PROSIM W: A PRODUCTION SYSTEM SIMULATOR

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ABSTRACT

This report deals with the development of a computer program to aid in the teaching of production-inventory control systems. The resulting program follows the outline of previous PROSIM programs. PROSIM W has added features over other systems, and is compact and portable. The simulator was used as a followup to a senior/graduate course in inventory control and a number of modifications in the student interface were made as opposed to the method used by Mize et al in PROSIM V. Some coding errors in PROSIM V are also documented.

INTRODUCTION

The overall purpose of this project was to develop a computer program which simulates a multi-line shop environment. This was to be done in such a manner that control systems can be tested (as opposed to testing shop designs). In particular, this program will be used with a course in production and inventory control including demand forecasting.

There are three specific reasons for using a simulation program technique of instruction rather than non-computerized techniques (e.g. case studies): 1) A dynamic situation is presented. There is no one problem definition after the student begins using and modifying the program parameters. Each student (or team) creates his own solution to his own problem. 2) The use of feedback to cause corrective action is extremely useful. Weaknesses in the applied control system (or instructor caused perturbations in the problem) will require ad hoc actions which will have recussions throughout a multi-period problem. 3) The data is presented serially to the student as opposed to being available at the beginning of a problem (as in a textbook problem). Only after a decision has been made are the results of that decision available in order to make the next set of decisions.

Other attempts at designing simulations similar to this have been made. Greenlawn and Hottenstein developed PROSIM at Pennsylvania State University in early 1969. While it implemented many of the characteristics of a multi-line shop including quality control, machine breakdown, and a dynamic work force, it had a fixed number of products all using the same fixed number of machines in a set order. The problem was more of assembly line balancing with multiple products.

PROSIM V was developed by Mize et al at Auburn University during 1971. It is not at all similar, except in purpose, to PROSIM. Mize removed many decisions from the simulation (notably quality control and machine maintenance) while allowing an extremely flexible shop design. In fact, many shop types, from one machine job shops through multi-line assembly line shops, can be modeled. Any combination of types can be used to provide a problem from real life to a class. More will be said about PROSIM V below.

PROSIM W is an attempt to meld its predecessors into a viable whole. Also, there has been some redesign of how to interface with the student. A new concept has been added in the tool crib area.

OVERVIEW OF PROSIM W

Mize et al identify 12 characteristics of an inventory-production-sales system. These are:

1) Several finished products -- sold in discrete units.

2) Periodic demand for each product is a random variable which may or may not have a trend.

3) Each product is composed of assemblies and parts.

4) At least some assemblies are composed of subassemblies and purchased parts.

5) There are common components and sub-assemblies among finished products.

6) Lead time for purchased parts is a random variable.

7) Fabrication and assembly operations are performed at "work stations".

8) Different assemblies require processing on some of the same work stations.
9) The quality (percent defective) of incoming raw materials and of manufactured goods is a random variable.
10) Processing times at certain work stations are essentially deterministic, and at others are random variables.
11) Machines at work stations experience breakdowns at random intervals.
12) Repair time of machine breakdowns is a random variable.

Two new characteristics were added by this author--

13) Each work station requires the use of a set of tooling specific to each task it will perform.
14) An order can be canceled anytime before it is completed.

Other characteristics which can be considered in the future are discussed later in this report.

PROSIM W includes 10 of these characteristics. Numbers 1 to 8 are included as an integral part of the carryover from PROSIM V. Characteristic nine is implemented only for finished products, and only in a quasi-random method. While the percent defective is considered a fixed variable, it is applied to production via a formula taking quality control expenditure into account. (By expending resources for quality control, the student can lower the rate of defective product.)

Also included is characteristic 13. A central tool crib has been added. The student may add to the contents of the crib by ordering tools as he orders raw materials.

Finally, characteristic 14 was implemented to allow the student to cancel any outstanding purchase or manufacturing order. However, a penalty cost may be incurred.

As for the other three characteristics all processing times are deterministic and machines are considered not to break down. While it might be desirable to add the realism of these concepts, a student could well be overwhelmed by the added complexity.

Procedure

1. Initialization:

A specific problem must be initialized in order to run the simulation. This process is performed by the instructor. A problem situation is designed by specifying the parameters of a factory (see fig. 1.). While a complete description of these items is included in the PROSIM W user's manual, some of the more important are:

1) Work station sequences for the manufactured items.
2) Parameters for lead time, quality, and demand generators.
3) Process and setup times for each item processed at the various work stations.
4) Component requirements for the various assemblies.
5) Tooling requirements for the various assemblies.
6) Costing data.

