MANAGEMENT SCIENCE
Vol. 15, No. 10, June, 1969
Printed in U.S.A.

A COMPUTER AIDED DECISION SYSTEM*†

ROBERT L. FERGUSON‡ AND CURTIS H. JONES§ ||

The use of on-line, real-time computer-based information systems to augment managerial decision making raises interesting and significant questions. In search of operational answers, the authors have developed and conducted experiments with a time-sharing computer model. By modeling the dynamics of a job shop the authors were able both to make use of and to evaluate academic research in job shop scheduling. The authors have devised a specific apportionment of the problem environment which permits users of their information system to explore the effects of various combinations of heuristics and programmed decision rules. The response of over 300 managers and academicians who have participated in the experiments provides evidence of the practicality of such an approach to multi-dimensional, time-variant problem solving.

Background

Recent conjectures and pronouncements concerning the impact of computers upon managerial decision making have focused attention upon on-line, real-time information systems.[1] Significant insights into the general aspects of such systems have been both illuminating and well-publicized. One indication of current activity in this area is the considerable effort that computer manufacturers and software firms have devoted to the development of interactive programming languages for time-sharing computers. In fact, persons not actively involved in the development of computer-based management information systems may well imagine that the major questions have already been answered. The scarcity of detailed descriptions of the characteristics of operation and the quality of results of such systems denies this conclusion.

The motivation for this research may be explained in terms of a quest for operational answers to key questions:

How should a problem environment be structured in order to effectively employ the abilities of both the manager and the on-line, realtime computer?

What level of computer expertise is required of managers using such systems?

Will interactive systems produce significantly better results than either the manager or the computer produces independently?

Will managers experience a measure of ease, or even enjoyment, when using these systems?

Our research strategy was formulated to investigate these questions from various vantage points. First, we anticipated an opportunity to explore the structuring problem in the process of designing and programming a prototype model. Using this model and assuming the managerial role, participants would then be in a position to experiment with our system, first hand. Finally, we planned to observe the interaction of experimental participants and our system. This paper reports the results-to-date of this exploratory research.

* Received July 1967; revised September 1968.

† This work was done in part at the Computation Center at M.I.T., Cambridge, Massachusetts. Financial support was provided by the Division of Research, Graduate School of Business Administration, Harvard University.

‡ Department of Operations Research and System Analysis, Polytechnic Institute of Brooklyn.

§ Graduate School of Business Administration, Harvard University.

|| The authors wish to express their appreciation for the helpful suggestions and criticisms offered by the referees and editors of *Management Science*.

[1] For a sample of diverse views, see references [1], [3], and [8].

The Problem Environment

Our first task was to select or define a decision situation representative of the day-to-day problems which an operating manager must face. Job shop scheduling was an appealing candidate for three reasons:

1. The ubiquity of the problem throughout industry suggested that practical results would be widely useful.
2. The decision options which arise in scheduling even a small job shop are sufficiently complex to insure useful activity, at least at the outset, for both the manager and the computer system.
3. Our research could build upon the extensive academic research which had accumulated for certain aspects of the problem.[2]

It is important to note that the problem environment which we have chosen to explore differs significantly from most research involving the simulation of job shops. These simulations have, in general, collapsed the scheduling problem to simply a sequencing question: "What job goes on a given machine next?" This simplification combined with a simple criterion for evaluating job shop operating effectiveness has permitted researchers to compare various sequencing rules in an atmosphere which allows a degree of statistical sophistication. Large job shops and a multiplicity of jobs enhance this analysis because the research has typically been concerned with measures of average times or standard deviations.

While wishing to take advantage of some of the conceptual approaches and sequencing algorithms advanced by this academic research, we were anxious also to attempt to extend the scope of the problem environment. In contrast to the standard simulations, we chose to investigate a scheduling situation which emphasizes the importance of individual decision consequences; e.g., the time that a particular job is actually shipped or the exact amount of overtime assigned to a specific machine. In addition to the sequencing questions, this research approach requires the man-computer to make short-term operating decisions on capacity, i.e., overtime, and acceptance or rejection of orders with specific promise dates.

