner occasionally scheduled two jobs of identical blend on adjacent cards to facilitate feeding. Discussion of this point between the production planner and the study group revealed that this factor was of marginal significance to his decision process. Because of this as well as the difficulty of incorporating card room geography in the analysis, this variable was not included.

(f) **End Use -- Yarns for Warp or Filling:** To avoid a possible build-up of in-process inventory, the planner attempts to move warp and filling yarns, intended for the same fabric, through the process in phase. Thus, the completion of a particular warp yarn
(at the carding stage) places an urgency on completion of the complementary filling.

The significance of this variable to the production planner's decision process came to light only upon completion of a five-week trial analysis which excluded this variable. A comparison was made on the basis of these trial data between the model's prediction of a carding schedule when presented with the actual weekly job file and the planner's corresponding card schedule for that week. Discrepancies were observed. Discussion of these discrepancies with the planner revealed that he was in fact sensitive to this end use variable.

This finding reinforced the view that significant refinements to the model could be derived from feedback at the validation stage. However, it also suggested the need to obtain detailed information on fabric constructions for those fabrics produced during the six months data period of the study. For proprietary reasons, information on these fabrics could not be released at the time the data were collected. After a suitable time had elapsed, a partially successful attempt was made to reconstruct this information; however, there were still significant gaps in most of the job files within the data period and the end use variable could not be incorporated quantitatively in the analysis.

The variables of slack time, count difference and blend change were therefore selected for use in the analysis. In eliciting information on
the significance of particular variables, the study group attempted to assume a passive role. The object of the investigation was to model the planner's actual decision process. The group therefore refrained as far as possible from suggesting variables which they considered might or ought to be a determinant of his decisions. However, this restraint was not always easy to maintain. For example, the classification of blends used in the analysis, as outlined above, was not regarded by the study group as being entirely satisfactory. They therefore suggested to the production planner that an alternative classification based on a combination of fiber type and fiber length might be more suitable. However, the planner was not provided with nor did he seek information on the fiber length or the fiber length distribution of the blends processed and this suggestion by the group was not adopted in developing the model.

3. THE FUNCTIONAL FORM OF THE DECISION:

The selection of a function by which to relate the independent variables, slack time, count difference and blend change to the dependent, dichotomous (yes-no) variable was the next step in the procedure. As in the choice of decision structure, the study group was predisposed to select a simple functional relationship as well as one which seemed to fit the planner's behavior. Three functional relationships were considered:
(a) **Product:** the priority index is the product of the independent variables raised to exponents obtained from data.

(b) **Sum:** the priority index is the sum of the independent variables weighted by coefficients obtained from data.

(c) **Mixed Product and Sum:** the priority index is the product of some of the independent variables times the weighted sum of the others, with the exponents and weightings obtained from data.

The product form was discarded immediately since 15 of the 18 independent variables will always be zero and the priority indices obtained would be indistinguishable. The third choice, the mixed product and sum, could have been used to circumvent this difficulty but it is a very difficult form to manipulate in a linear regression. Furthermore, it could lead to wrong answers. For example, if the values of two independent variables suggested that a negative (scheduling) decision would be made, their product could yield a positive priority.

The form which was selected for the priority function was thus a simple weighted sum of the independent variables. In addition to its simplicity both in the fitting of the coefficients and in its use in scheduling, this function seemed to be a reasonable description of the
way the planner combined the independent variables. For example, he was asked to vary one or two independent variables while holding the others constant, and the preferences he expressed in such hypothetical situations indicated that the linear function was a good representation of these preferences.

