DEVELOPMENT AND ANALYSIS OF A MAINTENANCE SHOP SIMULATOR - DECISION - MAKING GAME

by

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PREFACE

There is a need in industrial engineering education for "real world" problems that can be presented to students so that they can apply the methodologies and techniques learned in the classroom and practice the process of problem formulation and analysis. One way in which this can be achieved is by simulating these problems in the classroom.

The decision-making game is a method of simulating problems so that the participants can make decisions similar to those they might be expected to make in an actual industrial setting. There are many types of games ranging from simple pencil and paper games to completely computerized ones. However, most of these are nontechnical in nature and relate to the area of business administration. This has lead to the use of the terms "business games" or "management games" also being used to describe decision-making games.

This paper is divided into three main parts. The first describes why games are needed, the general features of games, and an evaluation of games.

The main part of the paper is the presentation of the Maintenance Game. Chapter 4 explains the important features and the objectives of this game. The next chapter describes the model used for the game. These chapters also explain the operation of the game in some detail. Additional information, such as the administrator and player instructions, are included in the appendix. The appendix also includes a

listing of the simulation program and sample output.

The validation of the game is given in the third part. A test of the game was performed in a senior industrial engineering course, and the results of this test are presented. This section also includes a chapter about suggested modifications and extensions.

Gratitude is acknowledged to the members of the faculty who have given advice during the development of this paper and to the students who have assisted in the refinement of the material by cooperating during the game test. Specific credit is due Dr. P. E. Torgersen for his direct contributions and to Drs. Prabhakar M. Ghare and Wolter J. Fabrycky for reviewing and commenting on the material.

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Part I

ANALYSIS OF DECISION-MAKING GAMES

Chapter I

THE NEED FOR SIMULATED PROBLEMS

Engineers are usually interested in the applications of scientific principles rather than in their discovery. With respect to the industrial engineer, application is achieved in the design, improvement, and installation of integrated systems of men, materials, and equipment. While the industrial engineer, like other engineers, has many techniques to help him, the nature of his job may require creativity in application.

The importance of the creative aspect of engineering is seen with the realization that there is a difference between knowing how to use scientific methods and techniques, and understanding when and where to use them. Therefore, problem formulation becomes a critical factor. "Many have recognized that problems recognition and formulation is frequently more difficult than problem solution; that a problem well put is more than half solved; and that an approximate solution to the right problem is usually more valuable than an exact solution to the wrong one."[1]

Even though the importance of the creative aspect, or the "art",

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[1]Porter, John C.; Sasieni, Maurice W.; Marks, Eli S.; Ackoff, Russel L.; "The Use of Simulation as a Pedagogical Device", Management Science Center, Wharton School of Finance and Commerce, University of Pennsylvania, Philadelphia 19104, p. 1.

of engineering has long been recognized, the attempts of most academic programs in this area have generally lacked the important ingredient of reality. Academic programs have been primarily directed toward exercising students in the application of methods to formulated problems, not in developing an ability to formulate problems so that the methods are applicable to their solution. It is because of this that the Steering Committee of the Industrial Engineering Division of ASEE made the following recommendation in Industrial Engineering Curriculum Goals Study:

"Our conclusion, adhered to by nearly all participants, is that the familiar project approach can be significantly improved, can contribute to teaching the process of problem-solving in the world of affairs, by confronting students with problems of design and synthesis which are unstructured and real. Augumenting these essentials is a subsidiary need: the real problems to be studied should embody application of as many as possible of the disciplines, methodologies, and techniques learned in the classroom, and should moreover, cause the student to make his own investigations."[2]

The ideal way to provide such experience is to send students out to the industrial environment to solve "real world" problems.

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[2]"The Curriculum in Industrial Engineering", Steering Committee of Industrial Engineering Division of ASEE, The Journal of Industrial Engineering, September 1967, Vol. XVII, No. 9 p. 515.

This is generally not practical; however, it is possible and practical to present simulations of such problems. If the problem is presented correctly, it is possible to simulate problem recognition and formulation as well as problem solution in the classroom. This can be done by exposing a student to a simulation of a "real world" system, letting him decide if a true problem exists, and giving him an opportunity to solve the problem and implement the solution. These types of decision-making exercises are possible through the mechanism of the "business or management game".

There are many categories of business games ranging from simple pencil and paper games to those which are completely computerized, but they all have one common characteristic. Participants are placed in a simulated environment and are required to make decisions that are similar to those which would have to be made in a real life setting. Most of these games, however, are managerially oriented and are structured to a large extent in that the problem is defined and all necessary information is automatically given to the participants. There is a need for games which can simulate the types of problems that a graduate industrial engineer might initially encounter. Such games should involve operating policies of various departments within a plant rather than economic problems of the total company, and the participants should have to search for information and learn how to analyze what they do obtain, rather than being given all necessary and relevant information at the onset.

This research activity had as its objective the development of such a game exercise. As an introduction, a brief discussion of games and the value of games will be presented. Following this, one specific game will be described. This is a non-interacting, competitive game simulating the maintenance of production facility. Validation of the game was achieved through the administration of the game in a senior level industrial engineering course. The results of the validation processes are described herein.

Chapter 2

GENERAL FEATURES OF DECISION-MAKING GAMES

Realism is the most important aspect to be sought in a decision-making game. All games involve the interaction by participants with a model which is representative of a realistic or seemingly realistic business system. The participants are able to determine operating policies for this modeled system, and these actions generally affect the environmental conditions under which subsequent decisions must be made. In this way, the operation of the modeled system can be studied and, from it, the properties concerning the behavior of the actual system can be inferred. Therefore, games generally attempt to teach concepts and principles rather than specific facts.

The more realistic the model, the more useful will be the principles learned. However, it is not enough that the model be structurally realistic only. The participants themselves must also believe that it is realistic so that they will be motivated to play the game and use any of the principles learned from playing it.

The system being simulated can be described as either "functional" or "total enterprise". A functional system is generally defined as a department within a company that is concerned with a specialized job or type of work. A total enterprise system is usually structured as a company itself, attempting to produce and sell goods and/or services. The decisions in a functional game are generally similar to those that engineers and lower level supervisors need to make,

while the decisions made in a total enterprise game are similar to those made by the upper levels of managerial personnel.

Most games are played by teams of participants, with the size of each team being determined by the complexity of the game and the number of decisions to be made. In addition, a game can be designed either with or without direct interaction between teams. Direct interaction games are usually total enterprise games. The decisions of any one team can affect the results of the others, and the teams are usually competing to sell goods and/or services in a limited market area. Non-interaction games, on the other hand, are usually functional games. The decisions of any one team have no affect on the business environment of any other team. Generally, the teams are trying to manage so as to optimize a particular function of the business system. Each team is given identical initial conditions and exposed to consistent future environmental changes.

There is competition in both types of games because one can measure each team's performance and compare it against that of the other teams. In the interaction type of situation, performance is a measure of both how good a team is in managing its operational system as well as how good it is in anticipating and adopting to actions taken by the other groups. Overt rivalry developes quickly in this type of situation with teams frequently trying to "hurt" or bankrupt other teams in an effort to improve their own relative position. Competition in a non-interaction game does not become hostile as might happen in a direct interaction situation. A group's

performance is solely a measure of how well it managed its particular system. However, there is still competition because all the teams operate in identical environments making their results directly comparable.

Another unique characteristic of management games is their use of simulated time periods with objective feedback. Team decisions are made for a day, month, year, or any other time period which is required by the game model. The system is then simulated for one time period after which a "real" performance report of some type is returned to the team members as feedback upon which to base future decisions. The amount of time allowed each group to make a decision could vary from a few minutes to a number of days, depending upon the complexity of the decisions and the intent to force decision making under the constraint of time compression.

The generation of a performance report will require computations. The amount and types of computations can vary considerably from simple hand calculations to complex computer programs. This provides an additional means of classification for games: the manual or "pencil and paper" games and computer programs. In a manual game, the computations are done either by clerks, the game administrator, or the participants. These games have an advantage in that they are relatively easy and inexpensive to conduct. The computer games use electronic computers to perform the calculations and have many advantages even though they are expensive to operate. The use of a computer allows for fast, accurate printed reports and less constraints on the form of the system model.

Chapter 3

EVALUATION OF GAMING

There has been much discussion but little agreement about the educational value of games. Some researchers have found or subjectively feel that students learned more when games were used to supplement lectures than when just lectures or lectures and case studies were used. However, other researchers have indicated that some games are fun but have little educational value. The results of this research seem to indicate that certain types of material such as forecasting, scheduling, quality control, etc., can be effective taught through the use of properly constructed games.[3]

Student reaction to games is usually very favorable, but the factors that cause this can be both desirable and undesirable. Most games are highly motivating. This seems to result from the challenge of making difficult management decisions, the stimulation of competition, and the "reward" for decisions which are received in the form of objective performance reports. The participants, therefore, usually voluntarily spend a considerable amount of time in playing a game. However, this time is not always used benefically.

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[3]Whitman, David; Love, Roy C., Jr.; "The Use of Games in Industrial Engineering Education"; American Society for Engineering Education Annual Meeting, June 19-22, 1967; p. 11.

