HURISTIC SEARCH METHODOLOGY FOR COMPOUND SIMULATION

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ABSTRACT

In recent simulation research related to complex automotive air pump assembly line operations, the major effort focused on finding the combination of sequential and parallel station capabilities that would minimize costs. A key variable is related to the in-process inventory that could reach very great proportions due to the high volume nature of the line. Within certain overall constraints, management can vary the output capability of each station by adjusting the number of work shifts scheduled. The in-process inventory also functions as a decoupling mechanism in this case.

As no practical algorithm provides the solution, simulation of the line in GPSS V has been utilized. Here the essential independent variable is a decision vector ($DV_1 \ldots DV_n$) identifying the assigned shifts at each operating station. A simple stepping search FORTRAN subroutine is linked to the simulation model to provide the engine for changing decision vectors.

In the context of a realistic line, the number of simulation runs can approach astronomical figures, consequently a rapidly converging search methodology is a real consideration.

Preliminary experimentation shows promise of achieving effective convergence through the mechanism of reducing search step sizes and decision vector upper and lower bounds as the search process identifies improved vectors.

A scaled down model i.e. 5 stations, is used for this study, however it retains the compound character of the original model. Selected decision rules are introduced and form the basis for the search methodology with the fundamental criteria relating to CPU time to achieve a target performance rating.

INTRODUCTION

A recent study (3) reported on a simulation model in combination with a simple stepping search that provided a mechanism for arriving at a good allocation of assembly line capabilities that would reduce in-process inventory costs while still meeting production requirements. While the search was executed by a computer sub-routine, the parameters for the search were manually modified as the decision vector approached optimum. The number of simulation runs and the computer time requirements were considered excessive. It was therefore hypothesized that appropriate decision rules introduced into the search methodology would result in more effecient simulation results. While a modified model has been constructed for the development of the decision rules, it is deemed necessary to describe the original model to establish the need for the search methodology and the decision mechanism.

PROCESS MODEL

The study environment involved is a precision pump assembly line, at a plant that responds directly to the needs of the automotive industry. It is of overriding importance to meet the automobile manufacturer's assembly schedule, if the pump manufacturer expects to continue as a supplier. Consequently, the current response to the requirements schedule is to establish a healthy margin of raw material and in-process inventory. While this insures customer satisfaction and continued orders, it has financial considerations of some consequence. It can be seen that the ability of the line to meet the stringent end-product requirements is greatly influenced by the amount of raw materials introduced into the process and the in-process queues at the various stations.

The physical line, which is illustrated in Table 1 and Illustration 1 involves 18 major stations.

Two are assembly stations that form branches into the main assembly. A number of stations are highly automated; these include the qualifiers that machine reference surfaces and the transfer stations where multiple operations are carried out automatically under computer control. On the other hand, a number of stations involve a degree of manual operation; for example, the rotor assembly operation and the vane mold and insert operation. An examination of the pump line reveals that the basic model is characterized by a large number of interacting, stochastic variables; thus, the possibility of solution by optimizing algorithm is ruled out. Consequently, a simulation approach was selected.

For this simulation, the General Purpose Simulation System has been selected. (5) Fundamental to the simulation is the development of the production times at each one of the stations in the form of a frequency distribution. This was accomplished using empirical data recorded during the month of June, 1976.

A determination of the length of the simulation was based on the pattern of manufacturing operations at the assembly plant. The normal manufacturing operations include two eight-hour shifts a day for a five-day week. When required, other shift operations are scheduled depending upon the current productivity of individual stations and observed