Perhaps the most significant consequence of our approach is that it requires the scheduler first to interrelate these various operating decisions in the short-term and then to rationalize this set of situational decisions with operating criteria which are broader in scope and more long-term in nature. Academic research has long recognized that the multiplicity of operating objectives with complex trade-offs between objectives frequently limits the value to operating management of solutions obtained by optimizing a relatively simple criterion. Although we did not fully realize the consequences of this condition from the beginning, this limitation virtually guarantees the need for the man in the decision process. The task of formulating a viable objective function for a particular job shop at a particular instant in time is, in this stage of computer technology and management science, decidedly the forte of human decision makers.

The situation we chose to model was a small job shop scheduling problem which had its beginning in a 1959 book of management games, was considerably modified by Professor William K. Holstein of Harvard University, and adapted by the authors.[3] Experience over several years in the MBA Program at Harvard has indicated that this problem is sufficiently realistic to provide student participants with a healthy appreciation of the complexities of scheduling a job shop. This problem environment has the

[2] In particular, the authors made use of the research in [2], [5], and [9].
[3] See references [6] and [7].

additional advantage that its essential parameters may be easily grasped:

A. The shop consists of six machines: a lathe, a grinder, two gear cutters, and two heat-treating furnaces.
B. The gear cutters require variable set-up times, depending upon the sequence of jobs.
C. Overtime premiums vary with machine type.
D. Each job is composed of three to five operations. Each job carries a different routing through the four types of machines.
E. A standard time is given for each operation of each job. Actual operating times vary from standard as normally distributed random variables.
F. Each job has associated with it a sales price, a raw material cost, a promise date, a penalty for late shipment and certain fixed costs.
G. Nine jobs constitute a three-day workload for the shop and fifteen jobs represent a five-day workload.
H. The task is to devise a three- or five-day schedule for this shop.

The Computer Program

Our research efforts were greatly augmented by the availability of the Massachusetts Institute of Technology's time-sharing computer facility [10]. The program, which was written in MAD, a problem-oriented language similar to FORTRAN IV, was developed and operates in real-time mode. Approximately three man-months of effort were required to produce a version of the system we were willing to present to our students.

Our program requires the participant to assume the role of production scheduler while sitting in front of an IBM 1050 typewriter console or a Model 35 Teletype console, which is in turn connected to a customized IBM 7094 computer at M.I.T.'s Computation Center. As the job shop operations unfold, status reports and requests for decisions are produced by the computer at appropriate times and printed out for the decision maker in generally understandable English. He, in turn, enters his decisions via the console for implementation by the computer program. The processing of the data by the computer is essentially instantaneous.

The computer program which we developed provides the scheduler with a range of decision choices running from purely manual systems to fully automatic systems which are closed to the possibility of human intervention. Our main systems design efforts were devoted to working out alternatives between these two extremes.

Both the interrelation of the various functions of the computer program and the man-computer intereaction may be more clearly understood by first examining the four subsystems and then considering the interaction of the total system:

1. *The Physical Subsystem* which was described in the previous section; i.e., the jobs, machines, process times, process sequences, and economic factors which together constitute the "rules of the game." Although this data could be changed from the console, this part of the system is closed to the participants.

2. *The Information Subsystem* which collects, stores, processes, and transmits operating data. This system informs the decision maker (either the scheduler or a decision rule embedded in the program) when machines have completed job operations and when new orders have arrived and must be accepted or rejected. It also provides additional data to assist the decision maker, develops operating ratios such as machine utilization, and maintains accounting records. We have endeavored to include in this information subsystem information useful to the planner in defining and suggesting

EXHIBIT 1

Decision Rules

ARULE—Rule for Accepting Orders

1. Accept all orders.
2. Reject all orders.
3. Calculate contribution which will be earned if job is processed on overtime. Reject if contribution is negative.
4. Console decision.
5. Determine straight time available and working time required for this job. The difference is CUSH. If CUSH is negative, reject job.
6. Assume that queue length behind each machine is now normal. If sum of queue time and working time required is greater than 16 hours times the number of days available between now and promise date, reject the order.
7. Reject the order if the existing load on any machine required for this job worked down at 16 hours per day will extend beyond the promise date.