The specific form of the linear function which was used in the current study is as follows:

\[
y_i = b_1 x_{i1} + b_2 x_{i2} + \sum_{j=1}^{4} \sum_{k=1}^{4} a_{jk} z_{ijk}
\]

where

\[
x_{i1} = \text{count for the } i\text{th observed decision}
\]

\[
x_{i2} = \text{slack time for the } i\text{th observed decision}
\]

\[
z_{ijk} = 1 - \text{if blend } j \text{ is on the machine, blend } k \text{ is on the job file in the } i\text{th observed decision}
\]

\[
= 0 - \text{otherwise}
\]

\[
b_1, b_2, a_{jk} = \text{weighting coefficients of the independent variables determined from the data}
\]

\[
y_i = \text{priority index for observation } i
\]

4. EVALUATING THE WEIGHTING COEFFICIENTS OF THE VARIABLES:

To evaluate the coefficients it was necessary to fit the function selected to the production planner's actual decisions. The analysis was aimed at ranking the relative urgency of job-machine combinations. It attempted to resolve the question: if when a
particular card becomes available, the production planner is required to select a job from his file, then which job will he select as having the highest priority for that card.

If the relative costs associated with alternative actions could be determined from plant data, it would be more reasonable to rank job priorities on a cost basis. For reasons already discussed this was not attempted. In principle, the Bowman approach assumes that the production planner is implicitly sensitive to cost considerations and ranks his job-machine priorities to reflect them. The weighting coefficients of the decision variables are in essence the visible evidence of his implicit cost criteria. Thus, for example, in the priority function selected above, where it is assumed that a high positive value of the dependent variable indicates that the job ought to be scheduled, a negative slack time coefficient \( b_2 \) would imply that the production planner resists the possibility of jobs running overdue and of incurring the associated delay penalties. Similarly, a negative count difference coefficient \( b_1 \) would suggest a resistance on the part of the planner to machine adjustments required for a change of count, with the associated down time. In principle the objective in fitting to his behavior is to infer the relative costs which on average he attributes to alternative actions.

The various possible decision modes of the planner have been
discussed in a previous section. It was now necessary to consider these different decision modes, as different modes of decision making require different treatments in analysis. The first decision mode outlined earlier was used in a trial analysis of five weeks of data. This trial cycle of the model was undertaken to evaluate the whole approach; to obtain feedback on variables other than those incorporated in the priority function which might prove to be significant; and to examine the decision mode used. The data consisted of 189 yes and no decisions. In this case the jobs actually scheduled within any week constituted the working job file for that week. The yes decisions referred to the fact that the planner scheduled job A on card 1; job F on card 2; job C on card 3, etc. The no decisions referred to the fact that he did not schedule job A on cards 2 through 9; he did not schedule job F on cards 1 or 3 through 9, etc.

The coefficients of the priority function were obtained in this trial cycle using a standard linear regression computer code with a dependent value of 1 for the yes decisions, 0 for the no decisions. The priority function thus obtained was inserted in a heuristic based on the first decision mode. The resulting decision rule was used to schedule jobs on machines for a sixth week outside the data period and the schedule so obtained was compared with the planner's actual schedule for that week. Four out of nine correct job-machine combinations
were chosen by the model and a fifth correct job was selected but was scheduled on the wrong machine.

As a result of this trial analysis several changes were made in the model. Following discussion of the results with the planner, the significance of the end use variable came to light. This has been discussed in a previous section. The trial run also suggested that the blend classification was satisfactory provided that a sufficiently representative body of data was investigated. Because there were only 189 data points in the trial, some of the rarer blend changes occurred only a few times, which led to unreliable values for the corresponding blend change coefficients. A decision was made to analyse a larger body of data for the main study and data for six months of scheduling were accumulated.

It was difficult to infer anything about the suitability of the first decision mode on the basis of the trial analysis since other recognizable influences led to discrepancies between the model's prediction and the planner's practice. This mode was investigated primarily because of a lack of complete information on the planner's job file within the five week trial period. As a result of the trial, the group was able to specify the additional job file information which would be required for the main study.

The second decision mode was used in analysis of the main body
of the data. The yes decisions in this case were analyzed on the same basis (what he actually scheduled on which card) as in the first decision mode. However, the no decisions in this case referred to the fact that because he scheduled job A on card 1 when it became available, he rejected all the other jobs (F, C through Z) on his job file for this particular machine opening.