Illustration 1

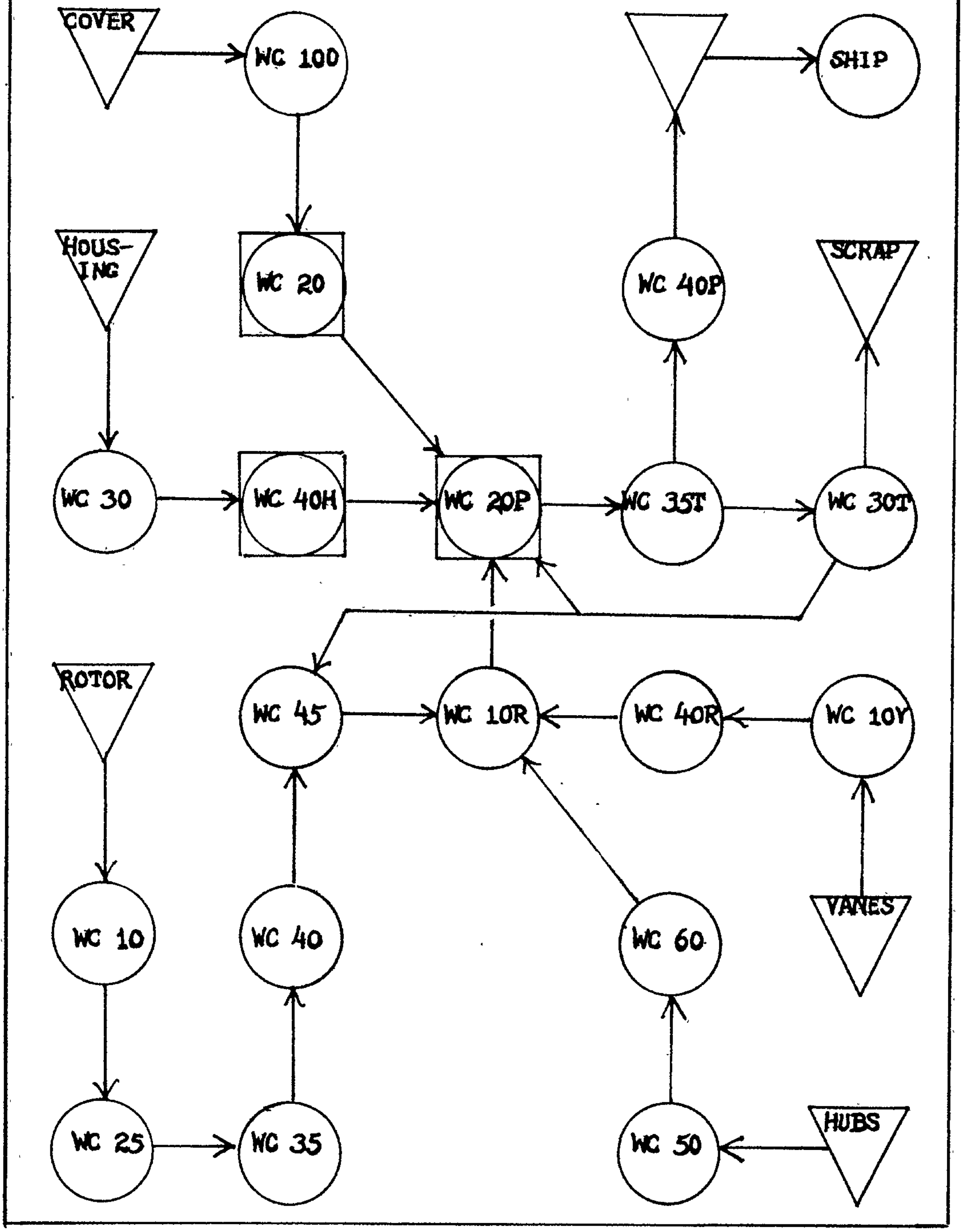


TABLE 1

Pump Line Designations

Work Center	Description
10	Rotor Slot Press
25	A & M Grinders
35	Rotor Finish Grind
40	Rotor and Liner Weld
45	Carbon Coat
100	Cover Qualifier
20	Cover Transfer
30	Housing Qualifier
40H	Housing Transfer
50	Hub Dial
60	Hub Broach
10V	Vane Mold
40B	Bearing Insert
10R	Rotor and Vane Assembly
20P	Pump Assembly
35T	Test Line
30T	Teardown
40P	Pack

