PROSIM V

A PRODUCTION SYSTEM SIMULATOR*

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Abstract

A production system simulator, called PROSIM V, is described that is capable of simulating a variety of realistic production environments. Its primary uses are: (1) as a teaching aid in both graduate and undergraduate production control courses, (2) as a research vehicle for evaluating theoretical concepts and procedures, and (3) as a training aid for persons engaged in industrial production control operations.

1. INTRODUCTION

Two basic approaches have been employed in teaching the design of production control systems. One approach is the ordinary textbook-lecture-homework approach, in which the several control functions are treated individually. The second approach is the case-study approach, in which real or hypothetical production systems are analyzed.

In teaching the design of a system, it is convenient if the instructor can bring the system into the classroom or laboratory so that pertinent design principles may be discussed. This is the usual procedure in teaching design principles for electrical and mechanical systems.

Since it is not generally possible to bring a production system into the classroom, it is convenient to bring a representation of the system to the classroom. This is now possible due to the development of a third and new way of teaching control system design. Specifically, a production system simulator, called PROSIM V, has been developed which is capable of simulating a variety of production environments.

The new approach complements the traditional textbook-lecture-homework approach by permitting the student to interact with a dynamic simulated production system. PROSIM V has been used at Auburn University as a teaching aid in both graduate and undergraduate production control courses and is also being readied for use at Arizona State University. Several other universities have expressed an interest in PROSIM V.

PROSIM V can be used as a "management game;" however, its primary purpose is to provide the user with a dynamic production environment for which a complete production control system must be designed. Random perturbations may be introduced periodically to determine whether a designed control system is capable of maintaining stability.

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PROSIM V should prove to be useful to persons engaged in teaching and research in the areas of industrial engineering, production management, and operations research. Also, it can be used as a training aid for persons engaged in industrial production control operations. It is a useful research vehicle for evaluating theoretical concepts and procedures.

2. RELATED EFFORTS

The use of computer simulation as a teaching aid is relatively new, with most applications having been developed within the past decade. Among the first such applications were the "management games." Perhaps the most widely used management game is the Carnegie Tech Management Game (1). Another management game is described in reference 3.

Much interest is being shown currently in the use of computer simulation as an aid in teaching concepts in industrial engineering, production management and operations research. References 5, 6 and 8 describe such efforts.

Computer simulation has also been used for studying higher order relationships between major components of a firm and between competing firms. The area of industrial dynamics, as developed by J. W. Forrester (2), is concerned with such relationships.

A computer simulation model, described in reference 4, was developed at the System Development Corporation for the purpose of studying problems of information flow, its control and its use in decision procedures. This particular simulator was not developed primarily for teaching purposes, but it has many similarities to PROSIM V.

3. CHARACTERISTICS OF THE SIMULATED ENVIRONMENT

PROSIM V is sufficiently flexible to simulate a large variety of operating environments, including non-manufacturing operations. It also permits broad flexibility in the type of operation control system that can be designed. The simulator will be described in this paper with reference to a manufacturing environment; however, it can also be used to simulate almost any type of operation that has a recognizable product or service as its output.

Shown in Figure 1 is a typical inventory-production -sales system that PROSIM V is capable of simulating. The system is assumed to possess the following characteristics:

(1) There are several finished products, sold in discrete units.

(2) Demand for each product is a random variable and may, or may not, follow a trend.

(3) Each product is composed of assemblies and parts.

(4) At least some of the assemblies are composed of subassemblies among the finished products.

(5) There are common components and subassemblies among the finished products.

(6) Procurement lead time for purchased parts is a random variable.

(7) Fabrication and assembly operations are performed at "work stations," as in Figure 1.

(8) Different assemblies require processing on some of the same work stations.

(9) Processing times at certain work stations are essentially deterministic, and at others are random variables.

(10) The quality (percent defective) of incoming raw materials and of manufactured items is a random variable.

(11) Machines at work stations experience breakdowns at random intervals.