It appeared that this mode was a better approximation to his actual scheduling procedure. Its principle defect appeared to be that for each job scheduled on a machine, on average some 50 other jobs on the file were rejected for that machine. It was felt that this imbalance between the number of yes and no decisions might significantly influence the weighting coefficients derived from analysis. However, the analysis was done using this mode as it was concluded that, again, any such deficiency would be evident at validation.

Because some 25,000 decisions were involved, special computer programs were written to facilitate preparation and analysis of the data. The values of the independent variables (blend change, count difference and slack time) were generated from the job file and machine opening data, and a discriminant analysis [4] was performed directly to avoid the need for generating the dependent variables. The weighting coefficients of the decision variables which were obtained from this analysis are shown in Table I.
Examination of the coefficients provides the first corroboration of the model. The diagonal elements in the blend change coefficients matrix are much larger than the off-diagonal elements indicating that on average the planner strongly favors scheduling jobs from his file on machines which have just finished processing a job of compatible blend. Furthermore, the symmetrically placed off-diagonal elements in the matrix are very nearly equal which suggests that the production planner is insensitive to the direction of the blend changes, e.g. he regards a change from wool to wool-mohair in the same light as a change from wool-mohair to wool. This provides an indication of the consistency of the planner's procedures and further suggests that the number of blend change variables could be reduced in further cycles of the analysis. The coefficients of count difference and slack time
seem compatible with what one would expect of the planner's behavior since they indicate that he resists job-machine combinations which entail either changes in count or large slack times. Considering the magnitude of typical count changes and slack times which occur in the data the coefficients imply that the planner's discrimination is heavily weighted in favor of avoiding changes of blend.

Using these coefficients in the priority function, tables of priority indices were prepared for two weeks of job file and machine information falling outside the six month data period of the investigation. For practical reasons these extensive tables are not presented here, but for purposes of illustration a typical selection of the indices is shown in Table 2.
<table>
<thead>
<tr>
<th>Job No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>(Recomputed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.38</td>
<td>10.69</td>
<td>2.63</td>
<td>11.00</td>
<td>10.89</td>
</tr>
<tr>
<td>2</td>
<td>11.21</td>
<td>9.52</td>
<td>4.01</td>
<td>9.83</td>
<td>9.43</td>
</tr>
<tr>
<td>3</td>
<td>2.15</td>
<td>0.46</td>
<td>28.15</td>
<td>0.77</td>
<td>0.63</td>
</tr>
<tr>
<td>4</td>
<td>13.67</td>
<td>14.56</td>
<td>3.95</td>
<td>14.87</td>
<td>Eliminated</td>
</tr>
<tr>
<td>5</td>
<td>12.25</td>
<td>13.11</td>
<td>2.49</td>
<td>13.42</td>
<td>12.21</td>
</tr>
<tr>
<td>6</td>
<td>12.28</td>
<td>10.59</td>
<td>2.52</td>
<td>10.90</td>
<td>9.10</td>
</tr>
<tr>
<td>7</td>
<td>8.11</td>
<td>6.42</td>
<td>0.77</td>
<td>6.74</td>
<td>5.33</td>
</tr>
<tr>
<td>8</td>
<td>11.97</td>
<td>10.28</td>
<td>2.21</td>
<td>11.59</td>
<td>11.01</td>
</tr>
<tr>
<td>9</td>
<td>4.64</td>
<td>2.95</td>
<td>3.17</td>
<td>3.25</td>
<td>2.79</td>
</tr>
<tr>
<td>10</td>
<td>1.53</td>
<td>0.16</td>
<td>27.52</td>
<td>0.15</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Table 2 -- Priority Indices**
5. VALIDATION

Predicting the Schedule: The priority indices shown in Table 2 rank the desirability of scheduling particular jobs on particular machines and thus provide the basis for predicting the planner's card schedule via the model. The higher the index, the more desirable it is to schedule that job on that machine. At this point it was necessary to devise a suitable scheduling heuristic using these priority indices. The use of the second decision mode in analyzing the production data implied that the planner first identified machine openings and then inspected his job file for suitable jobs for these openings. It seemed therefore desirable that the scheduling heuristic selected should conform as far as possible with this procedure.