queue lengths. This reflects breakdowns, maintenance requirements, personnel shortages, etc. Because it is necessary to manipulate the operational capabilities of each station in determining the optimum combination, a pattern of capabilities is introduced. The building block for this pattern is the one eight-hour shift operation involving a total of 480 production minutes. Capability variations are realized by changing the number of scheduled shifts at a station. For instance, at most stations, the capability can vary from one to four. This can be seen by examining several stations. At work center No. 30, the Housing Qualifier operation is a one-transfer machine installation. If this station is operated during a one-shift operation only, then the number of Housing Qualifiers introduced for a simulation would be one. On the other hand, if the Housing Qualifier was operated for a two-shift normal week operation, then the number of Housing Qualifiers that would be introduced into the simulation would be two. This could be expanded to a maximum capability of four Qualifiers if it was desired to examine the results for three shifts over the total week, including Saturdays and Sundays. Work center No. 25, A.M. Grinders, has four grinders available for operations during a shift. If the four grinders are operated in a one-shift regular operation, a capability of four would be introduced. Similarly, if they are operated on a two-shift basis for the regular week, a capability of eight would be introduced. Finally, if they are operated for the full three shifts during the total week, then as many as sixteen could be introduced into the simulation. In as much as GPSS accepts only integer number of storages, fractional capabilities could not be introduced into the simulation. A standard simulation run length of 960 minutes or the equivalent of two shifts was selected for comparison purposes.

COMPUTER SIMULATION MODEL

The total model can be viewed as having four parts:

a) the material flow, assembly line model
b) the control and communications link with the search program
c) the FORTRAN search sub-routine
d) the timer mechanism for the simulation

The major element in the simulation model relates to the flow of parts (housings, covers, hubs, rotors and vanes) through the operating stations and ultimately to the finished product shipping point. A second major element in the model relates to the mechanism that initiates transaction for the simulation cycle, communicates with the search sub-routine, sets and resets the capabilities of the operating stations, times the length of each assembly line simulation, calculates cost elements relating to the queues and the performance rating of the assembly line counter.

The third major element is the FORTRAN sub routine (SERCH) that communicates with the GPSS model through the HELPC blocks; sets the initial decision vector, decision vector boundaries, step sizes and other controls; evaluates the assembly line operations performance rating and terminates the simulation when a "best" decision vector is reached.

The search program (SERCH) generates changes to the capacity vector (DV) which in turn modifies the characteristics of succeeding simulations. Each succeeding simulation is costed and this cost figure returned to SERCH for evaluation and generation of a new capacity vector, if needed. Continual iterations of the capacity vector-simulation-cost-evaluation-search-new vector chain drives the model to solution and termination.

The General Purpose Simulation System V provides for the interface between the simulation model and the FORTRAN search and decision sub-routine. (1) The HELPC blocks, in series, is the communication link for the 19 variables (18 station capacities and 1 performance measurement) used in both programs. Program details are contained in the earlier study report (2).

CRITERIA FOR ANALYSIS

In order to arrive at a practical queue balance in the face of interacting variables, the following criteria were established:

1. Minimize the total in-process inventory on basis of standard costs.
2. Realize the daily output requirement.
3. Minimize aggregate shift requirements.