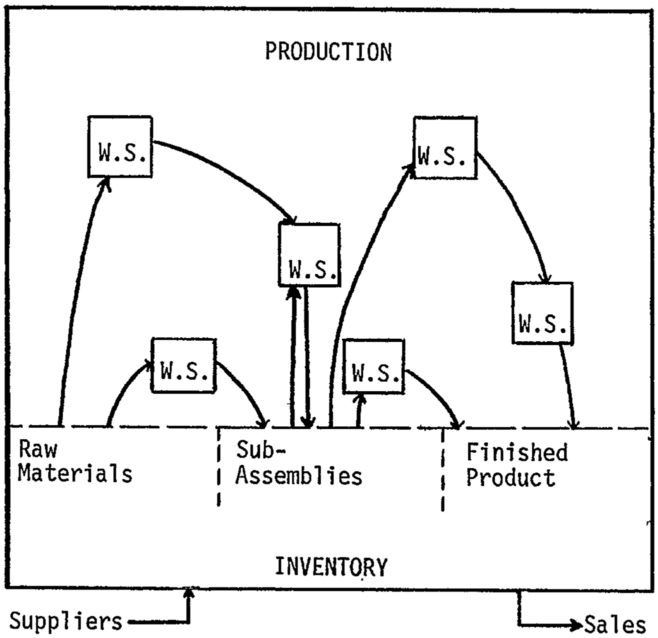
(12) Repair time of machine breakdowns is a random variable.

Presently, characteristics 1 through 8 are included in PROSIM V, and the simulator is being revised to include characteristics 9 through 12.

4. SIMULATOR CHARACTERISTICS

4.1 SIZE AND SPEED

An important characteristic of any production simulator is size of the problem it can handle and the computer time required for a typical simulation run.



W.S. denotes Work Station

Lines Represent Material Flow

FIGURE 1. TYPICAL INVENTORY-PRODUCTION-SALES SYSTEM

Generally, this characteristic depends upon the number of work stations (a work station is an area where an identifiable unit of work is performed) and the number of stock numbers (a unique stock number is assigned to each finished good, assembly, part, and raw material) the simulator is capable of handling. The simulator is limited in this respect only by the size of the available computer.* The manufacturing system consisting of 15 work stations, 60 stock number, and 3 finished goods studied in this paper requires 100,000 bytes of memory on an IBM 360/50 computer. Two large arrays were reduced to two byte word size because of the relatively small numerical values in the arrays.

There is no limit to the number of periods of simulation that can be run.

The computer time required for the simulation of one operating period depends upon the size of the manufacturing system being simulated. For the 15 by 60 problem, one week of simulated operation requires approximately 30 CPU seconds of IBM 360/50 computer time when the simulation time increment used is one minute. The computer time can be reduced considerably by using a larger time increment.

4.2 FLEXIBILITY

Another important characteristic of the simulator is its flexibility. The flexibility of PROSIM V is shown by the following features:

(1) The operating period is variable. Usually a period of one month or one week is used.

(2) Several periods of simulation can be run on one computer run.

(3) The time increment is variable. If a time increment other than one minute is used, all processing times and set up times must be in multiples of the time increment.

(4) The lot size is variable. Items may be produced in lots of any integer size.

(5) Certain features, such as random demand and random lead time, can be turned "on" or "off" with a parameter card.

(6) No more than five work stations may process any one stock number and no more than five raw materials or subassemblies may merge into one stock number. This restriction is overcome easily by specifying dummy assemblies.

5. OPERATION OF THE SIMULATOR

This section discusses the operation of the simulator when it is used as a teaching aid in a production control class. The procedures are only slightly different when it is used as a research vehicle.

5.1 OVERVIEW

The instructor selects the particular problem he wishes to use for the term. The problem (i.e., a

*If NWS is the number of work stations, NSN is the number of stock numbers, and NFG is the number of finished goods, the dimensioned variables in the computer model require the following number of words of memory:

1000 + (NSN) X (38) + (NWS) X (86) + (NFG) X (15) + (NSN) X (4).

The computer model itself is written in FORTRAN IV and consists of 1000 statements.

hypothetical manufacturing system) is translated into PROSIM V parameters and the simulator is initialized. The problem and the simulator are described to the class in a Student Manual that is given to each class member. The class is divided into teams, usually of three members each. The teams are given pertinent data, such as demand histories and costs. Each team then analyzes this data and designs a preliminary production control system.

The simulation now begins. Each team uses its control system to make a set of operating decisions for one operating period (usually one week). These decisions are keypunched in a prescribed format and are entered into the simulator. PROSIM V then simulates one operating period of plant operation under the control of the student's decisions. The results are printed out and returned to the student teams. The teams analyze their feedback, make appropriate adjustments to the control system, and then make a new set of decisions for the following period of simulated operation. The instructor may interject random disturbances (such as a change in the demand trend) at any time.

The above process is repeated for the desired number of simulated operating periods. More periods can be simulated during a term by requiring several period's decisions on one computer run.

PROSIM V accumulates all costs resulting from each team's sequential decisions. The teams are trying to operate the plant at lowest cost over the entire term. The student's grade in the course is influenced to some extent (usually 20%) by the performance of his system. The above process is shown in Figure 2.

5.2 INITIALIZING PROSIM V

All the variables and parameters pertinent to the manufacturing system being simulated must be initialized. Among the more important of these are:

(1) Work station sequences for each manufactured item.