There is a tendency of the players to "attack" the game model itself instead of trying to analyze the problem and develop operating policies. There is also a tendency in competitive games for the rivalry to become so intense that teams lose sight of the problem which they are trying to solve.

There are additional reasons why player reaction may not be a good measurement in evaluating a game. The structure of games allow the poorer players to copy others and remain relatively competitive. It is also sometimes possible for the participants to learn to "act out" those actions which the game referee thinks they should be learning. This is especially true when the manual for the game spells out explicitly the objectives and principles to be learned. In this type of situation, the players try to please the referee instead of trying to learn from the game.

Whitman and Lave[4] have also made an interesting speculation that a poorer student will frequently put a disproportinate amount of effort into a game because he feels he can get satisfactory feedback about his abilities which he does not get from his other work. This type of student usually feels that he is being forced in normal courses to learn difficult theories which will be of little

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[4]Whitman, David; Lave, Roy C. Jr.; "The Use of Games in Industrial Engineering Education"; American Society for Engineering Education Annual Meeting, June 19-22, 1967; p. 13, 14.

use to him in the real world or that he must learn to say what his teacher wants to hear. He looks then at a game as the true measure of his ability because he can play his hunches and use "good business sense". Because he puts additional time in on the game, he will usually be very successful. This point was supported by correlation analyses done at Carnegie Tech. Here it was found that no correlation existed between game success and gradepoint averages, entrance exam scores, or other ability measures. However, a high correlation was found between success and interest in a game.

Part II

THE MAINTENANCE GAME

Chapter 4

CHARACTERISTICS AND OBJECTIVES OF THE GAME

The Maintenance Game uses as its model a computerized simulation of a type of maintenance activity that is found in most industrial settings. A specialized repair facility is established with the responsibility of maintaining only a critical type of on-line manufacturing machine at least cost.

Usually the nature of this type of operation is such that it is desirable to maintain full production at all times. In order to meet this requirement, the process is frequently designed so that a machine can be removed for repair and a replacement used in its place instead of shutting down the whole manufacturing line and repairing the machine in place. The costs that are controllable in this type of situation are the regular and overtime wages of employees; the overhead or equipment required to perform the maintenance function, the investment costs of the spare machines which are required, and the cost of lost production or waste material.

In order to control the previous costs, the maintenance personnel need to develop an optimal operating policy. It is necessary that this policy defines the number of maintenance workers required, the number of work stations required, the number of spare machines needed, and an overtime procedure which could easily define when extra pay work is necessary. In addition to defining these critical variables, the policy must be dynamic in nature so that it

can adapt to changes in the operating environment.

The Maintenance Game is designed to be competitive but non-interacting in nature. In this way group rivalries can be maintained without the destructive agressiveness that can sometimes develop in an interaction-type game. The participants are divided into groups of four or six individuals each. The use of even numbers of participants is used to encourage the groups to develop an internal structure with delegation of responsibilities. A group which tries to solve a problem will usually have "tie votes" on which decision policies to use and may eventually have to develop some internal organization in order to achieve results.

Each group is given the responsibility for making monthly operating decisions. The effects of these decisions are reflected in monthly maintenance cost reports and other operating indices. Each group operates as completely independent but identical companies. Each receives the same initial conditions and changes in the business environment. In this way a group can easily compare its results with that of the other groups, but it can in no way affect the results of the others.

The objective of this game is not to train a person in the management of a maintenance shop, but rather to use this setting as a means of facilitating the development of a person's analytical abilities to problems which are structurally more complex than most problems found in text books. It is also possible for a student to gain experience in selecting and applying quantitative problem solving techniques to

a dynamic, relatively unstructured situation where all of the data is not completely deterministic and some of the assumptions required for certain techniques are not met. Finally, the student can gain experience by working as a member of a group in solving a problem. In this way participants are able to experience the whole process of problem solving - formulation, analysis, selection and evaluation of alternatives, and specification of a solution.

The advantages of such an approach are great. The complexity of the problem can easily be adjusted to match the background of the participants, and this complexity can be either increased or decreased as the game progresses. The development of each decision group can easily be monitored and additional guidance given whenever necessary. Furthermore, each individual has an ability to participate and be creative because the nature of the problem is such that delegation of responsibility and effective communication within each decision group is essential to group success. In fact, it is fairly easy to ascertain when an individual or groups of individuals are not participating fully in the game.

Chapter 5

THE GAME MODEL

While a number of different interpretations might be given to the game model, a specific example will now be used to describe the game in detail. This example concerns the operation of a maintenance shop in a hypothetical synthetic textile fiber plant and has been used successfully in an actual test of the game. The operation of the shop was simulated on an IBM 7040 using GPSS.

A critical phase of the process in this textile plant is the spinning of the yarn as a solution is passed thru small holes and hardens to form strands of yarn. This occurs at separate operating positions, and a machine is required as a part of each position to continuously wind the yarn into managable sized packages. These positions generally operate continuously twenty-four hours a day, seven days a week.

Because of the importance of the winding machines to the operation of the process, a special shop has been given the responsibility of maintaining this equipment. Whenever one of these machines fails, it is removed and sent to the shop to be repaired. Another machine is placed in the position, if a spare is available, so that production can be maintained. If there are no spares available, the position produces waste yarn until a winding machine is repaired and made available for it. It is assumed that the machines could be expected to fail randomly throughout a day.

The nature of the repair work is such that only one man could work on a machine at a time. Therefore, the shop requires at least one work station per man. The cost of equipping these work stations is relatively constant over time as is the lead time required for ordering and installation. The cost and lead time for winding machines is also assumed to be relatively constant. The cost of scrapping a winding machine or a work station is a fixed percentage of the original cost.

The repair time is independent of the number of machines waiting to be repaired; however, it is possible to estimate the amount of time required for a repair, and select machines from a queue according to the shortest estimated repair time. The nature of the repairs fit into two categories - major and minor repairs, and the repair times for each are assumed to be normal with different means and standard deviations. Even though the plant operates continuously, the people in the maintenance shop are on regular day work because the management feels that there are not enough of them to make more than one shift per day feasible. Overtime call-ins are permitted, and workers are guaranteed a minimum of two hours of work.

The participants are given four types of decisions to make each period. The first three are to determine the number of work stations to put in the shop, the number of workers to assign to these stations, and the number of winding machines that should be used by the plant. The last decision concerns overtime call-ins and is divided into two sub-decisions. The first is to specify a spare level to be maintained,

and the second is to establish a time limit during the non-working day beyond which workers would not be called for overtime. In other words, overtime would only be permitted if the number of spares available falls below the critical level at a time in the non-working day in which overtime is allowed. These parameters allow the decision groups to affect changes in all the controllable types of maintenance costs.

The group decisions must be made on a monthly basis for one quarter, or three months, at a time. This data is then used as input to the computer model (see figure 1) which simulates the operation of each maintenance shop during the quarter. During the simulation process, certain pertinent operational indices are collected on a monthly basis. Some of these are the regular wages paid, the overtime wages paid, lost production costs, investment costs, total costs, average inventory level, worker utilization, and the number of overtime jobs. A complete listing of these indices and an explanation of how they are obtained is given in Appendix A.

When the game is initiated the groups are given data for at least one quarter of operation so that they can analyze the problem and make decisions for the next quarter. Each group is given the same information at this stage of the game. This information is of two types. The first is a detailed description of how to play the game and an explanation of the business environment and operation of the maintenance shop. (see Appendix B). This information is general in nature and does not completely define the problem. The third type of information