This problem situation is then coded into a set of 'instructor change' cards and punched. The parameters are then loaded into various control matricies and written to disk (or tape). (A seperate program--PROSGO--performs these operations.) Also, all the data a student team needs about the problem is listed in a series of tables. Not all the problem specification data is listed for the student. The control of a system without a complete description is the task of the student.

2. Operation:

The student teams now construct control systems for forecasting and work force/production level smoothing and use the initial data given them to generate the first period's decisions. Seven items are required:

1) Forecasts of finished product demand.
2) Quality control expenditure.
3) Purchase orders for raw materials and tooling.
4) Manufacturing orders for assemblies and sub-assemblies along with the priority sequence for these orders.
5) Order cancellations for outstanding (from a previous period) purchase and/or manufacturing orders.
6) Manpower availability for each work station.
7) Inter-station buffer quantities.

These data are prepared for the simulator and the program is run. Extensive error checking is performed by the simulator and any ambiguous decision is corrected to predetermined standards. All decisions are echoed by the simulator and any errors and corrections are noted.

Feedback is provided to the student after the simulation run. Included are:

1) Forecast results with actual demand and running error indices.
2) Production system status in terms of outstanding production orders at each work station as well as work in progress and any items in a hold block.
3) Daily reports on purchase orders received, finished goods stockouts, and number of rejected finished goods.
4) Time usage data for each work station.
5) Inventory activity and final status.
6) Tool crib status.
7) Cost summary reports on labor,

FIGURE 1
Diagram of a typical problem situation.