(2) Parameters for demand generators (one demand generator for each finished product).

(3) Parameters for lead time generators (one lead time generator for each raw material).

(4) Process time and set up time for each manufactured item at each work station.

(5) All costs, parameters and constraints pertinent to the simulated system.

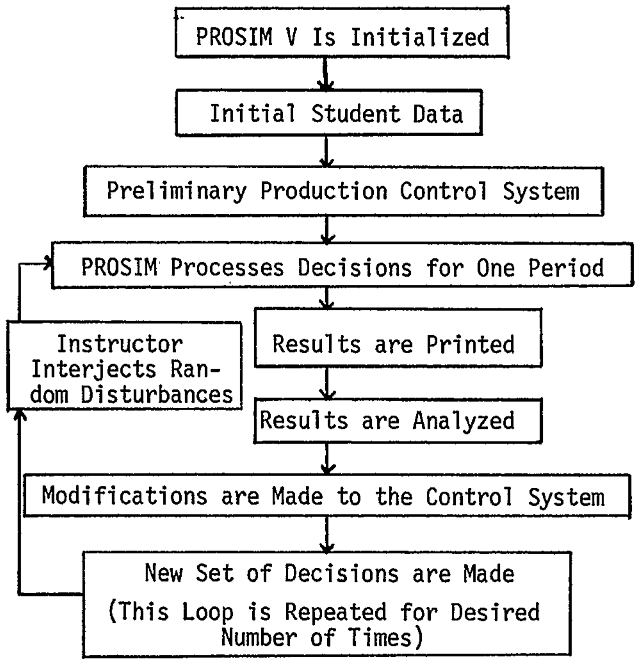


FIGURE 2. OVERVIEW OF THE OPERATION OF PROSIM V

5.3 INITIAL STUDENT DATA

The student is provided with the following data as a starting point for his analysis:

(1) Items 1, 4 and 5 from the preceding paragraph.

(2) A demand history for each finished product.

(3) Labor and work station rates for each work station; shift change cost; overhead rate; idle time cost.

(4) For each stock number: initial stock on hand, carrying cost, reorder cost, discount order quantity, regular price, discount price, average lead time, out of stock cost.

If desired, the student may be given a lot of largely irrelevant data. Part of his problem is to sort out the meaningful data from all that is available.

5.4 STUDENT DECISIONS

Each student team must design a production control system for the particular situation. The team must make the following decisions for each week of simulated operation:

(1) Demand forecast for all finished goods.

(2) Purchase orders for raw materials.

(3) Production orders and desired sequences for manufactured items.

(4) Time available for each work station (regular time, overtime, extra shifts).

(5) In-process buffer sizes.

In designing a control system to make the above decisions, the student relies on previous courses in operations research and industrial engineering. In such courses the student acquired a knowledge of inventory theory, scheduling techniques, forecasting techniques, production smoothing, etc. If PROSIM V is being used on the semester basis, it is possible to cover these topics early in the term and use the simulator during the last eight or ten weeks.

5.5 GROUND RULES

The following "ground rules" govern the manner in which PROSIM V acts upon the student's decisions and simulates the operation of the manufacturing system. These rules are pertinent to cases in which the operating period consists of one five-day week. Appropriate adjustments for other operating periods are obvious.

(1) A weekly demand quantity for finished goods is generated by PROSIM using Monte Carlo sampling. This quantity is divided by 5 to obtain a daily demand value. Conceptually, demand occurs instantaneously at the end of each day, regardless of the number of shifts of operation.

(2) If stock on hand (SOH) of a finished good (FG) is not sufficient to meet demand, a back order for the item is generated. Back orders for FG must be filled from production before the new daily demand is satisfied and before SOH can move above zero. An out of stock cost is incurred when demand cannot be met. Units backordered and out of stock costs are calculated after all transactions (production, demand, receipts) for the day have occurred.

(3) Carrying cost for each stock number is computed daily and is determined by multiplying 1/5 of weekly carrying cost times SOH at the end of each day after all transactions have occurred. Carrying cost is then summed for the week.

(4) The lead time for each purchase order is generated by PROSIM using Monte Carlo sampling. A purchase order can possibly come in during the same week in which it was placed. The components can be used in production the day following receipt of the order. No carrying cost is charged until the beginning of the day following the receipt.

(5) Components are subtracted from SOH as they are used at the various work stations.

(6) Assemblies are added to SOH as they are completed at the last work station in their network. They are immediately available for higher level assemblies.

(7) If there are insufficient quantities of components to produce one lot of an order, the queue is searched for an order that can be produced and this order is placed ahead of the order with the insufficient quantities.