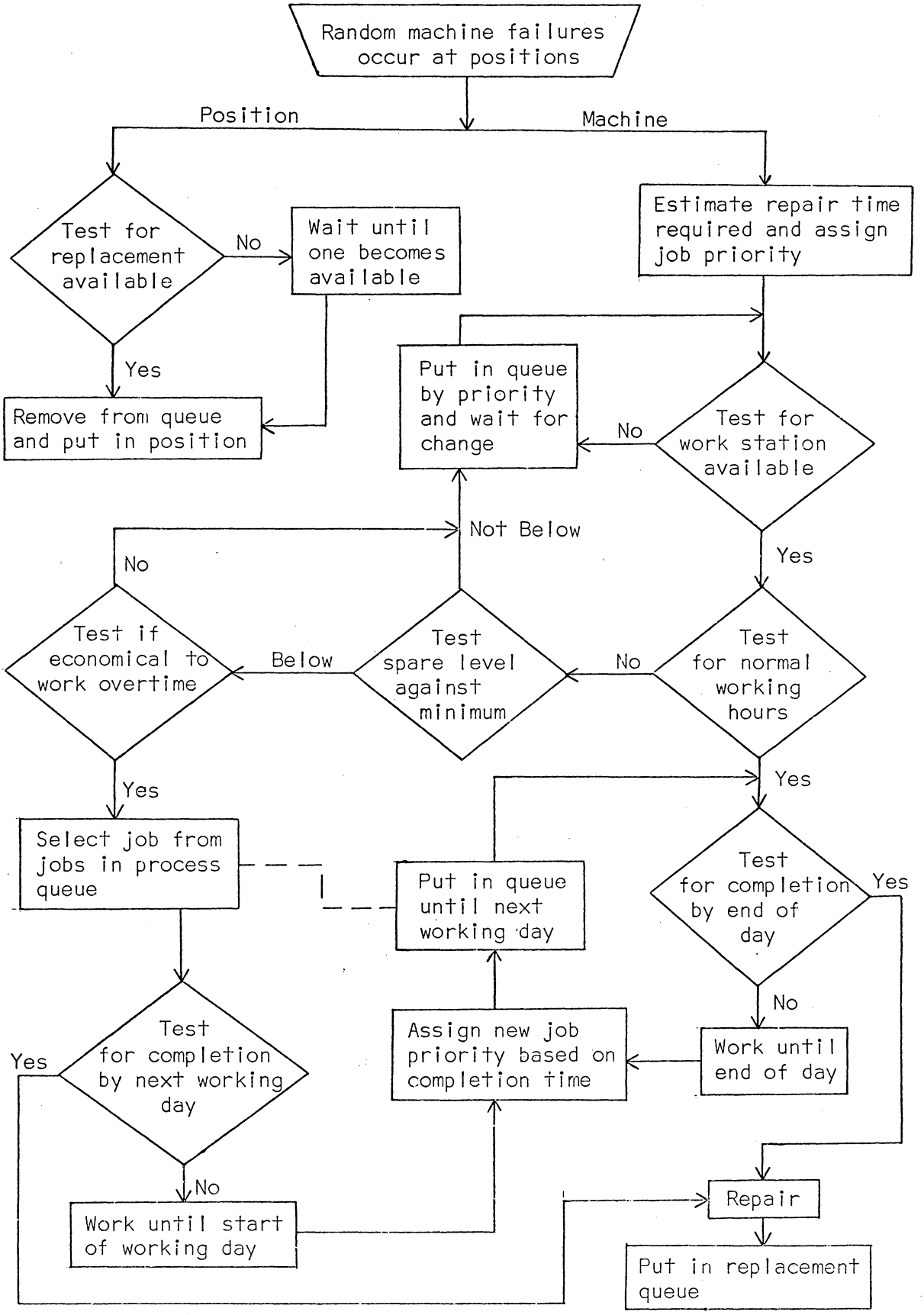

Figure 1 Simulation Model

provided is the previous monthly total costs of the maintenance function. As the game progresses there is additional data which is available to the participants. This is an important feature of this game and is what distinguishes it from most others presently in use. Knowledge of the types of additional information available is not given to the participants. Instead, each group must analyze the problem and decide what other facts they would desire. They then must request this information from the game administrator. There is no cost for this, but the game is designed so that some of the data which might be requested is either presented in a complex manner or is not available. However, some of the facts not directly available can be estimated by proper analysis of some of that which is available. This adds additional realism to the game and helps the participants develop their abilities in using whatever data they are given and estimating what they are not given.

Part III

VALIDATION OF THE GAME

Chapter 6

TEST OF THE GAME

The game described previously was conducted in a senior industrial engineering class containing forty students. These students were organized into ten equally sized groups. The game was conducted for a little more than three weeks with the participants making decisions three times a week. This enabled the simulation to cover a period of two and a quarter years. The cost of this simulation was about five dollars per participant. The purpose of this test was to validate the educational value of the game.

The participants had little experience in playing a management game. They had been participating in a manual game about equipment replacement for about two weeks, but they had never been envolved in a computerized game. Therefore, one period was used to explain the game to them. Unfortunately, it was necessary to conduct this game simultaneously with the equipment replacement game. This was initially confusing to the participants and affected the conclusions, based on the test, that could be made about the game. The major effect of operating the two games simultaneously was that proper analysis of both games by the participants was difficult because they only had about forty-five minutes for each period in which to make both sets of decisions.

Even with the undesirable conditions of a large group and a limited amount of time in which to conduct the game, the results of

the test were favorable. Most of the participants maintained great interest in the game, and friendly group competition developed quickly. In addition, a sampling of about 25% of the participants at the conclusion of the game indicated they felt that the experience had been beneficial to them.

In the initial stages of the game, the results were somewhat different from what had been expected. It had been assumed that the lack of data initially would cause confusion within the groups but that each group would rapidly define the variables which they needed to solve the problem. However, this did not occur. There were only three groups out of the ten which exhibited significant progress during the first three to four decision periods. The rest of the groups tried to solve the problem from only the given information and perhaps two to three other pieces of data which they asked for. In general, however, none of the groups asked for much significant information during this period of the game. In fact, no group had even asked for a complete breakdown of the maintenance costs.

Because of the lack of information requested initially and the limited period of time possible in which to play the game, it was therefore necessary to give considerable guidance to most of the groups. This was done by questioning them separately about the value of the data from which they were making decisions until they realized that additional information was required in order to make good decisions. This kept the poorer groups from falling too far behind in the game, but even at the end of the game about half of the groups

were considered to be using their information poorly.

A very successful aspect of the test was the manner in which interest and competition developed naturally as the game progressed. This was achieved by posting the monthly total cost results for each group on a board in the front of the classroom. This information was also summarized at the end of each business year.

An example of the monthly information is given in Table I. In addition to the actual cost information, each group's rank in a particular month was given so that the results could be easily compared. The example uses the information for the third and fourth quarters of the first year of the game and the first and second quarters of the second year. It was during this period that most of the groups began to significantly improve the operation of their maintenance shops and that competition developed. Table 2 shows the summaries of the monthly information and is for the whole game.

The conclusions from this test indicate that the game's objectives were achieved. The initial performance of the participants substantiates the need for such a game. Even though the actual learning achieved from playing the game could not be measured directly, the student reaction as mentioned previously was favorable. Most felt that they had gained an insight about "attacking" "real world" problems. In particular, they emphasized the difficulty they had in determining the effect of their decisions because no two months were exactly alike with respect to the number and distribution of repairs required. This lead most of them to stress that good historical data was important in

TABLE 1 - MONTHLY COSTS

Month		GROUP 1		2		3		4		5		6		7		8		9		10	
No.	W	Cost	R	Cost	R	Cost	R	Cost	R	Cost	R	Cost	R	Cost	R	Cost	R	Cost	R	Cost	R
7	4	10,519	10	8,583	9	8,432	5	8,546	7	7,232	2	8,592	8	8,481	6	7,927	4	7,211	1	7,492	3
8	5	12,720	10	10,992	9	10,550	6	10,833	8	9,316	1	10,744	7	10,042	4	10,229	5	9,429	3	9,368	2
9	4	9,457	10	8,549	5	8,559	7	8,668	8	8,109	3	8,895	9	8,364	5	8,133	4	6,885	1	7,817	2
10	4	13,833	10	7,653	3	8,184	7	8,099	6	7,866	5	8,880	9	7,563	2	8,341	8	6,866	1	7,679	4
11	5	15,131	10	10,874	8	10,198	6	9,317	1	9,408	2	11,268	9	10,325	7	10,077	5	9,665	3	9,729	4
12	4	22,556	10	7,863	4	7,606	3	8,513	7	6,992	1	9,019	8	8,444	6	8,351	5	9,233	9	7,067	2
13	5	10,521	9	9,914	3	10,935	10	10,339	8	9,891	4	10,270	7	10,229	2	9,389	2	10,221	5	9,276	1
14	4	7,793	2	7,958	6	7,933	5	8,103	8	9,166	10	7,595	1	7,980	7	8,969	9	7,796	3	7,823	4
15	4	7,429	2	8,524	8	7,409	1	7,924	3	8,396	7	9,025	9	8,050	4	9,525	10	8,198	5	8,247	6
16	4	6,877	1	7,747	3	7,764	4	8,966	10	7,060	2	7,950	6	8,000	7	7,818	5	8,923	9	8,273	8
17	5	9,138	2	10,000	6	9,539	5	10,767	9	10,345	7	9,384	3	9,403	4	8,399	1	11,164	10	10,348	8
18	4	6,933	1	7,843	6	7,423	5	7,086	3	8,787	10	8,225	9	7,328	4	8,213	8	7,066	2	7,928	7

W - Number of Weeks in the Month R - Rank in the Month

TABLE 2 - SUMMARY OF MONTHLY COSTS

Period	GROUP 1	2	3	4	5	6	7	8	9	10
Months	Cost / R	Cost / R	Cost / R	Cost / R	Cost / R	Cost / R	Cost / R	Cost / R	Cost / R	Cost / R
1-12	$141,385	$111,683	$110,702	$111,467	$105,851	$114,587	$110,925	$110,549	$106,481	$103,276
	10	8	5	7	2	9	6	4	3	1
13-24	115,332	102,705	102,205	106,496	102,450	107,239	97,322	101,446	106,999	99,184
	10	6	4	7	5	8	1	3	9	2
25-28	27,564	26,446	23,566	31,409	23,094	28,645	23,102	27,141	25,255	22,110
	8	6	4	10	2	9	3	7	5	1

Figure 2 Comparison of Monthly Costs

this type of problem so that operation policies could be developed which minimized costs over a long period of time rather than optimized each month at a time. These observations, in addition to the improvements shown in the operating costs, indicate that some learning did occur during the game.