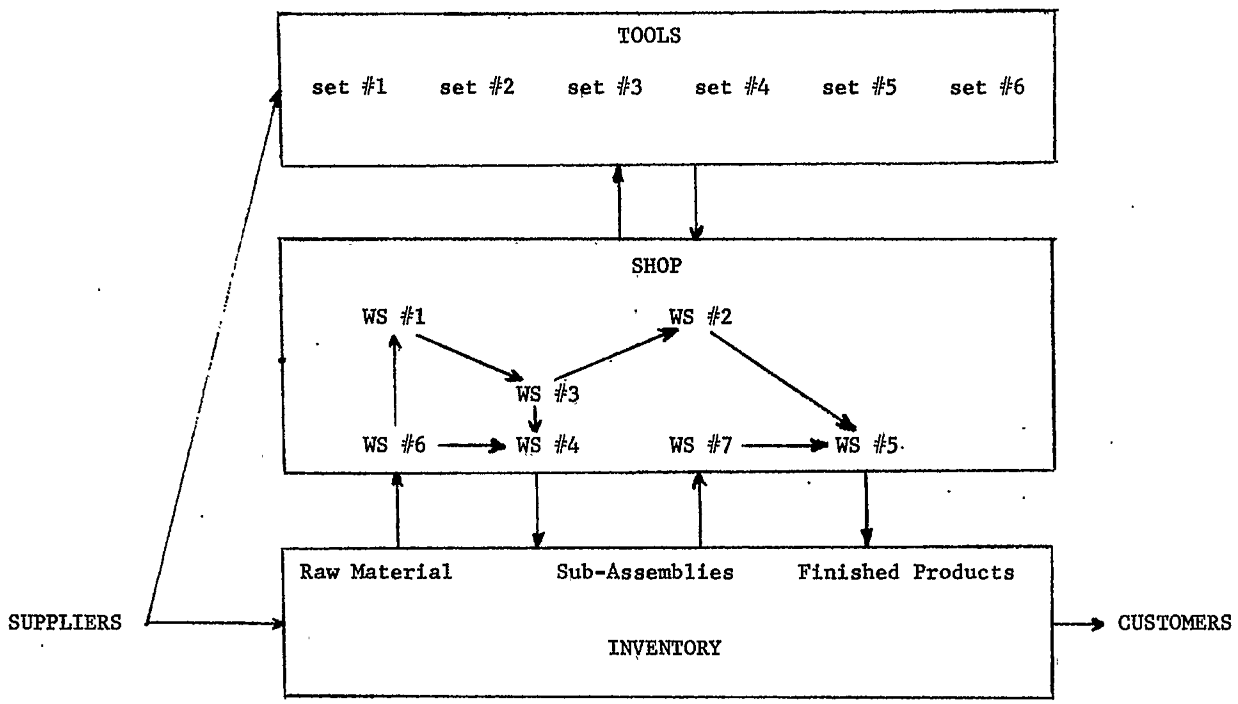
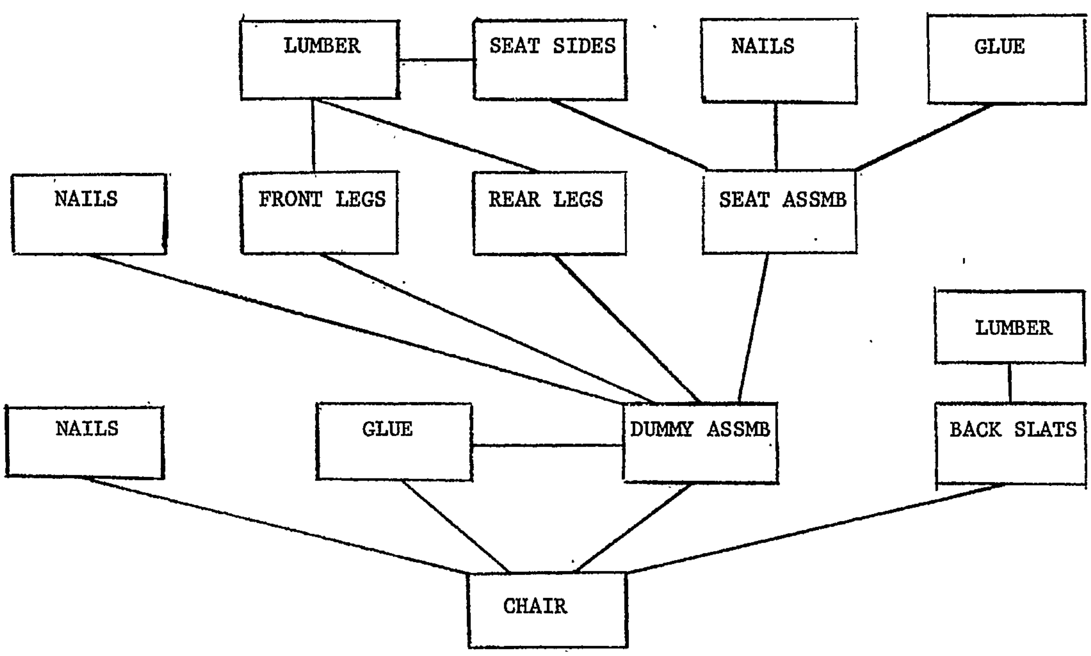


FIGURE 2
Typical problem routeing



ordering, and overhead for the period run and to-date.

With this new data, the team will modify their control system (if necessary) and then generate a set of decisions for the next period of simulation.

3. Final Instructor Grading:
PROSIM W creates a multitude of reports and each team will accumulate many copies of the various reports. Processing this data would be laborious and difficult when the instructor tries to grade the teams. Hence, PROSIM W keeps a set of summary data for each team. Using the program LSTTBL, the cost summary data for each period of simulation for each team is listed in a simple table. Also, graphs of forecasting errors, total plant cost per period, and production minutes in each period are produced for each team. (The smoothness of these graphs would indicate a 'good' control system.)

Characteristics

1. Size, Speed, & Language:
While the programming for PROSIM W is extensive (over 1500 statements), the major concern is the size of the problem situation, as very large, though occasionally sparse, matricies are required to contain the problem parameters. The present implementation is for a problem with up to 60 stock items, 15 work stations, 9 finished goods, and allows up to 200 outstanding purchase orders and up to 15 outstanding manufacturing orders at each work station. No more than 5 raw materials and/or sub-assemblies can be brought together at any one work station. Up to 16 periods of a simulation may be run for each problem. While this would require over 100,000 bytes of IBM 360/50 memory with PROSIM V, PROSIM W fits into the approximately 80,000 bytes of the Datacraft 6024/3.

Problems approaching this size can be run in less than 45 seconds of Datacraft cpu time when the period length is one week and a time increment of 10 minutes is used. Approximately the same time is used when a five minute time increment is employed on a 31 stock item problem.