HRULE—Rule for Overtime

1. Follow a specific schedule entered by operator.
2. All machines work HRS overtime all days.
3. Work overtime equal to sum of negative CUSH's now at this machine.
4. Console decision.
5. Work overtime equal to the load in the shop for this machine minus a constant HRS.
6. Work overtime equal to the load in the queue for this machine minus a constant HRS.
7. Work overtime equal to sum of negative CUSH's at this machine or coming to this machine after one or two operations are completed.

SRULE—Rule for Sequencing

1. Follow a specific sequence entered by operator.
2. Job with shortest immediate processing time goes first.
3. Job going to a machine with the shortest queue goes first.
4. Console decision.
5. Job arriving at this machine first goes first.
6. Job with the smallest CUSH goes first.
7. Job with the highest ratio of probability of lateness to process time on this machine goes first.

alternative courses of action, as well as in evaluation. Evaluation is supported by providing data on many different dimensions in the objective function. The user interacts with the information system by specifying his level of detail, the format, the frequency of reports.

3. *The Decision Subsystem* through which the user controls the physical system based upon operating data developed by the information system. The scheduler plans and controls the job shop by defining parameters for each of three decision options:

(a) Acceptance or rejection of individual orders, ARULE.

(b) Sequence within which each job is dispatched to an appropriate machine, SRULE.

(c) Hours overtime assigned by machine by day, HRULE.

As we have already noted, it is this subsystem which has claimed the major share of our systems development time. This is also the aspect of the overall system which claims the major share of the user's interest.

This decision subsystem is, by definition, open-ended. At present, there are 7 ARULEs, 7 SRULEs, and 7 HRULEs (see Exhibit 1). One rule in each decision category calls for ad hoc decisions by the scheduler at the moment when the decision is required. Another rule in each decision category controls the job shop according to a fixed plan which disregards current information. The remaining rules represent decision options intermediate between these two extremes.

For instance, SRULE = 2 causes the decision system to resolve sequencing problems by selecting from among the waiting jobs the job with the shortest immediate operation time. ARULE = 3 results in calculating the contribution which will be earned if a given job is processed exclusively in overtime and accepts the order unless the contribution is negative, and HRULE = 3 leads to an overtime assignment equal to the sum of the negative slacks on all the jobs waiting at a particular machine at the end of the regular shift (subject, of course, to the limitation that overtime may not exceed the 16 hours elapsing between the end of one shift and the start of the same shift on the next day).

If the shop is operating in an automatic mode by decision rule or by a specially entered schedule, the manager can instruct the computer program to return control to the console if certain constraints are violated (for instance, a certain job develops a negative slack) due to the occurrence of actual times different from the expected times. Thus, the decision-making system could be used as a control system flashing lights to warn the scheduler that his schedule had deteriorated.

At this point, it may be appropriate to remind the reader that the purpose of this research was not to discover the combination of scheduling rules which will result in universally optimal shop performance. It is our belief that the multiplicity of dimensions, the frequency of changes in the formulation, and the rapidity of alternation of coefficients in the criteria by which shop performance is measured by operating managers make the concept of mathematical optimality meaningless in this problem environment. Our goal was to devise an approach to assist operating personnel in finding and constructing schedules which they found useful. This utility would be based on a subjective weighing both of "hard" facts presented by the computer system such as expected profit, efficiency, and completion times of various jobs, and of "soft" facts gathered by the manager of situations extraneous to the computer system. (In a real operating system there would also be some hard quantitative knowledge to be introduced by the man because its occurrence was too low in probability to be included in the computer program.)

4. *The Simulation Subsystem* which permits the scheduler to investigate decision options in a "what would happen if" mode of operation. In this simulation within a simulation, the user is able to say, "Hold the present shop status fixed while I try various decision alternatives and decide which I like best on the basis of the resulting operating reports."