Further conclusions can be made about the particular way in which the game was conducted. It is necessary to conduct the game over a longer period of time. The participants should make a minimum of twelve sets of decisions, which is a three year simulation period. A simulation period of four to five years is recommended, but the game could be conducted for a much longer period of time and still maintain interest because of the large number of model parameters which can be changed. The advantage of the longer time periods is that less initial guidance needs to be given to the groups. The use of four man groups is also recommended with at least one hour allowed for a decision and only two or three decisions required per week.

Chapter 7

SUGGESTED MODIFICATIONS AND EXTENSIONS

The structure of the computer model for the Maintenance Game is such that modifications are fairly easy to make. In addition to the fifteen variables that can be changed during the game, any of the basic model parameters can easily be changed by correcting the program cards on which they occur. More complicated distributions can also be used in place of those in the program by substituting program cards. These changes are not difficult to perform and require only a very basic knowledge of GPSS.

Changes to the structure of the model itself are more difficult and should not be attempted without a thorough understanding of programming in GPSS. However, the program is divided into distinct parts to facilitate changesto it. Some changes that might be made would be to allow more than one person to repair a machine or to divide the workers into shifts.

Other changes can be made to the output data; however, the participants should neither be completely overwhelmed with data nor given all the information that they might desire. A possible extension would be to develop data for the distribution of overtime work performed. Other changes could be made to the form in which the information is presented. The regular GPSS language which was used is restricted to tabular output of numbers, but GPSS 360 has greater flexibility in output. Anyone who has a machine which uses this

language might want to have the distributional data printed out in the form of histograms instead of tables.

A desirable type of major extension to this game would be the development of additional functional simulation models which could be related to the maintenance model. For example, the production department which the maintenance services could be simulated in a manner similar to that of the Maintenance Game. These simulations could then be combined into a single game. In this type of game, the participants could be divided into teams that could be further subdivided into maintenance and production decision groups which would have to coordinate their decisions.

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APPENDICES

Appendix A

ADMINISTRATOR INFORMATION

ADMINISTRATOR INSTRUCTIONS

The Maintenance Game requires that at least one person be available to provide guidance to the participants and to process group decisions. However, this is not a very time consuming task. Even thought it is not essential that this administrator understand GPSS, it would be helpful if he has a general understanding of how the "Savevalue" and "Control" cards are used.

The first requirement for the administrator is to program the maintenance shop for each group. The complete program listing is attached and can be used as is except for perhaps the job control cards which might have to be modified for use in a different system. The program must be stored on separate job tapes for each shop that is to be established. These can be the small-size taped because the simulation program requires relatively little tape storage space. Once the simulation program has been stored on the tapes, quarterly simulation runs can then be achieved by only using the input routine. Changes to the variables are made by using "Savevalue" cards.

It is desirable for the administrator to familiarize himself with the game by playing it for several decision periods. In this way he can better understand the significance of the variables which he can control and the form of the input and output information.

After the administrator has become familiar with the operation of the game, he should distribute the information about the game to the participants. The participants should be divided into groups of from two to four members. In addition to the basic player instructions it is also necessary to provide further information about the specific conditions that are being simulated. For example, it would be necessary to indicate how often the workers are given raises and if any work is being done to reduce repair times or the number of machine failures.

The information which is given to the participants is general in nature. It will be up to them to analyze the problem and decide what additional information they need. This will cause some confusion initially, but they should develop an internal organization and begin to improve their decisions after about two or three periods.

The administrator will have to provide careful guidance during this time. He must keep the participants from becoming discouraged; however, he should not solve their problems for them. This can be done by circulating among the groups and questioning each one about the problem and the provided data in such a way that they can form their own conclusions. However, even this questioning process should not be overly used. The participants should be given one or two periods initially in which to study the problem without benefit of outside help.

The administrator must also process the group decisions and fill out the performance reports. Each group will turn in a set of three decisions for each business period. This information must then be put onto "Savevalue" cards for each month. However, these cards only have to be used when a change is to be made to a decision variable. This also applies to the model variables which the administrator can change. An example of this decision input is attached.

The participants will have decided what specific information they need, and then they must find out if it is available by asking the administrator. They should not be given a listing of the available information. Each type of information has an identification code which the administrator will give to a group if it is requested. This code is to be used on the decision form so that the administrator will know which information goes to what group.

After the simulations have been performed, the results are given to each group. Costs and other indices can be taken from the computer output and written on the decision forms for the particular period. The various distributional computer output may be detached and given to the participants as it is.

The administrator should also summarize the results for all the groups and make this information available to the participants. This can be done by posting the monthly total costs for each group on a chart and ranking these results. This permits the groups to easily

compare results, and this helps to develop interest and competition between them.

The final task for the administrator is to see that each group presents an accomplishment report at the end of the game. The purpose of this report is for them to explain how they approached the problem and what their recommendations are with respect to management of the maintenance shop.

Additional information about the game variables is attached. Because GPSS does not have a capacity for decimals, all "Savevalue" numbers must be treated as integers. Therefore, the decimal place on some numbers are shifted two places to the right and treated as integers. The administrator must learn to recognize these numbers. In addition, since the unit simulation time interval used in the program is five minutes, all numbers which relate to time use this time scale. For example a mean repair time of five hours would be written as 60 time units. A wage rate of 3.25 dollars per hour would be written in the form 325.

Description of Game Variables

A. Administrator Variables

X7 - The mean interarrival time between machine failures. The distribution is exponential.

X8 - The cost of lost production per time unit. (Decimal number)

X9 - The wage rate for workers including benefits. (Decimal number)

X10 - Number of positions requiring a machine.

X11 - Number of weeks in a month.

X12 - The overtime ratio. (Decimal number)

X13 - Cost of scrapping a work station.

X14 - Cost of scrapping a machine.

X15 - The proportion of jobs in the minor category. This refers to functions three thru seven.

X16 - The mean repair time for minor repairs. The distribution is normal.

X17 - The standard diviation of minor repair times.

X18 - The mean repair time for major repairs. The distribution is normal.

X19 - The standard diviation of major repair times.

X20 - The mean time it takes for a worker to arrive when called-in for overtime. The distribution is normal.

X21 - The standard diviation of worker call-in times.

B. Player Decision Variables

X35 - The number of workers.

X36 - The number of work stations.

X37 - The number of machines.

X38 - The minimum spare level.

X39 - The week day overtime limit.

X40 - The weekend overtime limit.

C. Operational Indices

X22 - The average spare level. (Decimal number)

X23 - The spare level at the end of the month.

X24 - The number of overtime jobs.

X25 - The utilization of workers during regular working hours. (Decimal number)

X26 - The lost production cost.

X27 - The regular wage cost.

X28 - The overtime wage cost.

X29 - The investment and scrapping cost.

X30 - The total cost.

T1 - The distribution of the lost production times.

T2 - The distribution of the times machines spent in queue waiting to be repaired.

T3 - The distribution of the repair times.

T4 - The distribution of the times between machine failures.

SUMMARY OF IMPORTANT CALCULATIONS

$$X22 = \frac{\Sigma\,(\text{spare level})\ \ (\text{length of time of occurrence})}{(\text{time per week})\ \ (\text{number of weeks})}$$

$$X25 = \frac{\Sigma\,\text{work performed}}{(\text{number of workers})\ (\text{working time per week})\ (\text{number of weeks})}$$

$$X26 = \Sigma\,(\text{lost time})\ \ (\text{lost production cost})$$

$$X27 = (\text{wage rate})\ (40)\ (\text{number of workers})\ (\text{number of weeks})$$

$$X28 = (\text{wage rate})\ (\text{overtime ratio})\ (\Sigma\,\text{overtime hours to be paid})$$

$$X29 = (3000)\ (.13538)\ (\text{number of machines})\left(\frac{\text{number of weeks}}{52}\right)$$

$$+(1000)\ (.16638)\ (\text{number of work stations})\left(\frac{\text{number of weeks}}{52}\right)$$

$$+(\text{number of scrapped work stations})\ (\text{scrapping cost})$$

$$+(\text{number of scrapped machines})\ (\text{scrapping cost})$$

$$X30 = X26 + X27 + X28 + X29$$

Appendix B

PLAYER INFORMATION

Maintenance Game Player Instructions

The game in which you are about to participate involves the establishment of optimal operating policies for a maintenance shop. Its purpose is not so much to give you experience in managing a maintenance facility as it is to give you experience in how to analyze problems from an engineering viewpoint.

The model for this game is a computer simulation of a maintenance shop. The simulation is based on the operation of an actual maintenance shop which was studied and then programmed. Certain aspects of the operation have been modified so that they are easier to study; however, the maintenance shop with which you will be dealing approximates reality very closely.

The game is designed so that you can make monthly decisions for the key factors that affect the operation of this facility. These decisions will then be used as input to the computer and the maintenance shop will operate as you have specified. You will be able to evaluate the effects of your decisions from monthly operating records.