Within the constraints of the total line, management is able to vary the capability at each station primarily by the number of shift operations scheduled. It is through this mechanism that a balance, as well as both scheduled and unscheduled maintenance and repairs, can be approached. For the purpose of arriving at a simulation run cost comparison as one criterion, the plant standard in-process part cost has been applied to the average in-process inventory at each station. A second requirement related to the production. Only those simulation runs that met this requirement were included in the analysis matrix. In this case, a requirement for a 5,000 units per day (two-shift operations) or 2,500 per shift has been used. In addition to the value of the in-process inventory, a work center utilization, i.e., number of shifts required has also been calculated as additional criteria. Finally, an overall performance rating is calculated for each run to facilitate statistical analysis. The introduction of a comprehensive performance rating facilitates the incorporation of program rules, as discussed by Maier, Newell, and Pazer. (4)

For each simulation, a performance rating is computed and this becomes the basis for the decision relating to terminating or continuing the simulation. Continuation of the simulation means the selection of a changed station capacity vector $DV_i \ldots DV_n$. This change is brought about by an analysis of the average queues and production output, as identifies in the prior run. The decision model generates changes to the capacity vector which in turn provides for further simulations. These are continued until both a significant improvement in the performance rating is realized and no further improvements are generated.

RESULTS

The results of the search decision simulation are shown below:

WORK CENTER		INITIAL VECTOR	UPPER BOUND	LOWER BOUND
25	AMGRN	14	16	12
30	QUALI	3	4	3
100	QUAL2	4	4	3
40H	TRN1	3	4	3
20	TRN2	3	4	3
20P	TRN3	4	4	3
35T	TST	4	4	3
40P	PACK	4	5	6
10	SLOT	4	4	3
35	FNGRN	7	8	4
40	WELD	4	4	3
45	COAT	4	4	3
10R	RVAS	4	4	3
10V	MOLD	4	4	3
40B	INSRT	4	4	3
50	DRL	4	4	3
60	BRCH	4	4	3
30T	TEAR	3	4	3

Performance Rating (Initial Vector) - 152
BEST Decision Vector - 14,4,4,4,3,4,4,5,4,7,4,4,
4,4,4,4,4,3
BEST Performance Rating - 220

Simulation in this experiment does provide a mechanism to support management's goals for a practical and least cost in-process inventory plan. Important to the usefulness of the simulation is the decision system whereby a measure is possible for determining the degree of success of the simulation and the basis for termination. The runs were executed on an IBM 370/158 computer and 512K of fast core was required. CPU time averaged about 40 minutes per run; consequently, it is essential to provide a decision system to ensure efficient computer operations.

HEURISTICS FOR CONVERGENCE

Initial efforts at development of a decision rule focused on the boundaries of the solution universe, that step size used in the stepping search routine (SERCH) and the duration of the simulation run (ADVANCE). The procedure adopted follows:

a) Initial Vector - 16,4,4,4,4,4,4,5,4,8,4,4,4,4,
4,4,4,4
Simulation run time (ADVANCE) - 240 minutes
Boundaries DVMAX - 16,4,4,4,4,4,4,5,4,8,4,4,
4,4,4,4,4,4
DVMIN - 4,1,1,1,1,1,1,1,1,1,1,1,1
1,1,1,1,1
Step size DVSTEP - 2
Number of Simulation runs - 45
Performance Rating (PR) - 84
Avg CPU time - 14 minutes 6.13 seconds
Cost - $51.00
Max Vector - 12,2,2,4,2,4,4,5,4,8,2,4,4,4,4,4,
4,4

b) Initial Vector (max vector from (a))
Simulation run time (ADVANCE) - 480 minutes
Boundaries DVMAX - 16,4,4,4,4,4,4,5,4,8,4,4,
4,4,4,4,4,4
DVMIN - 2,1,1,1,1,1,1,1,1,1,1,1,1,
1,1,1,1,1
Step size DVSTEP - 2
Number of simulation runs - 52
Performance rating (PR) - 2844
Avg CPU time - 29 minutes 3.71 seconds
Cost - $99.38
Max Vector - 14,2,2,4,4,4,2,5,2,8,4,4,2,4,4,
4,2,4