In Table 2, for any machine the higher the priority index among jobs, the more desirable it is to schedule that job on that machine. On the other hand for any job the higher the index across machines, the more desirable it is to schedule that job on that machine.

On these grounds the use of what might be called a max-max heuristic appeared to be most compatible with the planner's decision process. With this heuristic all jobs are examined in relation to the first machine which becomes available. From these jobs is selected that one which has the maximum priority index for that machine. However, the job thus singled out may be even more compatible with
another machine. Thus, the priority indices for that job in relation 
to all the machines are examined. By this means the maximum index 
across machines is determined for that job. It is scheduled on that 
machine; it is eliminated from the job file; the machine thus scheduled 
assumes a new position in the machine opening sequence; the priority 
indices for this machine are recomputed in relation to all the 
remaining jobs; and the cycle of the heuristic is repeated until all 
machine openings for the week under consideration are filled.

The use of this heuristic will be illustrated with reference to 
Table 2. The machines in this Table are numbered in the sequence in 
which they become available. For the first machine opening (card 1) 
the job with the highest priority index is job 4(with an index of 13.67). 
However, on looking across machines, this job should preferably be 
scheduled on card 4. Thus, job 4 is scheduled on card 4 and is eliminated 
from the job file. The priority indices for all the remaining jobs, with 
respect to card 4, now change. The indices are therefore recomputed 
for this card. With job 4 scheduled the highest remaining priority 
index on card 1 is 12.38 for job 1. This is also the max-max index for 
this job (maximum between jobs -- maximum across machines). Job 1 
is scheduled on card 1 and is eliminated from the job file. The indices 
of all remaining jobs on the file change with respect to card 1 and are 
recomputed. The other machines are scheduled in a similar fashion.
The procedure of recomputing the priority indices with respect to a card just scheduled was adopted on consideration of the actual practice of the production planner. Each week he drafts his schedule for two weeks hence. The first week's schedule is firm and is used to determine production in that week. The second week's schedule is tentative and is prepared to provide him with guide lines when he comes to draft his schedule the following week; inspection of his schedules within the data period shows that this tentative schedule is invariable revised a week later to better reflect his production situation at that time.

This procedure of drafting a tentative schedule did provide a justification for recomputing the priority indices in that it may be more desirable to delay a job to get compatibility in the future with one of the machines just scheduled rather than process that job now on a machine with which it may be less compatible. This also appears to be the implication in the planner's procedure of drafting a tentative schedule beyond the week under consideration.

Using this scheduling heuristic, the model's prediction of a suitable card schedule for two week's job file data outside the data period was obtained and is shown in Tables 3a and 3b along with the production planner's firm card schedules for those weeks.

**Testing the Model's Predictions:**

With reference to Tables 3a and 3b, it is seen that for the two
FIRST WEEK:

<table>
<thead>
<tr>
<th>CARD NUMBER</th>
<th>MODEL'S PREDICTED SCHEDULE (By Job Numbers)</th>
<th>PLANNER'S ACTUAL SCHEDULE (By Job Numbers)</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34</td>
<td>34</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>41</td>
<td>Predicted job not scheduled by production planner</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>28</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>15</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>9</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>7</td>
<td>48</td>
<td>48</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>9</td>
<td>19</td>
<td>11</td>
<td>Predicted job not scheduled by production planner</td>
</tr>
</tbody>
</table>

TABLE 3a - THE COMPARATIVE SCHEDULES
SECOND WEEK:

<table>
<thead>
<tr>
<th>CARD NUMBER</th>
<th>MODEL'S PREDICTED SCHEDULE (By Job Numbers)</th>
<th>PLANNER'S ACTUAL SCHEDULE (By Job Numbers)</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>56</td>
<td>56</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>2</td>
<td>44</td>
<td>39</td>
<td>Predicted job not scheduled by production planner</td>
</tr>
<tr>
<td>3</td>
<td>58</td>
<td>58</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
<td>36</td>
<td>Predicted job not scheduled by production planner</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>24</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>25</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>7</td>
<td>33</td>
<td>33</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>8</td>
<td>47</td>
<td>47</td>
<td>Same job - Same card</td>
</tr>
<tr>
<td>9</td>
<td>51</td>
<td>20</td>
<td>Predicted job not scheduled by production planner</td>
</tr>
</tbody>
</table>

TABLE 3b - THE COMPARATIVE SCHEDULES
weeks' trial period, the model's prediction of an appropriate carding schedule differs from that actually decided on by the production planner. The purpose of the validation step of the procedure was to assess the model's predictive power in specific instances and to expose any deficiencies in the model's understanding which could be refined in further cycles of the analysis. However, proposals for refinement of the model by feedback from validation must relate to some definition of what constitutes a deficiency.

In the absence of an objective criterion of efficiency in terms of which the model's prediction and the planner's schedules could be compared, a suitable definition of a deficiency is not readily obtained. In the first trial week the model correctly predicted what the production planner would do in 7 out of 9 instances; in the second trial week, 6 out of 9 corresponding decisions were made. Had the model made 9 correct decisions in both weeks, it could either be concluded (a) that the model duplicated the planner's decisions, which in terms of the Bowman theory would not necessarily be desirable, or (b) that the planner was consistent in his behavior, which seems unlikely and which would further be at variance with the hypothesis of the Bowman theory. Any recommendation which is made for repairing deficiencies in the model must be made with regard to both of these possible interpretations of a discrepancy.
It first seems desirable to establish that the schedules predicted by the model provide a greater number of correspondences with the planner's decisions than those which would be generated by a random selection of jobs and machines. This test of the model is conducted by computing the probability that a random selection would provide 7 (out of 9) job-machine matches in the first trial week and 6 matches in the second trial week. It is assumed for this test that there are 50 jobs on the job file at the time the schedule is generated and that only one job is scheduled on each machine for the week in question. The random selection of job-machine combinations must not only select the correct jobs from the file, but these must also be scheduled on the correct or corresponding machines. For any week, the probability that n or more matches are made at random is the probability that an ordered sample of nine taken from fifty contains n or more items in the correct order. This probability as computed for the present case is:

Probability of 7 or more matches out of 9 given 50 choices

\[ = 6.87 \times 10^{-11} \]

Probability of 6 or more matches out of 9 given 50 choices

\[ = 6.92 \times 10^{-9} \]

Thus, the probability that the decisions predicted by the model could have been generated at random is very low.

This test is very severe in that it assumes no knowledge at all
about either the jobs or the machines. A less stringent test can be applied in which clairvoyance about the selection of jobs from the file is assumed. That is, it is assumed that the nine correct jobs have been selected from the fifty jobs on the file and the probability is computed that these jobs are put on the matching machines. This computation gives:

Probability of 7 or more matches out of 9 given 9 choices

\[ = 1.02 \times 10^{-4} \]

Probability of 6 or more matches out of 9 given 9 choices

\[ = 5.65 \times 10^{-4} \]

These probabilities are again low which further supports the contention that the model performs in better than a random way in duplicating the production planner's behavior.