Each group will be given identical shops to operate, and an operating report for the previous business period will be provided. Each group will operate independently of the others, but you will be able to compare results since each group will operate in the same simulated environment. The monthly total maintenance costs for all the groups will be made available and ranked.

The plant in which the shop is located produces a synthetic fiber. The key step of the process is where the molten polymer is forced thru small holes and allowed to cool so that a continuous filament is formed. This is done in 100 identical operating positions. Each position contains a machine that winds the yarn into managable sized packages as it is produced. Whenever one of these machines breaks down, it is sent to the maintenance shop to be repaired and another machine is placed in the empty position if one is available. If a spare is not available the yarn that is produced is allowed to fall into a waste container. The plant operates continuously 24 hours a day, seven days a week; however, the people in the maintenance shop are on regular day work because there are not enough of them to make more than one shift per day feasible.

Assume that you have been assigned the responsibility for operating this shop at minimum cost. The problem is to determine the optimal operating policies with respect to the number of work stations and people you want to assign to your shop, the overtime policy for the shop, and the number of machines required. The overtime policy is composed of three decisions. One is the critical spare level. If the number of spares (extra repaired machines) falls to this level during non-working hours, a worker is called in on overtime to fix a machine so that an additional spare is available. The other two decisions relate to times beyond which you do not want to call people in on overtime. If you do not want to work anyone on overtime, then set the time limits equal to the time for the end of

the normal working day. There is a limit for the Monday thru Thursday non-working hours, and one for the weekend which starts on Friday afternoon. (See attached time chart) At the end of the game you will be asked to explain the basis for your decisions and to specify a system which could be used by someone else in managing the shop.

Each business period will consist of three months. At the beginning of each period, each group must make their decisions for the entire period. There must be a full set of decisions completed for each month in the period. These decisions will be made on a form which will be provided. At the end of the period, this form will serve as the operating report. It will be returned to each group and will contain any operational data for the period that was requested. The only information that will be given automatically is the total cost and number of weeks in each month. Additional information desired must be specified on the decision form. It will be necessary to decide specifically what is desired and then ask the game administrator if it is available.

Additional Information

Each machine costs $3000 and require three months purchase lead time. They are expected to be good for 15 years.

The cost of equipping a work station is $1000, and this requires one month lead time. Only one man can work at a work station; therefore, the number of men you assign to the shop must be less than or equal to the number of work stations. The work stations are expected to have a ten year life.

Money is worth 10% to the company continuously compounded.

The time to repair a machine is independent of the number of units waiting to be repaired. If a queue does occur, the machines are taken from it on the basis of the shortest estimated repair time.

The cost of scrapping a machine or a work station at any time is about 10% of the original cost.

The machines breakdown on a random basis during a day.

Workers can be called in for overtime during the non-working hours; however, a worker is limited to 8 hours of overtime in a day. A worker is quaranteed two hours of overtime pay even though less time than this is required to finish the repair on a machine. In addition, a half-hour break is provided after 4 hours of work.

GROUP _____ REPORT _____

I Operating Decisions:

Number of Men	_____	_____	_____
Number of Work Stations	_____	_____	_____
Number of Machines	_____	_____	_____
Critical Spare Level	_____	_____	_____
Week Day Overtime Limit	_____	_____	_____
Weekend Overtime Limit	_____	_____	_____

II Operating Report:

No. Weeks in Month	_____	_____	_____
Total Cost	_____	_____	_____

Additional Data

_____	_____	_____	_____	
_____	_____	_____	_____	
_____	_____	_____	_____	
_____	_____	_____	_____	
_____	_____	_____	_____	
_____	_____	_____	_____	
_____	_____	_____	_____	
_____	_____	_____	_____	
_____	_____	_____	_____	