c) Initial Vector (max vector from (b))
Simulation run time (ADVANCE) - 480 minutes
Boundaries DVMAX - 16,3,4,4,4,4,4,5,3,8,4,4,
3,4,4,4,4,4
DVMIN - 6,1,1,4,4,1,1,2,1,3,1,1,1,
4,4,4,1,4
Step size DVSTEP - 2/1
Performance rating (PR) - 4987
Avg CPU time - 14 minutes 9.51 seconds
Cost - $50.28
Max vector - 16,1,2,4,4,4,2,5,1,8,4,4,2,4,4,
4,1,4

d) Initial vector (max vector from c))
Simulation run time (ADVANCE) - 480 minutes
Boundaries DVMAX - 16,2,3,4,4,4,3,5,2,8,4,4,
3,4,4,4,3,4
DVMIN - 4,1,1,4,4,4,1,5,1,2,4,4,
1,4,4,4,1,4
Step size DVSTEP - 1
Performance rating (PR) - 6309
Cost - $37.61
Max vector - 14,1,3,4,4,4,2,5,1,6,4,4,2,4,4,
4,1,4

e) Initial vector (max vector from (d))
   Simulation run time (ADVANCE) - 960 minutes
   Boundaries DVMAX - 16,2,4,4,4,4,3,5,3,8,4,4,
   3,4,4,4,3,4
   DVMIN - 4,1,1,4,4,4,1,5,1,2,4,4,
   1,4,4,4,1,4
   Step size DVSTEP - 1
   Performance rating (PR) - 18923
   Cost-$30.17
   Max vector - 16,1,3,4,4,4,2,5,1,6,4,4,2,4,4,
   4,1,4

MODIFIED MODEL

While a "BEST" decision vector has been realized on the basis of the performance rating, it is apparent that the computer time involved is excessive. This is not surprising when we realize that the stepping search methodology results in a 960 minute simulation each time that a modification is made to a single variable in the decision vector. In order to avoid the excessive time resulting from simple step by step change to the variables of the decision vector it is apparent that some form of accelerated progress toward the "BEST" vector is desired. A heuristic paralleling the logic in the manual manipulation of the search methodology seems to have merit.

The original pump assembly model has been scaled down, not only to reduce computer time during the decision rule development phase but also to simplify the analysis of results. This reduced model followed the same GPSS V pattern of the original, however only 5 of the 18 basic operations have been retained, the Housing Qualifier, Cover Qualifier, Rotor Slot Press, Assembly and Test Line. The teardown and reintroduction of salvage parts was also retained in the model. Illustration 2 describes the scaled down model. The simulation program is similar to the details in (3).

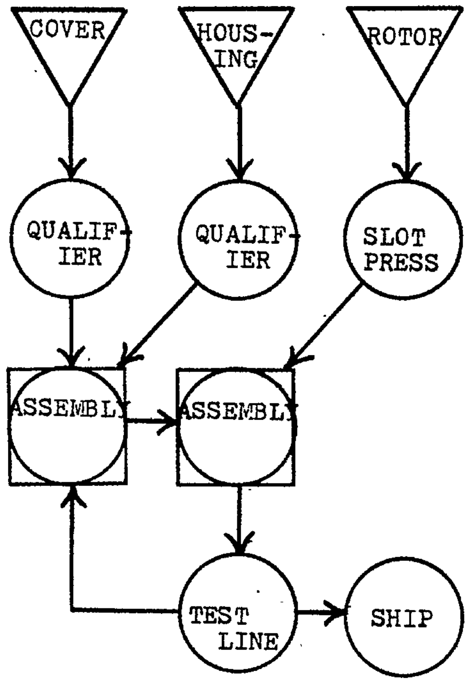
The stepping search routine SERCH has also been modified primarily because only six SAVEVALUES of the original nineteen, need to be communicated. The modified SERCH subroutine is similar in detail to the program in (2).