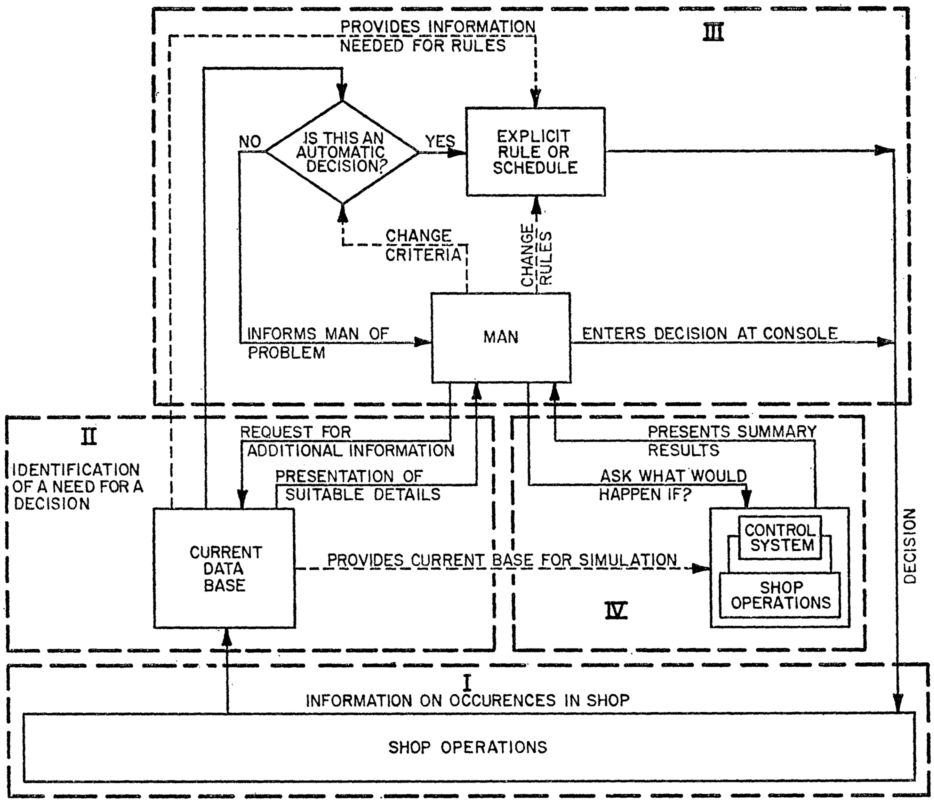
Thus, he can, in the midst of the ad hoc mode of decision making, explore the consequences of following other SRULE and HRULE combinations. In this simulation mode, standard times or some fractile of expected times are used to lay out the expected results of the decision rules. Making use of this new information, the scheduler then has the ability to return to the present shop status and continue operations according to a new set of decision system options.

While he is trying out alternative schedules, the decision maker can ask the computer to retain and recall possible schedules as well as to make ad hoc changes to these schedules. He can, for instance, save the best schedule he has found and then modify it by changing job sequences and/or overtime assignments.

5. *The Total System*—A pictorial representation of the four subsystems is provided in Exhibit 2. Areas I through IV correspond to the subsystems in the sequence in which

EXHIBIT 2

A Diagram of the Scheduling System



they were discussed. The solid arrows indicate the flow of the total system while the dotted arrows show the passage of data without transfer of control.

Area I, the physical subsystem, corresponds to the actual shop operations. This is the area in which metal is cut, orders are received, and products are shipped. Our first research objective was to design a planning and control structure to govern these operations.

Area II encompasses the information subsystem which is both a communications network and a set of files for maintaining data on the current status of jobs, workers, and machines. Current status is derived by netting reports of occurrences in the physical subsystem against historical data and standards.