Figure 3 Decision Form

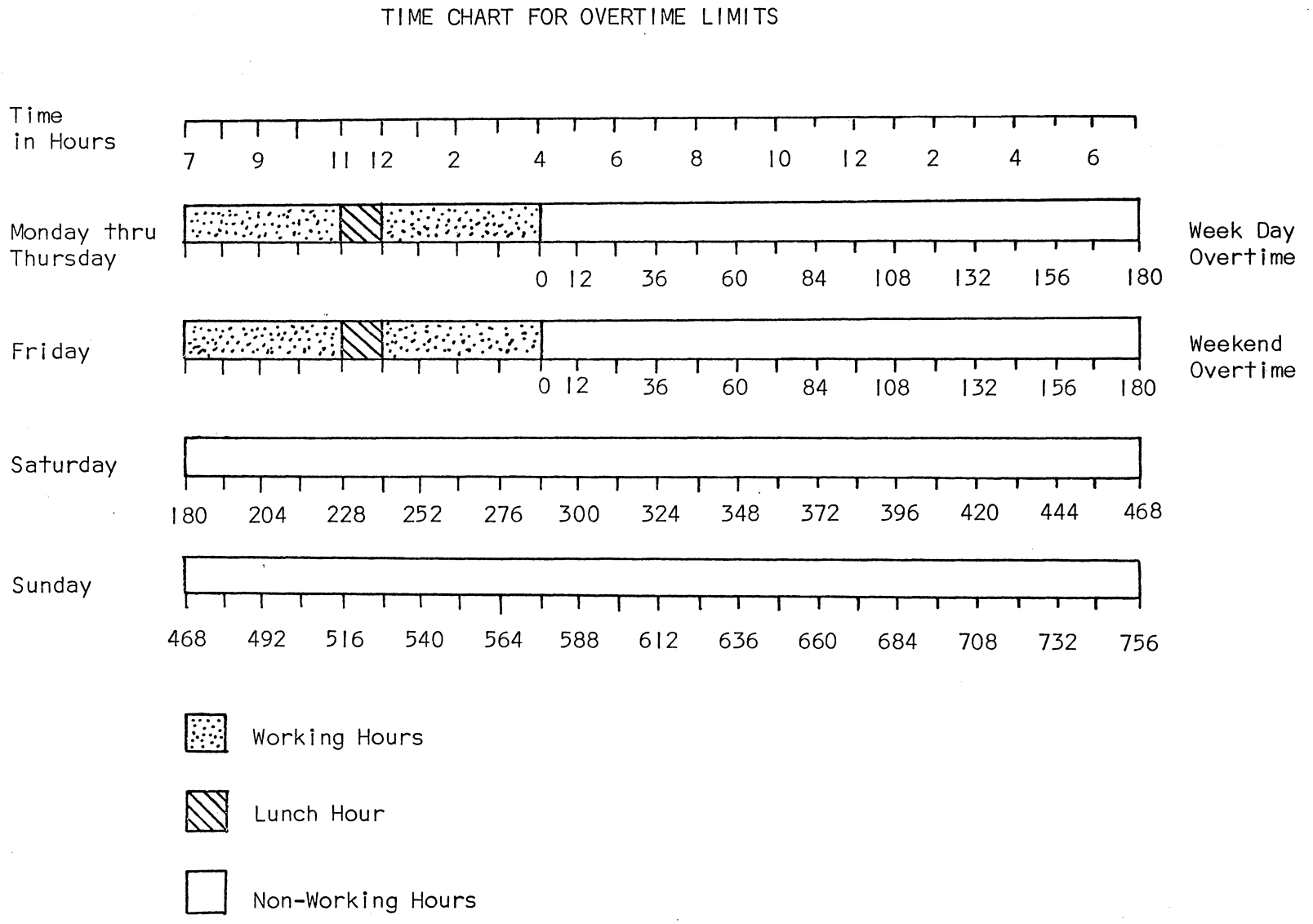

Figure 4 Time Chart for Overtime Limits

Appendix C

PROGRAM LISTING AND OUTPUT

```
                                G A M E : M O D E L

                                GPSS III ASSEMBLY INPUT                                PAGE  1

BLOCK
NUMBER      *LOC   NAME        A,B,C,D,E                          COMMENTS

            *      SIMULATE
            *
            *      MAINTENANCE SHOP SIMULATION
            *
                   INITIAL     X7,8000                 MODEL PARAMETERS
                   INITIAL     X8,75
                   INITIAL     X9,385
                   INITIAL     X10,100
                   INITIAL     X11,4
                   INITIAL     X12,159
                   INITIAL     X13,125
                   INITIAL     X14,350
                   INITIAL     X15,6
                   INITIAL     X16,78
                   INITIAL     X17,12
                   INITIAL     X18,180
                   INITIAL     X19,36
                   INITIAL     X20,7
                   INITIAL     X21,2
                   INITIAL     X23,13
                   INITIAL     X31,8
                   INITIAL     X32,113
                   INITIAL     X33,113
                   INITIAL     X34,113
                   INITIAL     X35,8
                   INITIAL     X36,8
                   INITIAL     X37,113
                   INITIAL     X38,1
                   INITIAL     X39,108
                   INITIAL     X40,684
                10 STORAGE     25
            *
            *      TIMING ROUTINE
            *
                11 VARIABLE    K25-X35
                12 VARIABLE    X31-X36
                13 VARIABLE    X34-X37
                17 VARIABLE    X9*K40*X35*X11/K100
                18 VARIABLE    X9*X12*X5/K12000/K10
                19 VARIABLE    V35+V36+V37+V38
                20 VARIABLE    X26+X27+X28+X29
                22 VARIABLE    X22*K100/X11/K2016
                24 VARIABLE    K480*X35*X11
                25 VARIABLE    X6*K100/V24
                35 VARIABLE    K3000*K13538*X34/K10000/K10*X11/K52
                36 VARIABLE    K1000*K16638*X31/K10000/K10*X11/K52
                37 VARIABLE    X1*X13
                38 VARIABLE    X2*X14
1                  GENERATE    1,,,1                   CREATE TIME INDICATOR
2                  SAVEVALUE   3,K1                    START TIME CLOCK
3           SET    SPLIT       1,LINK                  SAVE NEXT INDICATOR
4                  SAVEVALUE   1,K0
5                  SAVEVALUE   2,K0
6                  SAVEVALUE   3,K0
```

```
7                SAVEVALUE  4,K0
8                SAVEVALUE  5,K0
9                SAVEVALUE  6,K0
10               SAVEVALUE  22,K0
11               SAVEVALUE  24,K0
12               SAVEVALUE  26,K0
13               TEST G     X31,X36,CHK2       TEST FOR LESS STATIONS
14               SAVEVALUE  1,V12
15               SAVEVALUE  31,X36             NO. STATIONS
16          CHK2 TEST G     X34,X37,CHK3       TEST FOR LESS MACH.
17               SAVEVALUE  2,V13
18               SAVEVALUE  34-,X2             NO. MACH
19               SAVEVALUE  33-,X2
20               SAVEVALUE  32-,X2
21               ASSIGN     10,X2
22          TRY20 UNLINK    20,ADJ1,1,,,TRY30  SCRAP EXTRA MACH.
23               BUFFER
24               LOOP       10,TRY20
25               TRANSFER   ,CHK3
26          TRY30 UNLINK    30,ADJ2,1,,,SUBT1  SCRAP EXTRA MACH.
27               BUFFER
28               LOOP       10,TRY30
29               TRANSFER   ,CHK3
30          SUBT1 SAVEVALUE 23-,K1
31               LOOP       10,SUBT1
32          CHK3 TEST G     X35,X31,START-5    TEST NO. MEN
33               SAVEVALUE  35,X31
34               LEAVE      10,S10             CLEAR OLD STORAGE
35               ENTER      10,V11             SET-UP NO. STATIONS
36               UNLINK     30,NEWMO,ALL       JOBS IN PROGRESS
37               BUFFER
38               ASSIGN     2,X11              NO. WEEKS
39          START ASSIGN    1,K4               BEGIN MONTH
40               LOGIC R    9
41          LOOP LOGIC R    10                 MORNING
42               UNLINK     30,MORNT+1,ALL
43               UNLINK     20,FULLT,ALL
44               BUFFER
45               ADVANCE    48
46               LOGIC S    10                 LUNCH
47               ADVANCE    12
48               LOGIC R    10                 AFTERNOON
49               UNLINK     20,FULLT,ALL
50               BUFFER
51               ADVANCE    48
52               LOGIC S    10                 OFF HOURS
53               UNLINK     40,LEVEL,ALL
54               BUFFER
55               ADVANCE    180
56               SAVEVALUE  3+,K288              ACCUM. TIME
57               LOOP       1,LOOP              START NEXT DAY
58               LOGIC R    10                 FRI. MORNING
59               UNLINK     30,MORNT+1,ALL
60               UNLINK     20,FULLT,ALL
```

```
61                BUFFER
62                ADVANCE     48
63                LOGIC S     10                LUNCH
64                ADVANCE     12
65                LOGIC R     10                AFTERNOON
66                UNLINK      20,FULLT,ALL
67                BUFFER
68                ADVANCE     48
69                SAVEVALUE   3+,K108           ACCUM. TIME
70                LOGIC S     9                 WEEK END
71                LOGIC S     10
72                UNLINK      40,LEVEL,ALL
73                BUFFER
74                ADVANCE     756
75                SAVEVALUE   3+,K756
76                LOOP        2,START           START NEXT WEEK
77                SAVEVALUE   22,V22
78                SAVEVALUE   27,V17            NORMAL LABOR COST
79                SAVEVALUE   28,V18            OVERTIME LABOR COST
80                SAVEVALUE   29,V19            MACHINE INVESTMENT COST
81                UNLINK      10,COUNT,ALL      GET LOST PROD. COST
82                BUFFER
83                SAVEVALUE   30,V20            TOTAL COST
84                SAVEVALUE   25,V25            SHOP UTIL.
85                SAVEVALUE   31,X36
86                SAVEVALUE   34,X33
87                SAVEVALUE   33,X32
88                SAVEVALUE   32,X37
89                PRINT       22,30,X
90                PRINT       1,4,T
91                UNLINK      1,SET,1
92                TERMINATE   1                 COMPLETE SIMULATION
93         LINK   LINK        1,FIFO
                  *
                  *       NORMAL REPAIR ROUTINE
                  *
                   1      FUNCTION    RN1,C24
                  C       0      .1   .104  .2    .222  .3    .335  .4    .509  .5    .69
                  .6      .915   .7   1.2   .75   1.38  .8    1.6   .84   1.83  .88   2.12
                  .9      2.3    .92  2.52  .94   2.81  .95   2.99  .96   3.2   .97   3.5
                  .98     3.9    .99  4.6   .995  5.3   .998  6.2   .999  7     .9997 8
                   2      FUNCTION    RN1,C7
                  0       0      .0228 10000 .1587 20000 .5000 30000 .8413 40000 .9772 50000
                  1.000 60000
                   3      FUNCTION    RN1,D2
                  .30     1      1.0   3
                   4      FUNCTION    RN1,D2
                  .40     1      1.0   3
                   5      FUNCTION    RN1,D2
                  .50     1      1.0   3
                   6      FUNCTION    RN1,D2
                  .60     1      1.0   3
                   7      FUNCTION    RN1,D2
                  .70     1      1.0   3
```

```
                1 VARIABLE   P2/K12
                2 VARIABLE   K108-V40
                3 VARIABLE   V40+P2
               23 VARIABLE   C1*X23-X4*X23
               29 VARIABLE   X10-Q1
               30 VARIABLE   X7/V29
               31 VARIABLE   X16-X17*K3+FN2*X17/K10000
               32 VARIABLE   X18-X19*K3+FN2*X19/K10000
               40 VARIABLE   C1-X3
94      NEWMO  GATE SF       10,ENTER+2          ADJUST JOBS EACH MONTH
95             QUEUE         10
96             LINK          20,LIFO
97             GENERATE      V30,FN1,,,1         CREATE INTERARRIVAL TIME
98             TABULATE      4
99             ASSIGN        1,C1                SAVE ARRIVAL TIME
100            SPLIT         1,SPARE             GO TO REPLACEMENT ROUTINE
101     TRAN   TRANSFER      FN,X15,TRAN         MAJOR - MINOR
102            ASSIGN        2,V31               REPAIR TIME
103            TRANSFER      ,PRIOR
104            ASSIGN        2,V32               REPAIR TIME
105     PRIOR  ASSIGN        3,V1                DETERMINE PRIORITY
106            TABULATE      3
107            QUEUE         10                  INTER QUEUE 10
108     FULLT  GATE SF       10,TIMET            ARE THE FACILITIES FULL
109     WAIT   LINK          20,P3
110     TIMET  GATE LR       10,WAIT             IS IT DURING WORK TIME, IF NOT WAIT
111     ENTER  PRIORITY      2
112            DEPART        10
113            ENTER         10                  ENTER A FACILITY
114     MORNT  TEST LE       V40,K48,ANOON       IS IT DURING THE MORNING
115            TEST G        V3,K48,FIXN         CAN JOB BE COMPLETED IN MORNING
116            ASSIGN        2+,K12              IF NOT, ADD LUNCH TIME TO JOB TIME
117            SAVEVALUE     6-,K12
118     ANOON  TEST G        V3,K108,FIXN        CAN JOB BE COMPLETED IN AFTERNOON
119            ASSIGN        8,V2                IF NOT, HOW MUCH WORK CAN BE DONE
120            ADVANCE       P8                  WORK UNTIL END OF DAY
121            SAVEVALUE     6+,P8
122            ASSIGN        2-,P8               INDICATE AMOUNT OF WORK REMAINING
123            LINK          30,P2               HOLD TILL NEXT WORKING PERIOD
124     FIXN   ADVANCE       P2                  WORK ON JOB UNTIL COMPLETED
125            SAVEVALUE     6+,P2
126     LEAVE  LEAVE         10                  RELEASE THE FACILITY
127            TEST E        P7,K1,ADD1
128            UNLINK        40,END,1
129     ADD1   SAVEVALUE     23+,K1              INDICATE REPLACEMENT UNIT AVAILABLE
130            SAVEVALUE     22+,V23
131            SAVEVALUE     4,C1
132            UNLINK        20,TIMET,1
133            UNLINK        10,LOSTD,1          RELEASE ANY TRANSACTION WAITING
134            TERMINATE                         DESTROY TRANSACTION
135     ADJ1   DEPART        10
136            TERMINATE
137     ADJ2   LEAVE         10
138            TERMINATE
```

```
*
*      OVERTIME ROUTINE
*
          4 VARIABLE   P4+48
          5 VARIABLE   P9+K48
          6 VARIABLE   V40+P2
          7 VARIABLE   K756-V40
          8 VARIABLE   V40+P2
          9 VARIABLE   K288-V40
139       NEWJ1 PRIORITY   2                  WEEK END OVERTIME
140             DEPART     10
141             ENTER      10
142       TEST1 TEST G     V6,K756,OVT1       CAN JOB BE COMPLETED DURING WEEK END
143             ASSIGN     6,V7               IF NOT, HOW MUCH WORK CAN BE DONE
144       BACK  TEST G     P6,V5,WRKOT        TESTS NO. OF BREAKS REQUIRED
145             ASSIGN     9+,K48             ADD 4 HOURS
146             TEST NE    P10,K1,INDX1       TEST INDEX
147             ASSIGN     10,K1              SET INDEX TO 1
148             ASSIGN     2+,K6              ADD 30 MINUTES FOR BREAK
149             TRANSFER   ,BACK              RETEST
150       INDX1 ASSIGN     10,K0              SET INDEX TO 0
151             TRANSFER   ,BACK              RETEST
152       WRKOT PRIORITY   2
153             SAVEVALUE  24+,K1
154             ADVANCE    P6                 WORK OVERTIME
155             ASSIGN     7,K1
156             SAVEVALUE  5+,P6              ACCUMULATE OVERTIME WORKED
157             ASSIGN     2-,P6              INDICATE AMOUNT OF WORK REMAINING
158             UNLINK     50,HOLD,1          HOLD MAIN ROUTINE TRANSACTION
159             LINK       30,P2              HOLD TILL NEXT WORKING PERIOD
160       NEWJ2 PRIORITY   2                  WEEK DAY OVERTIME
161             DEPART     10
162             ENTER      10
163       TEST2 TEST G     V8,K288,OVT2       CAN JOB BE COMPLETED BEFORE NEXT DAY
164             ASSIGN     6,V9               IF NOT, HOW MUCH WORK CAN BE DONE
165             TRANSFER   ,BACK              GO TO TEST FOR NO. BREAKS REQUIRED
166       OVT1  TEST G     P2,V4,FIXOT        TEST NO. OF BREAKS REQUIRED
167             ASSIGN     4+,K48             ADD 4 HOURS
168             TEST NE    P5,K1,INDX2        TEST INDEX
169             ASSIGN     5,K1               SET INDEX TO 1
170             ASSIGN     2+,K6              ADD 30 MINUTES FOR BREAK
171             TRANSFER   ,TEST1             RECHECK JOB COMPLETION TIME
172       INDX2 ASSIGN     5,K0               SET INDEX TO 0
173             TRANSFER   ,TEST1             RECHECK JOB COMPLETION TIME
174       OVT2  TEST G     P2,V4,FIXOT        TEST NO. OF BREAKS REQUIRED
175             ASSIGN     4+,K48             ADD 4 HOURS
176             TEST NE    P5,K1,INDX3        TEST INDEX
177             ASSIGN     5,K1
178             ASSIGN     2+,K6              ADD 30 MINUTES FOR BREAK
179             TRANSFER   ,TEST2             RECHECK JOB COMPLETION TIME
180       INDX3 ASSIGN     5,K0               SET INDEX TO 0
181             TRANSFER   ,TEST2             RECHECK JOB COMPLETION TIME
182       FIXOT PRIORITY   2
183             SAVEVALUE  24+,K1
```

```
184              ADVANCE    P2                 WORK ON JOB UNTIL COMPLETED
185              ASSIGN     7,K0
186              TEST L     P2,K24,ADDX5       DID IT TAKE 2 HOURS
187              ASSIGN     2,K24              IF NOT, WORKER GETS PAID FOR 2 HOURS
188           ADDX5 SAVEVALUE 5+,P2             ACCUMULATE OVERTIME WORKED
189              UNLINK     50,END,1
190              TRANSFER   ,LEAVE             LEAVE FACILITY
                 *
                 *  REPLACEMENT ROUTINE
                 *
                 15 VARIABLE   C1-P1
                 16 VARIABLE   V15*X8/K100
                 33 VARIABLE   X20-X21*K3+FN2*X21/K10000
191           SPARE QUEUE      1                 ENTER QUEUE 1
192              TEST LE    X23,K0,TAKE1       ARE THERE ANY SPARES, IF SO TAKE 1
193              SPLIT      1,OVTT
194              LINK       10,FIFO            IF NOT, WAIT
195           LOSTD SAVEVALUE 26+,V16           ACCUMULATE LOST PRODUCTION COST
196           TAKE1 SAVEVALUE 23-,K1            PUT SPARE IN OPERATION
197              SAVEVALUE  22+,V23
198              SAVEVALUE  4,C1
199              DEPART     1                  LEAVE QUEUE 1
200           LEVEL TEST G  X23,X38,OVTT       IS SPARE LEVEL BELOW THE MINIMUM
201           END   TERMINATE                  IF NOT, DESTROY TRANSACTION
202           OVTT  GATE LR 10,CALLT           ARE THE WORKERS OFF, IF SO - CALLT
203           HOLD  LINK    40,FIFO            IF NOT, HOLD
204           CALLT GATE LS 9,WKDAY            IS IT WEEK END
205              TEST G     V40,X40,YES1       IS OVERTIME ALLOWED
206              LINK       40,FIFO
207           WKDAY TEST LE  V40,X39,HOLD       IS OVERTIME ALLOWED
208              TEST L     V40,K108,YES2
209              LINK       40,FIFO
210           YES1  ADVANCE  V33                WAIT FOR WORKER
211              GATE LS    10,HOLD
212              UNLINK     30,TEST1,1,,,NWJB1  START OVERTIME ROUTINE
213              BUFFER
214              LINK       50,FIFO            HOLD TRANSACTION
215           NWJB1 GATE SF  10,UNLK1
216              LINK       40,FIFO
217           UNLK1 UNLINK   20,NEWJ1,1
218              BUFFER
219              LINK       50,FIFO
220           YES2  ADVANCE  V33                WAIT FOR WORKER
221              GATE LS    10,HOLD
222              UNLINK     30,TEST2,1,,,NWJB2  START OVERTIME ROUTINE
223              BUFFER
224              LINK       50,FIFO            HOLD TRANSACTION
225           NWJB2 GATE SF  10,UNLK2
226              LINK       40,FIFO
227           UNLK2 UNLINK   20,NEWJ2,1
228              BUFFER
229              LINK       50,FIFO
230           COUNT SAVEVALUE 26,V16            COUNT LOST PRODUCTION
231              ASSIGN     1,K0
```

```
232                 LINK        10,FIFO
                    *
                  1 QTABLE      1,0,12,100
                  2 QTABLE      10,0,12,840
                  3 TABLE       P2,0,6,100
                  4 TABLE       IA,0,12,100
                    *
                    START       1,NP
                    RESET
                    INITIAL     X11,4
                    START       1,NP
                    RESET
                    INITIAL     X11,5
                    START       1,NP
                    SAVE
                    END
```