Finally, in order to introduce a mechanism for efficiently converging the stepping search program SERCH an additional subroutine TRIM has been constructed. TRIM is called by SERCH in accordance with preset rules. TRIM in turn changes the control parameter of SERCH primarily to accelerate convergence on a BEST decision vector. TRIM influences SERCH as a result of the application of decision rules in the form of manipulation of program constraints. Illustration 3 is a block diagram of the total simulation system and it shows the relationship between SERCH and TRIM.

SUBROUTINE TRIM

From a practical viewpoint a compound simulation as represented by the pump assembly operations system cannot be examined by simply changing the variables in a sequential fashion. The purpose of TRIM therefore is to seek a more efficient convergence by automatically modifying search boundaries, search

Illustration 2



step size and simulation run time in much the same manner as the manual techniques used earlier. TRIM's basic logic involves the measurement of the sensitivity of each decision vector variable and to generate search boundaries and step size changes on the basis of this sensitivity.

Specifically TRIM accomplishes the following:
a) A record of the number of times that TRIM is called.
b) A measure of the improvement in the performance rating.
c) A measure of the current difference between upper and lower search boundaries.
d) A record of the current simulation run time.
e) The difference between the current decision vector variables and the previous vector.
f) A calculation of the current sensitivity of each decision vector variable.
g) A calculation of the new step size and the new upper and lower boundaries of the search area.
h) A calculation of the new simulation run time and the basis of the number of times that TRIM has been called. Illustration 4 is a block diagram of the TRIM logic.

Currently TRIM is being used in conjunction with SERCH and the GPSS simulation to arrive at the most advantageous constants (decision rules) for the pump assembly modified model. Accumulated data is insufficient as yet to provide for the selection of decision rules. The next phase involves the augmentation of TRIM and SERCH so that it will be compatible with the original, 18 variable model.