These two tests correspond to those applied by Clarkson in the portfolio selection study discussed earlier. Clarkson applies a further test which provides an additional criterion for the study reported here. In this case, a schedule is generated using a naive decision rule and this schedule is compared with the model's predictions. Several decision rules of this kind could be proposed, but the one used for the purposes of this test was as follows: select that job from the file which has the lowest slack time for a given machine and schedule that job on that machine. In the event
of a tie between jobs, schedule that job which is more compatible on a blend basis. If the tie is still unresolved, schedule the job which involves the smallest count adjustment on a machine. The resolution of ties by this means was done on consideration of the relative weightings of the blend change and count difference variables as determined by the discriminant analysis of this study.

This naive decision model was applied to the job file data for the same two-week trial period of the model's prediction. Despite the application of the three decision variables, a few ties remained unresolved. Wherever this occurred that job-machine combination was selected which was most sympathetic to the planner's actual decision, this being regarded as a conservative procedure for testing the model's predictions. The naive decision rule thus applied made 4 (out of 9) correct decisions in both of the trial weeks, though in two cases (the first week) it scheduled jobs on different machines to those selected by the production planner.

The principle difficulty in applying this naive decision rule proved to be the resolution of ties. The procedure adopted for their resolution was an arbitrary one, but in four cases (in the two-week period) the correct decision was made on the basis of slack time alone; in one case, the blend variable provided the basis for discrimination; in an additional case, a correct decision was made on the basis of
count difference; and two ties were unresolved. It is interesting to note that 8 correct decisions (out of a total of 18) were made using this simple decision rule, whereas the model made 13 correct decisions in the same period. However, inspection of the job file for any week reveals that by any simple criterion of discrimination certain jobs would almost certainly be scheduled correctly. A more subtle decision process is required for resolution of the majority of cases.

A final test was conducted to evaluate the max-max heuristic derived from the planner's actual behavior. In this case, the priority function itself is used to choose the schedule without reference to the production planner's procedure. The job with the maximum overall priority index is scheduled. The chosen job is eliminated from the job file and the priority indices are recomputed for all the remaining jobs with respect to the chosen machine; the maximum priority index is again determined and the process is repeated until all machines are thus scheduled. With these procedures only two exact matches were obtained for the first week, but three other jobs were correct but were scheduled on the wrong machines. For the second week, three exact matches were made but, again, three correct jobs were scheduled on the wrong machines. Thus, the virtue of the max-max heuristic appears to be that of scheduling the jobs in the correct order on machines rather than in the selection of the jobs to be scheduled.
Discussion of the Scheduling Discrepancies:

Before proceeding to a detailed discussion of individual discrepancies, it may be appropriate to consider how in fact the discrepancies might be expected to arise. As has been suggested earlier, it seems reasonable to assume that the planner's schedule will differ from that predicted by the model either because the model is not an accurate description of the production planner's average behavior and/or because the planner is not consistent in his behavior. The model which is proposed here claims to describe the production planner's average behavior. This average has been determined from observation of his scheduling practice over a finite time period. In extrapolating the model outside the data period covered by the analysis, it seems almost inevitable that inconsistencies from this computed average pattern will be observed. That these inconsistencies represent actual deviations from his average behavior is not necessarily established as the model may have failed to comprehend all possible decision situations because of the limited data analysed. Furthermore, in the development of the model and in its application, various simplifications of structure and procedure were introduced in the interests of practicality. These simplifications have been discussed at the appropriate points in the text. In evaluating the discrepancies between the model's and the planner's schedules, it seems desirable to consider
the possible consequences of these simplifications and how these consequences might relate to the discrepancies observed.

It also seems reasonable to suppose that the production planner will not be consistent in his behavior considering the complexity of the process which he is regulating and considering the changing circumstances under which his schedule is prepared from one week to the next. However, as has already been implied, without the benefit of an objective criterion of efficiency which could be applied to the respective schedules, the interpretation of the discrepancies must tend to give the planner the benefit of the doubt.

The values of the variables and of the priority indices corresponding to the discrepancies observed in the comparative schedules are shown in Tables 4a and 4b. The following explanation of individual discrepancies is proposed.