(8) Total overtime for each work station is divided by 5 and assigned equally to the five days of the week.

(9) The week will usually end with several production orders in process at various work stations. These are processed first at the beginning of the following week.

(10) At least one full shift (40 hours) must be employed at all times for all work stations and no more than three shifts can be employed. A week always consists of five days. The first shift or second shift (depending upon the number of full shifts the work station is working) may work overtime up to the Maximum Weekly Overtime permitted by the particular problem.

5.6 OUTPUT

PROSIM V processes the student's decisions for one period according to the ground rules just discussed.

The student then receives feedback in the form of a set of reports. These are identified and described briefly below:

(1) Results of Forecast. This report compares the forecasted demand to the actual demand on a weekly and cumulative basis.

(2) Status of Production System. This report shows the production orders waiting to be processed at each work station at the end of the simulation.

(3) Idle Time. This report shows the amount and cost of idle time at each work station.

(4) Inventory Status. This report shows all inventory transactions (receipts, issues, on order, back ordered, carrying cost, stock on hand) for each stock number.

(5) Total Manufacturing Costs. This report shows manufacturing costs for the following factors: labor, machine, materials, overhead, and shift change.

(6) Cost Summary Report. This report summarizes all costs for this period and cumulative.

The student uses the above information to make any necessary adjustments to the parameters of his control system.

5.7 STUDENT EVALUATION ROUTINE

PROSIM V accumulates data on each student team which aids the instructor in evaluating the designed control system. After all simulated periods have been run, the evaluation routine constructs several charts which show the stability of the control system, how well it reacts to disturbances, etc. In this way the several designs can be compared.

6. FUTURE PLANS

PROSIM is currently being modified to include characteristics 9 through 12, mentioned in an earlier section. Also, at some time in the future the simulator will be completely re-written using the GASP II simulation language (7). This will permit a next event type simulation rather than the uniform increment procedure currently being used.

An investigation will be made into the feasibility of converting PROSIM to a remote terminal mode. It is noted that this approach was found to be unsatisfactory in at least one similar application (5).

It is hoped that eventually the simulator will be of such modular nature that student-written subroutines (such as an automatic ordering system) can be inserted to override "canned" subroutines that control the simulation.

An Instructor's Manual is being written that will explain the simulator and its use from the instructor's point of view. Upon completion, the Instructor's Manual, the Student's Manual, and the computer program will be available from the author.

7. SUMMARY

Our experience indicates that PROSIM V is an effective teaching aid. In comparison with the ordinary textbook-lecture-homework approach to teaching production control, PROSIM has the following advantages:

(1) It emphasizes the design of production control systems.

(2) It forces the student to consider the dynamic nature of the production environment.

(3) It provides a conceptual understanding of the total production control system and of the interactions between system components.

(4) It fosters an appreciation of the concepts of feedback, corrective action, and integrated information systems.

There is every reason to believe that an appropriate simulator could be designed for many other courses, such as quality control, plant design, project management, etc.

REFERENCES

1. Cohen, K.J., et. al., The Carnegie Tech Management Game. Richard D. Irwin, Homewood, Ill., 1964.

2. Forrester, J. W., Industrial Dynamics. M. I. T. Press, Cambridge, Mass., 1961.

3. Jucker, J. V., DECIDE. Graduate School of Business, Stanford University, 1966.

4. Kagdis, J., and M. R. Lackner, "A Management Control Systems Simulation Model," Management Technology. Vol. 3, No. 2, Dec., 1963, p. 145.

5. Marks, Eli S., Use of Simulation in Teaching Production and Inventory Control. Presented at TIMS/ORSA Joint Meeting, San Francisco, May 1-3, 1968.

6. Porter, J. C., et. al., "The Use of Simulation as a Pedagogical Device," Management Science. Vol. 12, No. 6, Feb., 1966, p. B-170.

7. Pritsker, A. Alan B., and Philip J. Kiviat, Simulation with GASP II. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1969.

8. Vollmann, T. E., "A Gaming-Monte Carlo Simulation Approach to Teaching Some Fundamental Concepts of Operations Research." Presented at the 1968 ORSA-TIMS Joint National Meeting in San Francisco, California, May 2, 1968.

BIOGRAPHY

Joe H. Mize is Professor of Engineering at Arizona State University. He was Associate Professor of Industrial Engineering at Auburn University for five years, where he was also Director of the Computer Center for one year He is co-author of the texts ESSENTIALS OF SIMULATION (Prentice-Hall, 1968) and OPERATIONS PLANNING AND CONTROL SYSTEMS DESIGN (Prentice-Hall, contracted for 1970). He earned his Ph. D. at Purdue University.