The entire program of PROSIM W is written in FORTRAN IV with disk I/O extension. Except for the disk I/O and the machine dependent random number generator, the entire program conforms to ASA FORTRAN IV standards (which PROSIM V does not).

2. Flexibility:

PROSIM W gives the instructor great flexibility in designing the problem to be simulated. Any number of days may make up a simulation period. Usually 5 days are used, and a week is simulated with each run. Yet daily, fortnightly, or even monthly periods are usable. Closely related to period length is the time increment. This number is the time between snapshoot updates of the system. All processing and setup times must be multiples of the time increment. When the problem designer chooses compatible lot sizes and setup times, time increments of 10 or 15 minutes make for decreased run time.

Lot size is the number of batches of an item processed at one time. It can be considered the minimum manufacturing order quantity. A batch is the smallest quantity of an item to which a processing time can be assigned. The main need for a batch arises when the processing time of an item is less than one minute--the minimum time increment. While the batch can be one item, many items require batch sizes up to 20, 30 or even higher, due to short processing times. This would allow a factory to produce both bolts and bicycles in the same problem.

While the present implementation only allows five items to be combined into a given assembly, the use of dummy assemblies lets large items be constructed (see fig. 2). A stock item is defined as a sub-assembly even if it has no physical meaning. This sub-assembly of up to five components becomes one component of the next assembly of this product.

To provide the instructor maximum flexibility, many parameters can be changed dynamically during a student's run by adding "instructor change" cards to the student's deck. Hence prices, demands, lead times, or quality levels may be easily modified after any number of simulation runs. (One use may be to test the stability of student decision models under perturbed conditions.)

3. Ease of operation:

In all cases simplicity is desired. PROSIM W makes three types of computer runs. To initialize a problem, all data are loaded to disk by the FILECRE8 program which blocks the input of instructor change cards, PROSGO is run once for each student team. The student teams enter their data in a given sequence; any data which is not provided is set to default values to lower the need for student card preparation. Finally, the instructor runs LSTTBL for each team to generate tables and charts of summary data on forecasts, costs, and manpower usage for a given team.

4. Relationship to PROSIM V:

The logic pattern of PROSIM W is similar to PROSIM V. However, many economies were realized by some reprogramming and new sections of coding have been added. The input and output formats have been expanded radically, especially during initialization. (PROSIM V did not lend itself to use with any problem not covered in its User's Manual. Much data a student team would need was only described in the manual; no attempt at a comprehensive printout was present.)

In general, PROSIM W presents somewhat smaller (in terms of number of work stations and/or stock items) problem while considering more aspects of the situation (quality, tooling, and cancellations). In this manner, the realism of the problem situation is increased without information overload. Also, the increased modularization of PROSIM W lends itself to future extensions (q.v.).

DEVELOPMENT OF PROSIM W

Returning to the purpose of this project--to develop a computer program which simulates a shop environment in order to test production control systems--a sequence of decisions and tasks ensued. First there was the choice of PROSIM V as a starting point. Other alternatives were the use of PROSIM (Greenlawn & Hottenstein), use of another management game, or to develop an entirely new system. Two considerations were foremost in this decision--time and computer availability. Many of the programs were for relatively large machines. The programming effort to start from scratch would take more time than available. Hence, the availability of PROSIM V and the straightforeward problem of compressing sparse matricies made its use the final choice.

At first the parts of the program written in IBM 360 assembler language were converted to FORTRAN coding. A small problem version of PROSIM V was then compiled and tested on Datacraft 6024/3. Next, redundant sections of coding were removed, and variables used only in one subroutine were overlayed on similar variables in other subroutines. DO loops were streamlined by removing fixed value expressions and fixed subscript references. This compression in size and increase in speed allowed compilation and execution of the large size problem situation program described previously.

Finally, new sections of coding and new control matricies were added to allow the new features of quality control expenditure, order cancellation, and the use of tooling from a central tool crib. The reader should refer to Appendix I for some further details of coding differences in PROSIM W.

An extended problem was constructed and tested. This problem was then presented to students in 1E624 (Or Techniques in IE-II). Their comments and successes (or lack thereof) helped write the user's manual for PROSIM W. Even more data was required at the initialization stage (beyond the first change from PROSIM V). Better definitions of 'batch' and 'lot' were also developed during this experimental session.