FIRST WEEK:

Card 2: The model predicted job 27 with priority index 11.31

The planner scheduled job 41 with priority index 9.52

The model's prediction in this case appears to be the more suitable choice since job 27 is more urgent and the change in count required is smaller. However, job 27 was not actually scheduled by the production planner until 3 weeks later at which point it was running overdue, according to
FIRST WEEK:

<table>
<thead>
<tr>
<th>MODEL'S PREDICTION</th>
<th>PRODUCTION PLANNER'S SELECTION</th>
</tr>
</thead>
</table>
| JOB NUMBER 27 on Card 2  
Δ Count 0.4  
Slack Time 20 days  
Blend Change 1-1  
Priority Index 11.31 | JOB NUMBER 41 on Card 2  
Δ Count 0.8  
Slack Time 25 days  
Blend Change 1-1  
Priority Index 9.52 |
| JOB NUMBER 19 on Card 9  
Δ Count 2.95  
Slack Time 27 days  
Blend Change 4-4  
Priority Index 22.17 | JOB NUMBER 11 on Card 9  
Δ Count 0.5  
Slack Time 23 days  
Blend Change 4-2  
Priority Index 4.00 |

TABLE 4a - SCHEDULING DISCREPANCIES: JOB-MACHINE SPECIFICATIONS

SECOND WEEK:

<table>
<thead>
<tr>
<th>MODEL'S PREDICTION</th>
<th>PRODUCTION PLANNER'S SELECTION</th>
</tr>
</thead>
</table>
| JOB NUMBER 44 on Card 2  
Δ Count 0.0  
Slack Time 21 days  
Blend Change 1-1  
Priority Index 12.49 | JOB NUMBER 39 on Card 2  
Δ Count 0.0  
Slack Time 30 days  
Blend Change 1-1  
Priority Index 11.55 |
| JOB NUMBER 26 on Card 4  
Δ Count 0.4  
Slack Time 11 days  
Blend Change 1-1  
Priority Index 12.25 | JOB NUMBER 36 on Card 4  
Δ Count 0.0  
Slack Time 31 days  
Blend Change 1-1  
Priority Index 11.45 |
| JOB NUMBER 51 on Card 9  
Δ Count 0.0  
Slack Time 42 days  
Blend Change 4-4  
Priority Index 30.02 | JOB NUMBER 20 on Card 9  
Δ Count 0.5  
Slack Time 19 days  
Blend Change 4-2  
Priority Index 4.42 |

TABLE 4b - SCHEDULING DISCREPANCIES: JOB-MACHINE SPECIFICATIONS
the job file information on due date for this job. This suggests that the planner was possibly aware of some circumstance relating to this job which was not identified in the job file or in the memoranda written by the production planner to advise the study group of special situations.

Card 9: The model predicted job 19 with priority index 22.16
The planner scheduled job 11 with priority index 4.00
The model's decision in this case was heavily weighted in favor of putting a compatible blend on this card. The planner decided to change blends apparently weighting his decision in favor of a smaller change of count. This discrepancy points to a possible deficiency of the model. Restrospective inspection of the data revealed that blends 3 (wool-rabbit) and 4 (wool-other) were frequently very short runs involving but 0.5 - 1.0 days of carding. Thus, the production planner could take or defer action on these jobs without incurring a serious risk of their running overdue depending on his expectation of the overall blend changes which would be required. Had he scheduled job 19 for the week as predicted by the model, it would imply that he did not anticipate getting blend compatibility with that job at a later point. He actually scheduled job 19 two weeks later and did get blend compatibility
at that time with a job on card 3. His judgment in this
instance appeared to be correct. He gained a reduction of
in-process inventory at the expense of the risk involved that
a subsequent blend change might be necessary to accommodate
job 19 without running overdue. Furthermore, he expedited
job 11 which required 8 days of process time.