D E C I S I O N I N P U T

```
$JOB    45        826711207      BACHMANN


$*                JOB NEEDS ONLY B4 FOR SCRATCH
$*                B6 AND B7 ARE NOT NEEDED
$PAUSE            MOUNT JB1 ON B5, HIT START
$EXECUTE          GPSS
*       SIMULATE
        READ
        RESET
        INITIAL     X7,8500
        INITIAL     X8,75
        INITIAL     X11,4
        INITIAL     X35,5
        INITIAL     X36,6
        INITIAL     X37,110
        INITIAL     X39,110
        INITIAL     X40,700
        START       1,NP
        RESET
        INITIAL     X11,5
        INITIAL     X35,6
        START       1,NP
        RESET
        INITIAL     X11,4
        START       1,NP
        SAVE
        END
$IBSYS
$PAUSE            MOUNT JB2 ON B5, HIT START
$EXECUTE          GPSS
*       SIMULATE
        READ
        RESET
        INITIAL     X7,8500
        INITIAL     X8,75
        INITIAL     X11,4
        START       1,NP
        RESET
        INITIAL     X11,5
        START       1,NP
        RESET
        INITIAL     X11,4
        START       1,NP
        SAVE
        END
$IBSYS
```

SAVEX	NR,	VALUE	NR,	VALUE	NR,	VALUE	NR,	VALUE	NR,	VALUE
	22	699	23	2	24	1	25	54	26	117
	27	4928	28	12	29	3632	30	8689		

TABLE NUMBER 1

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
88	1.943	8.633	171.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	82	93.18	93.2	6.8	.000	-.225
12	1	1.14	94.3	5.7	6.175	1.165
24	1	1.14	95.5	4.5	12.351	2.555
36	2	2.27	97.7	2.3	18.526	3.945
48	1	1.14	98.9	1.1	24.702	5.335
60	1	1.14	100.0	.0	30.877	6.725