RESULTS AND DISCUSSION

The first result is that the problems which can be run under PROSIM W are overwhelming to students--at first. Most of them have not had to integrate areas of expertise before. PROSIM W demands consideration of a multitude of factors, some without rigorous solutions (e.g. discounts on quantity purchases of raw materials). However, proper problem design can control this situation. Any of the variable characteristics (from demand to quality) can be dropped from the problem by setting various parameters to zero. Hence, only certain areas could be taught at one time. Then, once each area is explored singularly, multivariate problems can be presented to a class. Also, students gain familiarity with and confidence in using the program.

The short experience with eight students over two weeks has shown that the initialization data given the students is most important. Even with the great increase in listing content (from PROSGO) with level W, students had trouble picturing the problem situation. However, the extensive charts and diagrams in Mize's book limit problem variations. The instructor should have an easy method to convey his particular problem situation to his class. Further changes to PROSGO listings were made before use by students in the Fall of 1973.

Future Extensions

Use of PROSIM W has generated a number of ideas for future extensions. These are discussed separately below, but should be considered in the light of adding facets to a teaching tool. PROSIM V and PROSIM W both aim, not at simulating reality per se, but rather at teaching integration of techniques in problem solving (,and perhaps the futility of many present rigorous methods in production management.)

The most obvious extensions are mentioned by Mize in his list of characteristics (q.v.). The addition of machine breakdown, repair time, and (per PROSIM) preventive maintenance would bring an entirely new facet to the decision process. (These features could be added with little extra programming effort, but a new control matrix, by introducing a subroutine call during the daily initialization processing. This routine would set a time off and a time on switch for each work station. If the master timer was between these values, the work station would be down. However, this technique would allow a maximum of only one breakdown per day per station.)

One idea from the experimental teams is the inclusion of tool wearout. This would force decisions concerning tool purchases. The logic would be added in the period processing section, just before listing tooling status. (This has been added as of 8/73.)

A second extension of the new areas in PROSIM W is the the randomization of defect levels. While this would require only a little core space and programming effort, it would, in my opinion, add little to the purpose of the program. Variations in defects encountered occur naturally in PROSIM W as a result of production delays and the serial processing of orders.

More complete control of order priority was definitely desired by some students. The addition of order cancellation is only a start. By paying an extra fee, purchase order lead times could be shortened. Also, rush production orders could be made possible. This status of higher priority should be implemented so that it can be designated to any outstanding order, not just to new orders at the time of placement. This feature would allow any erroneous decisions to be corrected in a more realistic manner than at present. (PROSIM W requires total cancellation of an order to move a subsequent order forward in a work station queue.

New orders are then placed for the cancelled ones. This is a very artificial method and slows the cancelled order to an extreme.)

Other sought after additions would be the ability to close down a work station for a period and to shift workers from station to station at a cost less than the shift change cost now used. This added control would benefit users with problem situations dealing with small volume at some work stations and large volume at other stations.

The control of report generation by the student could be included. By creating "report groups", students could request only the groups of reports they desire for each run. A certain cost would be charged for each group. This would logically belong in the variable overhead cost as reports are generated in a real situation by staff personnel. The content of the report groups would have to be balanced against each group's cost. Also, some data now considered restricted could be made available at a relatively high cost.

Greenlaw and Hottenstein had implemented a few other concepts--notably variable operator proficiency and related training cost to speed gains in proficiency. Mize's characteristic of raw material quality also should be considered. However, as more additions are considered so will a problem design difficulty--balance.

Balance

When the problem situation is designed, all the costs must be realistic relative to each other. They need not be realistic per se. It must be remembered that it is desired for 'good' solutions (e.e., smooth ones) to generate low total costs. Stockout costs normally are high as many inventory models in use require this, or a similar constraint of few stockouts.

With these ideas in mind, the process of balancing remains one of continual experiment. As new problem situations are developed, much time is spent setting and resetting cost parameters.

CONCLUSION

The original goal of this research, to develop a teaching aid, has been met. Specifically, PROSIM W can be used to demonstrate the following areas: 1)demand forecasting, 2)operations planning, 3) inventory planning and control, 4) operations scheduling, 5) dispatching and progress control, 6) quality control, and 7) tool usage control.

To the student user, PROSIM W is a super-set of PROSIM V. It includes the quality control, order cancellation, and tooling considerations not found in PROSIM V. The improved initialization listing benefits the instructor in design of new problem situations by providing much of his documentation and in helping find keypunching errors. PROSIM W increases the number of concepts which can be integrated into a problem.