Area III, the decision subsystem, is activated when the information system reports that an order has arrived and must be accepted or rejected, a machine has completed one operation and is ready for a new job, or that it is time to make an overtime decision. If the decision subsystem finds the problem meets the existing criteria for an automatic decision, the appropriate decision rule is applied and the resulting decision sent on to the shop. Otherwise, the computer prints out the decision requirement and some relevant information. Prior to making the decision, the manager may call for more information or he may elect to try out several alternatives before making up his mind. After

EXHIBIT 3

Gantt Chart Print Out of Simulation Run

```
①→ MACHINE 1 IS FREE AT TIME  80,SETUP 1
      IN QUEUE    JOB  PROM  LEFT  CUSH    IQ SETUP TIME
                   2   240    47    33     4    1    19
                   4   720   305   -65     6    1    39
                   6   720   177    63     4    1    59
                   9   960   167   153     4    1    59
     ASSIGN JOB USING THE FORMAT JOB=1*
②→ forsim=1*
    TIME IS NOW   80
    YOU ARE NOW IN A LOOK AHEAD SIMULATION. DO YOU WISH TO CHANGE PARAMETERS
③→ hrule=5,hrs=0,srule=6,ffreq=10*
④→   90   4  5  8  1  3 99
     100   4  5  8  1  3 99
    TIME  110 JOB  1 HAS SHIPPED ON TIME.  REC'D  680 DOLLARS
     110   4  8  7 99  3 99
     120   2  8  7 99  3 99
     130   2  8  7 99  3 99
     140   6  8  4  2  5 99
     150   6  8  4  2  5 99
     160   6  7  4 99  5 99
     170   6  7  4 99  5 99
     180   6  7  4 99  5 99
     190   6  7  4 99  5 99
     200   8  7  4 99  5 99
     210   8 99  4 99  5 99
     220   8 99  4 99  2 99
     230   8 99  4 99  2 99
     240   8 99  4 99  2 99
     250   3 99  4 99  2 99
     260   9  4  8 99  2 99
    TIME  270 JOB  2 HAS SHIPPED LATE.  REC'D 490 DOLLARS
     270   9  4  8 99  6 99
     280   9  4  8 99  6 99
     290   9  3  8 99  6 99
     300   9 99  8  3  6 99
     310   9 99  8  3  6 99
     320   7 99  4  3  6  8
    TIME  330 JOB  3 HAS SHIPPED ON TIME.  REC'D  570 DOLLARS
     330   7 99  4 99  6  8
     340   7 99  4 99  6  8
     350   7 99  4  6  9  8
     360   7 99  4  6  9  8
     370   5 99  4  6  9  8
     380   5 99  4  6  9  8
     390   5 99  4  6  9  8
     400   5 99 99  6  9  8
    TIME  410 JOB  6 HAS SHIPPED ON TIME.  REC'D  530 DOLLARS
     410   5 99 99  4 99  8
```

Notes on Exhibit 3

①→Computer informs console operator of a sequencing decision to be made at time 80 (8:00 a.m. in the morning of the first day). The list of jobs refers only to those waiting for Machine 1 at this time.

The headings in this format are as follows:

JOB	Job number
PROM	Promise time measured in tenths of hours. 240 is midnight tonight and 720 is midnight of the day after tomorrow.
LEFT	Total processing time on all machines for this job measured in tenths of hours.
CUSH	Cushion: straight time available between now and promise date minus working time required.
IQ	Number of operations.
SETUP	Setup type
TIME	Time required for this job on this operation.

②→Console operator responds by requesting a look-ahead simulation.

③→Operator supplies the HRULE, SRULE and HRS values to be tested and requests a status printout every ten time units.

④→In the printout, the first column gives the time (in tenths of hours). The second column shows the job number currently running on machine one, the next column shows the job number currently on machine two, and so forth. The figure 99 indicates an idle machine.

carrying out some of this research, he may elect to change the criteria for automatic decisions or to change the active set of decision rules.

Area IV encloses the simulation area in which the man tries out alternative rules or schedules. This is, in effect, a reduced version of the total system without the opportunity for manual intervention.