The planner’s selection of job 11 thus appeared to be the more
suitable one in this instance. However, in the second trial
week (Table 4b) the economic consequences of delaying a
similar job (job 51) did not prove to be so favorable. In this
case, the planner deferred action on job 51 for an
additional two weeks, but it proved necessary to change
blends again at that point to accommodate this job.

Observation of these discrepancies suggests the desirability of
incorporating process time as a variable in further cycles of the
analysis. Inclusion of this variable in the priority rule would reflect
the attitude of the production planner towards jobs with long and short
process times.

SECOND WEEK:

Card 2: The model predicted job 44 with priority index 12.49

The planner selected job 39 with priority index 11.55

Card 4: The model predicted job 26 with priority index 12.25
The planner selected job 36 with priority index II.45. As can be seen from Table 4b, the model's preference on these cards was primarily based on slack time considerations. Jobs 44 and 26 were actually scheduled by the production planner the following week. Thus, these discrepancies are not regarded as being highly significant, particularly on consideration of the comparative values of the priority indices.

Card 9: As has been discussed above, analysis of this discrepancy reinforced the conclusion that process time should be included as a variable of the analysis. Job 51 predicted by the model required but 0.5 days of carding and the production planner delayed action on it with apparently unfavorable economic consequences.

With the exception of the two scheduling discrepancies which arose because of the omission of the process time variable, the discrepancies between the model's prediction and the production planner's practice do not appear to be serious. Furthermore, the alternatives proposed by the model would appear to be acceptable.

In conclusion, it may be appropriate to reconsider here the basic assumptions of the approach taken in this investigation. Throughout the analysis it was assumed that job shop scheduling of the wool textile process is a decision situation where determinate factors
such as slack time, blend, etc., play a significant part in their influence on a particular planner performing this operation. It was further assumed that the interaction between these decision variables is in some way predictable. The results of the investigation bear out these assumptions to some extent, though discrepancies have been noted and discussed. It is possible, on the other hand, that each scheduling decision is unique and that the activity does not lend itself to a descriptive model of the kind proposed here. However, discussions between the production planner and the study group over a period of two years led the group to conclude that the planner operated to some set of relatively consistent criteria, not necessarily well defined by the analysis.

It seems justifiable to propose that if, on the basis of data obtained over a significant period of time, a model can be outlined which describes the pattern of job shop scheduling for that period, then that model might be employed to prescribe the planning of future schedules. The time period selected for generation of the model would need to incorporate all the conditions which are likely to be encountered in future time periods. If, at some later date, a condition arises which is foreign to the model's experience, it could be dealt with outside the framework of the model; and in the light of these exceptions the model's understanding could be enlarged.
While such a prescriptive model might be deficient in flexibility, it could perhaps make amends by its consistency.

The model could be used prescriptively in several ways. It could be operated in parallel with the manager, yielding no production decisions but providing a check on his actions. At this level it could provide him with new insights into his own decision process and provide him with the basis for a critical evaluation of his procedures. The model could further be operated as an integral part of the planner's decision process. That is, it could provide him with the guide lines on which to base his weekly schedule; relieve him of the need to make routine decisions; and allow him to concentrate on those decisions which might be expected to have a more significant influence on his scheduling efficiency.

Finally, the decision rule could be used to generate the schedule with only sporadic review by the manager. This would enable the manager to concentrate on some higher level non-programmed decisions for which time was not available before.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the participation in this study by William E. Morgan, Jr., who developed the computer programs required for the analysis and who assisted in analyzing the data. They are also indebted to Professor Edward H. Bowman who inspired their interest in the problem and who made many valuable
suggestions during the course of the work; and to Professor Stanley Backer for helpful comments in the final stages of preparation of the manuscript. The computations for this study were done in part at the M.I.T. Computation Center, Cambridge, Massachusetts.

REFERENCES


FOOTNOTES

1 March and Simon, p. 40

2 Simon, pp. 21-22

3 Bowman, p. 310