For the programmer, new and comprehensive commenting has been provided in the program listings. Also, modularization has been increased. This should aid in adding more features if so desired. The program's size has been decreased so that users with limited core machines may now run larger problem situations.

APPENDIX I

Technique Problems in PROSIM V

There are a few coding errors in the published version of PROSIM V. All of these are in the subroutine PRODTN.

Lines 109+3 to 109+5
- two errors--the IF K4K .LT. zero in line 109+5 cannot be true due to line 109+2.
- --the IF K4K .GT. J50 must logically come before lines 109+3 and 109+4 or else subscript overflow can result.

Lines 112+2 and 112+3
- since K4K indicates a non-existent work station, these statements cause subscript overflow.

Lines 3336+4 and 149+2
- CALL's to WRITE6 contain the parameter FCST. The SUBROUTINE statement for WRITE6 does not contain any corresponding parameter.

Lines 142+8 to 142+10
- whenever the time increment is not one minute, these three statements will incorrectly calculate idle time and its cost.

The coding of the XZERO subroutine is not documented as to method. Knowledge of IBM 360 BAL and BAL/FORTRAN interfacing are required to decipher the exact workings of this subroutine.

The great bulk of the initialization data lends itself to keypunching errors. PROSIM V echoes less than 35% of all input data for PROSGO, the initialization program. PROSIM W echoes nearly 80% of its initialization data, not only for error checking, but also for providing documentation on new problem situations.

APPENDIX II

Glossary of Terms

ASSEMBLY--a combination of raw materials and/or sub-assemblies constructed at a work station with a set processing time.

BALANCE--the setting of costs and time parameters so that a 'good' solution will affect the PROSIM model ti incur low total cost.

BATCH--the number of items or units of a stock item which can be produced in the specified processing time. Used for processing times less than one minute.

COMPONENT--a raw material or sub-assembly which is used by a work station to construct an assembly.

COSTS--any charge incurred to run the simulated system including: direct labor and machine costs, idle labor and machine costs, overhead, shift change cost, quality control cost, ordering costs, carrying costs, out of stock cost, purchase costs, and penalty costs.

CRIB--a conceptual location in which tooling not in use is kept.

FINISHED GOOD--a stock item for which there is an external demand.

HOLD BLOCK--a buffer following a work station in which lots being processed are accumulated before movement to the next work station in sequence or to inventory.

ITEM--any raw material, sub-assembly, or assembly held in inventory.

LEAD TIME--the time between the placing of an order and its receipt.

LOT--the number of batches of an item which are processed at one time at a work station; the minimum manufacturing order size.

MANPOWER AVAILABILITY--the number of minutes per period which a work station will be manned. This includes regular and overtime hours.

MASTER TIMER--an internal clock controlling all events; updated by the value of the time increment (q.v.).

ORDER--the coded decision to purchase a raw material or tool set or to produce a manufactured item.

OVERHEAD--composed of a fixed dollar cost per period and a percentage of direct labor cost.

OVERTIME--the number of minutes worked beyond a multiple of eight hours. Regular overtime ends either at the use of all allowed time or the lack of work at the station. Forced overtime ends only when all allocated time is used.

PERIOD--the number of days for which one set of decisions is required.

PROBLEM SITUATION--the production system being modeled by PROSIM W. This system is specified by the control parameters loaded to the program PROSGO.

PURCHASED PART--an item ordered from an outside vendor.

QUEUE--the conceptual location in which orders for production are held pending processing by a work station. Each work station has a queue of fixed capacity.

RAW MATERIAL--see purchased part.

STOCK NUMBER--an identifying number assigned to each item (q.v.).

SUB-ASSEMBLY--any assembly(q.v.) which is a component (q.v.) to another assembly.

TIME INCREMENT--the number of minutes skipped between master timer updates or snapshots. All activities must end at a multiple of the increment.

TOOL NUMBER--an identifying number for a set of tools used to perform a task at one or more work stations.

VARIABLE OVERHEAD--that portion of overhead costs which change a a percentage of some other factor incurred during the period in which charged.

WORK STATION--a conceptual location where work is performed on components to produce an assembly. The actual configuration of the work station is purposefully ambiguous as it is not necessary to the solution of the problem. Each work station consists of a queue, the work station proper, and a hold block, or buffer.

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