A significant aid to manager-computer interaction is the variety and flexibility of the reports provided by the simulation subsystem. One of the printout options is specifically designed to assist the manager in making his own sequencing decisions by printing out the digital equivalent of a Gantt chart of the current schedule. Exhibit 3 offers an example of this report. In this exhibit, the first column presents the time (measured in tenths of hours) and the next six columns show the jobs currently running on each on the six machines. A 99 indicates that the machine is idle. In this problem, Job 2 is promised for midnight of Day 1, or Time 240. The scheduler has to take a $200 penalty if the job is not shipped by Time 240.

This Gantt chart suggests two alternative ways of shipping Job 2 three hours earlier so as to avoid the lateness penalty. Job 2 could be run on Machine 1 ahead of Job 4 (although the negative slack, or cushion, attached to Job 4 in the opening table of jobs waiting for Machine 1 indicates this may be an unattractive solution) or Job 5 could be held back on Machine 5 to allow Job 2 to precede it (since Job 5 does not go on the following machine until Time 370, this move would not delay Job 5's completion). The program is designed to make it easy for the scheduler to make either one of these small changes and to examine the consequences of the decision with another simulation run.

An important part of the printout in these look-ahead options is the different dimensions by which a schedule is measured. In some situations, it may be very important to know when a specific job will be shipped. At other times, the manager may be most concerned about the utilization of the grinder or the amount of overtime on the lathe. There may be situations where the net short-run profit is the only important figure. There may also be times when the scheduler should be vitally concerned about the availability of work in the shop for workers at 8:00 a.m. on the morning following the simulated period. Exhibit 4 shows two standard simulation summaries.

Experimental Results

The computer program which we have just described provided the framework in which some 300 businessmen, students, professors, and research assistants have assumed the role of job shop schedulers and made short-term operating decisions. For a variety of reasons, this research has not followed the orderly pattern of an experiment carefully designed for statistical analysis. Our approach in these experiments varied with the time available, the interests of the participants, and their backgrounds. Most of the participants came to us as paying students in degree-granting programs or short courses. Our primary goal was the enrichment of these participants' understanding of the scheduling process and the man-computer program interaction possibilities.

As preparation for interacting with this decision system, most participants were requested to familiarize themselves with the scheduling problem, the decision options, and some specialized terminology. They received a copy of the problem, a list of the ARULE, SRULE, and HRULE options, a glossary, and a sample output. The schedulers were required to know virtually nothing about the intricacies of the program, the programming language, or the computer facility.

The "best" schedule found by each group of participants was dependent on many variables including the value structure of the participants, the time they had to prepare

EXHIBIT 4

Results of Two Simulation Runs

```
forsim=2*
 TIME IS NOW   80
 YOU ARE NOW IN A LOOK AHEAD SIMULATION. DO YOU WISH TO CHANGE PARAMETERS
srule=6,hrule=3,hrs=60*
 TIME  110 JOB  1 HAS SHIPPED ON TIME.  REC'D  680 DOLLARS
 TIME  430 JOB  2 HAS SHIPPED LATE.  REC'D 490 DOLLARS
 TIME  630 JOB  3 HAS SHIPPED LATE.  REC'D 370 DOLLARS
 TIME  690 JOB  8 HAS SHIPPED ON TIME.  REC'D  830 DOLLARS
 TIME  690 JOB  6 HAS SHIPPED ON TIME.  REC'D  530 DOLLARS
    L M       J  I NEXT KACT PROM LEFT CUSH LIPR COMP SETUP    IQ
  720 5 JOB   4  4    4    3  720  138 -138   50  850     1     2
  720 1 JOB   5  3    2    3 1200  147   13   40  840     1     3
  720 6 JOB   7  4    9    3  960   79    1   49  770     1     1
  720 4 JOB   9  3    9    1  960   59   21   59  690     1     2
    L M       J  N  RUN KUSE OTME WRKP SETP IDLP COMP SETUP TLOAD INQUE QLOAD
  720 1 MACH  5  7    0    3   60   97    2    0  840     1    49     0     0
  720 2 MACH 99  5    0    1   56   55    1   42  600     1    19     0     0
  720 3 MACH 99  5    0    1   60   88   11    0  640     3    59     0     0
  720 4 MACH 99  3    0    1   50   50    1   48  690     1   296     1    59
  720 5 MACH  4  5    0    3   60   58   42    0  850     1    59     0     0
  720 6 MACH  7  2    1    3   81   36    0   62  770     1   296     1    59

 NET=  198 SLS= 2900 OVTM= 410 MATL= 198 SEXP= 350 OVHD= 784 FIXD= 960

 TIME IS NOW  720

 IF YOU WANT TO SEE THE SEQUENCE OF JOBS AND OVERTIME, TYPE SCHED=1*
forsim=2*
 TIME IS NOW   80
 YOU ARE NOW IN A LOOK AHEAD SIMULATION. DO YOU WISH TO CHANGE PARAMETERS
srule=2,hrule=6,hrs=80,qz=-201*

 NET=  661 SLS= 3240 OVTM= 328 MATL= 198 SEXP= 350 OVHD= 743 FIXD= 960

 TIME IS NOW  720

 IF YOU WANT TO SEE THE SEQUENCE OF JOBS AND OVERTIME, TYPE SCHED=1*
```