Illustration 3

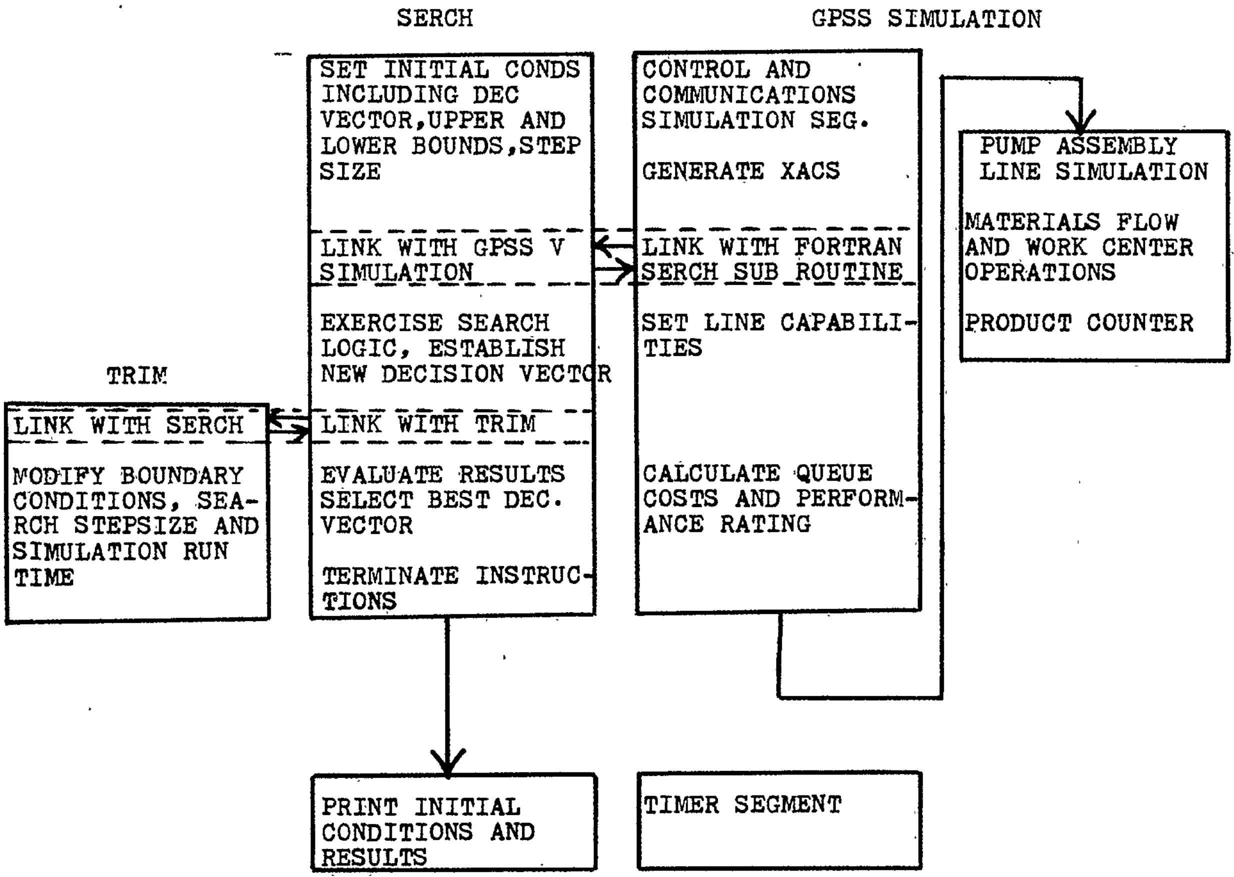


Illustration 4

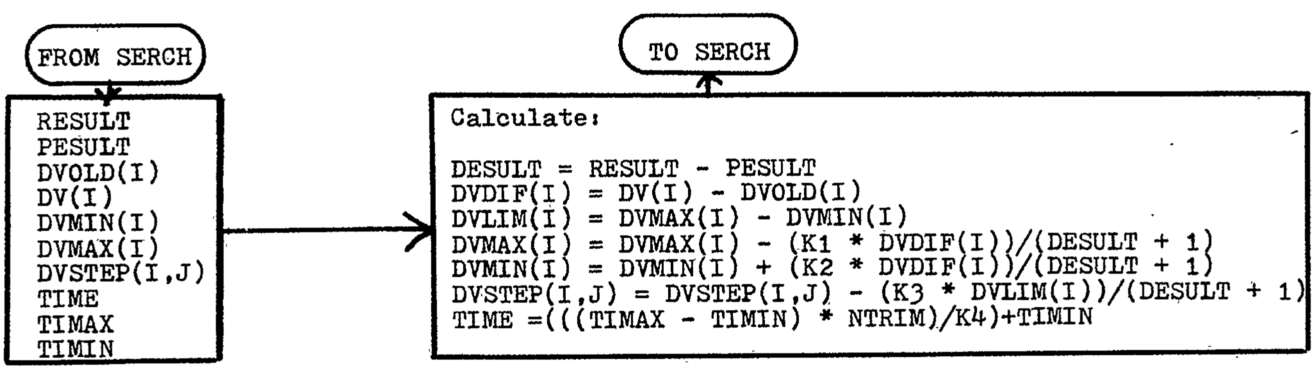


Illustration 4 (continued)

Where:

RESULT = The current performance rating
PESULT = The previous best performance current rating
DESULT = The difference between present and previous rating
DV(I) = The current decision vector
DVOLD(I) = The previous best decision vector
DVMAX(I) = The upper limit of the search region
DVMIN(I) = The lower limit of the search region
DVSTEP(I,J) = The latest step size for the new decision vector search
DVDIF(I) = The difference between the present and previous decision vector
DVLIM(I) = The difference between the current upper and lower limits of the search region
TIME = The current simulation run time
TIMAX = The maximum possible run time
TIMIN = The minimum possible run time
K1,K2,K3,K4 = Constants introduced manually to arrive at maximum TRIM effectiveness
NTRIM = The current number of times that TRIM has been called

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