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 2

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
93	194.806	208.548	18117.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	17	18.28	18.3	81.7	.000	-.934
12	4	4.30	22.6	77.4	.062	-.877
24	2	2.15	24.7	75.3	.123	-.819
36	3	3.23	28.0	72.0	.185	-.761
48	4	4.30	32.3	67.7	.246	-.704
60	2	2.15	34.4	65.6	.308	-.646
72	2	2.15	36.6	63.4	.370	-.589
84	5	5.38	41.9	58.1	.431	-.531
96	1	1.08	43.0	57.0	.493	-.474
108	4	4.30	47.3	52.7	.554	-.416
120	3	3.23	50.5	49.5	.616	-.359
132	3	3.23	53.8	46.2	.678	-.301
144	1	1.08	54.8	45.2	.739	-.244
156	2	2.15	57.0	43.0	.801	-.186
168	2	2.15	59.1	40.9	.862	-.129
180	4	4.30	63.4	36.6	.924	-.071
192	1	1.08	64.5	35.5	.986	-.013
204	0	.00	64.5	35.5	1.047	.044
216	1	1.08	65.6	34.4	1.109	.102
228	3	3.23	68.8	31.2	1.170	.159
240	0	.00	68.8	31.2	1.232	.217
252	0	.00	68.8	31.2	1.294	.274
264	0	.00	68.8	31.2	1.355	.332
276	2	2.15	71.0	29.0	1.417	.389
288	0	.00	71.0	29.0	1.478	.447
300	2	2.15	73.1	26.9	1.540	.504
312	1	1.08	74.2	25.8	1.602	.562
324	4	4.30	78.5	21.5	1.663	.619
336	0	.00	78.5	21.5	1.725	.677
348	2	2.15	80.6	19.4	1.786	.735
360	0	.00	80.6	19.4	1.848	.792
372	0	.00	80.6	19.4	1.910	.850
384	0	.00	80.6	19.4	1.971	.907
396	0	.00	80.6	19.4	2.033	.965
408	1	1.08	81.7	18.3	2.094	1.022
420	0	.00	81.7	18.3	2.156	1.080
432	3	3.23	84.9	15.1	2.218	1.137
444	0	.00	84.9	15.1	2.279	1.195
456	1	1.08	86.0	14.0	2.341	1.252
468	0	.00	86.0	14.0	2.402	1.310
480	0	.00	86.0	14.0	2.464	1.368
492	1	1.08	87.1	12.9	2.526	1.425
504	1	1.08	88.2	11.8	2.587	1.483
516	1	1.08	89.2	10.8	2.649	1.540
528	1	1.08	90.3	9.7	2.710	1.598
540	0	.00	90.3	9.7	2.772	1.655
552	0	.00	90.3	9.7	2.834	1.713
564	1	1.08	91.4	8.6	2.895	1.770
576	1	1.08	92.5	7.5	2.957	1.828
588	2	2.15	94.6	5.4	3.018	1.885
600	1	1.08	95.7	4.3	3.080	1.943
612	0	.00	95.7	4.3	3.142	2.000
624	0	.00	95.7	4.3	3.203	2.058
636	0	.00	95.7	4.3	3.265	2.116
648	0	.00	95.7	4.3	3.326	2.173
660	0	.00	95.7	4.3	3.388	2.231
672	0	.00	95.7	4.3	3.450	2.288
684	1	1.08	96.8	3.2	3.511	2.346
696	1	1.08	97.8	2.2	3.573	2.403
708	0	.00	97.8	2.2	3.634	2.461
720	0	.00	97.8	2.2	3.696	2.518
732	0	.00	97.8	2.2	3.758	2.576
744	0	.00	97.8	2.2	3.819	2.633
756	0	.00	97.8	2.2	3.881	2.691
768	0	.00	97.8	2.2	3.942	2.748
780	0	.00	97.8	2.2	4.004	2.806
792	0	.00	97.8	2.2	4.066	2.864
804	1	1.08	98.9	1.1	4.127	2.921
816	1	1.08	100.0	.0	4.189	2.979

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 3

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
109	126.697	59.040	13810.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-2.146
6	0	.00	.0	100.0	.047	-2.044
12	0	.00	.0	100.0	.095	-1.943
18	0	.00	.0	100.0	.142	-1.841
24	0	.00	.0	100.0	.189	-1.739
30	0	.00	.0	100.0	.237	-1.638
36	0	.00	.0	100.0	.284	-1.536
42	0	.00	.0	100.0	.331	-1.435
48	0	.00	.0	100.0	.379	-1.333
54	1	.92	.9	99.1	.426	-1.231
60	4	3.67	4.6	95.4	.474	-1.130
66	8	7.34	11.9	88.1	.521	-1.028
72	8	7.34	19.3	80.7	.568	-.926
78	11	10.09	29.4	70.6	.616	-.825
84	7	6.42	35.8	64.2	.663	-.723
90	10	9.17	45.0	55.0	.710	-.622
96	5	4.59	49.5	50.5	.758	-.520
102	3	2.75	52.3	47.7	.805	-.418
108	1	.92	53.2	46.8	.852	-.317
114	1	.92	54.1	45.9	.900	-.215
120	2	1.83	56.0	44.0	.947	-.113
126	1	.92	56.9	43.1	.994	-.012
132	2	1.83	58.7	41.3	1.042	.090
138	0	.00	58.7	41.3	1.089	.191
144	1	.92	59.6	40.4	1.137	.293
150	2	1.83	61.5	38.5	1.184	.395
156	4	3.67	65.1	34.9	1.231	.496
162	2	1.83	67.0	33.0	1.279	.598
168	5	4.59	71.6	28.4	1.326	.700
174	3	2.75	74.3	25.7	1.373	.801
180	1	.92	75.2	24.8	1.421	.903
186	6	5.50	80.7	19.3	1.468	1.004
192	1	.92	81.7	18.3	1.515	1.106
198	2	1.83	83.5	16.5	1.563	1.208
204	3	2.75	86.2	13.8	1.610	1.309
210	2	1.83	88.1	11.9	1.657	1.411
216	1	.92	89.0	11.0	1.705	1.513
222	4	3.67	92.7	7.3	1.752	1.614
228	2	1.83	94.5	5.5	1.800	1.716
234	1	.92	95.4	4.6	1.847	1.817
240	0	.00	95.4	4.6	1.894	1.919
246	2	1.83	97.2	2.8	1.942	2.021
252	3	2.75	100.0	.0	1.989	2.122

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NUMBER 4

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
108	72.880	64.370	7871.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-1.132
12	15	13.89	13.9	86.1	.165	-.946
24	15	13.89	27.8	72.2	.329	-.759
36	10	9.26	37.0	63.0	.494	-.573
48	10	9.26	46.3	53.7	.659	-.387
60	6	5.56	51.9	48.1	.823	-.200
72	10	9.26	61.1	38.9	.988	-.014
84	4	3.70	64.8	35.2	1.153	.173
96	6	5.56	70.4	29.6	1.317	.359
108	4	3.70	74.1	25.9	1.482	.546
120	7	6.48	80.6	19.4	1.647	.732
132	5	4.63	85.2	14.8	1.811	.918
144	4	3.70	88.9	11.1	1.976	1.105
156	1	.93	89.8	10.2	2.141	1.291
168	2	1.85	91.7	8.3	2.305	1.478
180	2	1.85	93.5	6.5	2.470	1.664
192	2	1.85	95.4	4.6	2.634	1.851
204	0	.00	95.4	4.6	2.799	2.037
216	0	.00	95.4	4.6	2.964	2.223
228	1	.93	96.3	3.7	3.128	2.410
240	1	.93	97.2	2.8	3.293	2.596
252	1	.93	98.1	1.9	3.458	2.783
264	0	.00	98.1	1.9	3.622	2.969
276	1	.93	99.1	.9	3.787	3.155
288	0	.00	99.1	.9	3.952	3.342
300	0	.00	99.1	.9	4.116	3.528
312	0	.00	99.1	.9	4.281	3.715
324	0	.00	99.1	.9	4.446	3.901
336	0	.00	99.1	.9	4.610	4.088
348	0	.00	99.1	.9	4.775	4.274
360	1	.93	100.0	.0	4.940	4.460

REMAINING FREQUENCIES ARE ALL ZERO

DEVELOPMENT AND ANALYSIS OF A MAINTENANCE SHOP SIMULATOR - DECISION - MAKING GAME

by

John A. Bachmann

ABSTRACT

This research was directed toward the development of a non-interacting, competitive decision-making game involving a maintenance facility in a textile fibers plant. The first part of this paper is a discussion and analysis of decision-making games in general.

The second part contains the description of the objectives and the model of the game. An important feature of the game is that the participants must decide what data they need instead of being automatically provided with all of the available information.

The validation of the game is presented in the last part of the paper. A test was conducted in a senior industrial engineering course.

The appendix contains the administrator and player instructions. In addition, the program listing and sample output are included.