Notes on Exhibit 4

Capital letters indicate computer printout. Small letters are typed in at the console.

Time is measured in tenths of hours. 80 is 8:00 a.m. this morning. 240 is midnight tonight. 320 is 8:00 a.m. tomorrow morning. And so forth.

SRULE, HRULE, and HRS are the values of the decision rules and a constant in the HRULE which the operator wishes to try out. QZ = −201 is a request for limiting the printout to the net profit line.

	forsim = 2* is a request to continue in the simulation mode.
L	Simulated time (measured in tenths of hours) when report is generated.
M	Machine job is currently at
J	Job number
I	Operation number
NEXT	Machine job will go to next
KACT	Indication of job activity: 3 = running, 1 = idle
PROM	Promise time of job
LEFT	Amount of work left on this job on all machines
CUSH	Cushion of straight time between PROM and LEFT
LIPR	Work left in process in this operation
COMP	Time when this machine will complete current operation
SETUP	Setup type on this operation

IQ	Number of operations remaining
L	Simulated time (measured in tenths of hours) when report is generated
M	Machine number
J	Job number currently on this machine (99 indicates idle)
N	Number of jobs which have been processed through this machine
RUN	Status indicator: 0 shows machine not staffed now, 1 indicates man is currently at machine
KUSE	Indicator of how machine is being used: 1 is idle, 3 is running
OTME	Overtime cumulative total
WRKP	Percentage of scheduled time spent working
SETP	Percentage of scheduled time spent being set up
IDLP	Percentage of scheduled time spent idle
COMP	Completion time of current or last operation
SETUP	Setup type currently on machine
TLOAD	Total work load in the shop for this machine
INQUE	Number of jobs waiting to go on this machine
QLOAD	Total work load ready to go on this machine now
NET	Net profit in dollars
SLS	Sales in dollars
OVTM	Overtime expense in dollars
MATL	Material cost
SEXP	Sales expense
OVHD	Overhead
FIXD	Fixed costs incurred

a schedule manually, the time we allowed them to work at the console, our skill in presenting the vocabulary and format of the program, the stage of development of the program, the rapidity of the computer response (this varied with the load on the computer), and the participants' interest in the program.

Our most common experimental procedure was to ask groups of two, three or four participants to begin by preparing a manual schedule. We then demonstrated at the console the ways in which the computer could assist them. The participants were asked first to try their most profitable manual schedule. They then had an opportunity to try to devise a better schedule. These trial schedules were attempted in the simulation mode where all operation times were known exactly. If time permitted, we asked the participants to implement their scheduling decisions in a situation where random deviations from the standard times occurred.

Throughout this experimental process, we attempted to listen closely to their comments and over time tried to adapt our program and presentation to some of these comments. The following list summarizes the reactions we think are significant:

1. The participants tended to be universally impressed by the flexibility of this computer-based decision aid and the ways in which it can assist schedulers.

2. Format and vocabulary were crucial to the success of the system. As we developed formats and vocabulary which were more universally understandable and learned to present the terminology and lay-out of information more clearly, participants made increasingly better use of the system.

3. The participants readily accepted among their most important functions their roles as utility estimators. They were comfortable using a system in which a man close to the problems makes the final evaluation as to which schedule is superior. They were

happy with the computer presentation of many dimensions of the results and their role of assigning weights to the various dimensions.

4. When we suggested to the participants that, for the purpose of this experiment, they should assume the role of short-term profit maximizers, most groups made more profitable schedules when they used the computer to assist them than when they worked manually.

5. A few of the more capable and more eager participants were able to produce manual schedules which were the equal of any computer-aided schedules they made. These same participants tended to be among the first to notice how much faster they could perform the same task with the aid of the computer.

6. Most participants took advantage of the similarity between the computer process of using the decision rules and the normal process they had just gone through in generating a schedule. Almost all groups given the task of devising a manual schedule first laid out some feasible schedule for the three-day period in a Gantt chart presentation and then pushed, pulled, squeezed, and otherwise manipulated the schedule. The value of each group's final schedule was a function of the original feasible schedule and of the group's success in manipulating the schedule. The participants quickly appreciated the ability of the computer to generate several different schedules which were error-free and feasible in considerably less time than it takes to generate one manually. The participants were then able to apply their imagination to the most promising basic schedule instead of feeling forced by time pressures to work on their first schedule.

Summary

These experiments have demonstrated that participants, in many instances devoid of computer backgrounds, can make meaningful use of a sophisticated interactive approach to decision making. The participants were able to comprehend and to work with a pre-arranged structuring of a typical managerial problem. They were able to explore and to evaluate combinations of heuristics and programmed decision rules. Working in a simulation environment they were able to select schedules which indicated that their decision making abilities were in most instances enhanced.

In conclusion, we conjecture that over the next several years, similar interactive man-computer approaches will prove useful for a whole range of managerial problems of a combinatorial nature; e.g., investment budgeting, personnel staffing, facilities location, and plant layout. The structuring of the problem environment will, of course, vary from application to application. We believe, however, that the manager-computer interaction will become an essential ingredient of many of the resulting decision and information systems.

References

1. Carroll, Donald C., "Implications of On-Line, Real-Time Systems for Managerial Decision Making," *The Management of Aerospace Programs*, Vol. 12, Science and Technology Series, 1967, Tarzana, California. American Astronautical Society 1967.
2. Conway, Richard W., "Priority Dispatching and Work-in-Process Inventory in a Job Shop," *Journal of Industrial Engineering* (March-April 1965), pp. 123–130.
3. Dearden, John, "Myth of Real-Time Management Information," *Harvard Business Review* (May–June 1966), pp. 123–132.
4. Emery, James, "An Approach to Job Shop Scheduling Using a Large-Scale Computer," *Industrial Management Review*, III (Fall, 1961), pp. 78–96.
5. Gere, William S., "Heuristics in Job Shop Scheduling," *Management Science* (November, 1965), pp. 167–190.

6. GREENE, J. R. AND SISSON, R. L., *Dynamic Management Decision Games*, John Wiley & Sons, New York, 1959.
7. Harvard Business School, *Job Shop Scheduling Problem*, IM 1874R.
8. LICKLIDER, J. C. R., "Man-Computer Partnership," *International Science and Technology*, May 1965, pp. 18–26.
9. MOORE, J. M. AND WILSON, R. C., "A Review of Simulation Research in Job Shop Scheduling," *Production and Inventory Management* (January 1967), pp. 1–10.
10. M.I.T. Computation Center, *The Compatible Time-Sharing System, A Programmer's Guide*, M.I.T. Press, Cambridge, Massachusetts, 1963.