DECISION OPTIMIZATION FOR GASP IV SIMULATION MODELS

Claude Dennis Pegden
Department of Industrial and Systems Engineering
The University of Alabama in Huntsville

Michael P. Gately
PATRIOT Project Office
U.S. Army Materiel Development and Readiness Command

ABSTRACT

This paper describes an optimization module which can be added to the GASP IV software package to provide automated optimization of a set of user defined decision variables. The optimization procedure is a variation of the Hooke-Jeeves pattern search and can be used for decision optimization in discrete, continuous, and combined simulation models. The application of the optimization module is illustrated with two examples.

INTRODUCTION

Frequently a simulation model has associated with it a measure of system performance which is to be optimized. In practical simulation problems, the decision variables may be mixed integer and real valued and the simulation model may be continuous, discrete, or combined (continuous/discrete). While combined simulation languages such as GASP IV [4] greatly simplify the simulation modeling of combined systems, the user is still faced with the problem of optimizing the system performance over the set of feasible decisions. In a recent survey of combined simulation languages, Ören [3] noted the desirability of optimization capability within combined continuous/discrete software.

This paper describes an optimization "module" which can be added to the GASP IV software package to provide for automated optimization of a set of user defined decision variables. The module consists of a set of ANSI FORTRAN subroutines designed to allow the user to invoke the optimization routine in a straightforward manner. Once initiated, the optimization module controls the values for the decision variables, the length of each simulation run, and the number of simulation runs.

OPTIMIZATION PROCEDURE

The optimization procedure consists of a variation of the well-known Hooke-Jeeves pattern search [2]. The Hooke-Jeeves pattern search is based upon the intuitive notion that a search strategy that was successful in the past is a good search strategy for the future. The procedure alternates a series of "exploratory" and "pattern" moves. Although the Hooke-Jeeves procedure begins cautiously with short excursions from the base search point, the step size grows with repeated success. When a failure occurs the step size is reduced, and if a change in direction is required, the technique will start over again with a new pattern. The presumed optimum is obtained when no search point yields an improved objective function value.

The Hooke-Jeeves pattern search has been found to be a particularly effective search procedure when applied to a large range of explicit functions. However, there are a number of unique problems encountered when applying the Hooke-Jeeves pattern search to the optimization of a simulation model. In a model of this type, a simple function evaluation corresponding to a set of decision values is replaced by a simulation run of the model. Additionally, the value of the objective function will normally be a random variable, where the accuracy of the estimate of the mean is dependent upon the length of the simulation run. Therefore, a new search point can be evaluated as being improved or unimproved only within the context of a probabilistic statement.

The optimization module classifies a search point as improved or unimproved by automatically monitoring the objective function mean, variance of the mean, and degrees of freedom for each simulation run. This monitoring is performed by subroutine SSTOP which employs a t-test to test for the difference in means between the new search point and the previous best search point. If the test reveals that the means are significantly different, then the simulation run is terminated and the new search point is classified as either improved or unimproved. The values of the decision variables are then adjusted and the simulation corresponding to the new search point is initiated.

If the t-test indicates no significant difference between the means, the simulation is continued and the t-test is reapplied at the next monitor time. The procedure continues until either the run is terminated as the result of the detection of a statistically significant difference between the means or until simulated time advances to TTFIN. At time TTFIN, the simulation is terminated and the search point is classified as either improved or unimproved by a simple comparison of the means. The next search point is then initiated.

The above procedure can significantly reduce the required simulation run time to obtain an optimum solution by early termination of significantly improved or unimproved search points.

An additional consideration with the traditional Hooke-Jeeves pattern search occurs when applied to a simulation model because the search strategy will at times result in a repetition of some search points. For the optimization of an explicit function, the repetition of search points is of no practical importance. However, when applied to the optimization of a simulation model, the repetition of search points represents wasted simulation runs. Therefore, the optimization module includes provisions for avoiding the repetition of previously evaluated search points.

The optimization module also allows the user to specify upper and lower bounds in each decision variable and independently control the minimum, maximum and starting search step size for each decision variable. By appropriate selection of the step size parameters, the user can define the variables as either integer or continuous. The independent step sizing provisions permit the user to formulate combined GASP IV simulation optimization models with mixed integer and continuous decision variables.

PROGRAM DESCRIPTION

The only modification required to a standard GASP IV simulation model to initiate the optimization module is the addition of a new labeled COMMON block and an EQUIVALENCE statement in each user written event routine involving the decisions, and the addition of a CALL OPTMZ statement to the GASP IV user written subroutine INTLC.

Subroutine OPTMZ controls the direction and step size of the search and schedules the monitoring of the simulation runs by subroutine SSTOP. In addition, subroutine OPTMZ reads a data card containing general descriptive data followed by one data card for each decision variable. The data card for each variable contains the variable label, initial value, lower bound, upper bound, initial step size, minimum step size, maximum step size, and expansion factor for the step size.

In addition to the above coding and data card requirements, the user must also write and include SUBROUTINE OBJCT (XMN, VAR, NN) which returns estimates of the objective function mean (XMN), variance of the mean (VAR), and degrees of freedom plus one (NN). Methods for estimating the variance of the mean include batching and autoregression and are discussed in Fishman [1].

The relationship between GASP IV subprograms, the optimization subprograms, and the user written subprograms INTLC and OBJCT is depicted in Figure 1. At the beginning of each simulation run, GASP calls DATIN which calls the user written subprogram INTLC for setting initial conditions for the simulation run. To invoke the optimization package, the user includes within INTLC a call to subprogram OPTMZ. In subprogram OPTMZ, the current search point is determined and the decision variables are automatically set accordingly. In addition, the monitoring of stopping conditions is scheduled on the event calendar by use of a modified GASP IV MONTR subprogram which calls subroutine SSTOP. At each monitoring of the stopping conditions, subprogram SSTOP compares the objective function of the current simulation obtained by a call to subroutine OBJCT (XMN, VAR, NN) to the best objective function value todate and attempts to statistically classify the current search point as an improved or unimproved point. If the point can be classified, the current simulation run is automatically terminated by subprogram SSTOP by setting MSTOP = -1 before returning to GASP. The process of setting the decision variables in subprogram OPTMZ and controlling run length in subprogram SSTOP is repeated until the presumed optimum is reached. These two subprograms function as an executive to GASP IV controlling the values for the decision variables, the length of each simulation run, and the number of simulation runs to be made.

A number of GASP IV variables have slightly different interpretations when used in conjunction with the optimization module. The GASP IV variable NNRNS is interpreted as the maximum number of simulation runs to be executed during the optimization process as opposed to simply the number of runs to be executed. Likewise, TTFIN is interpreted as the maximum ending time of the simulation as opposed to simply the ending time of the simulation.

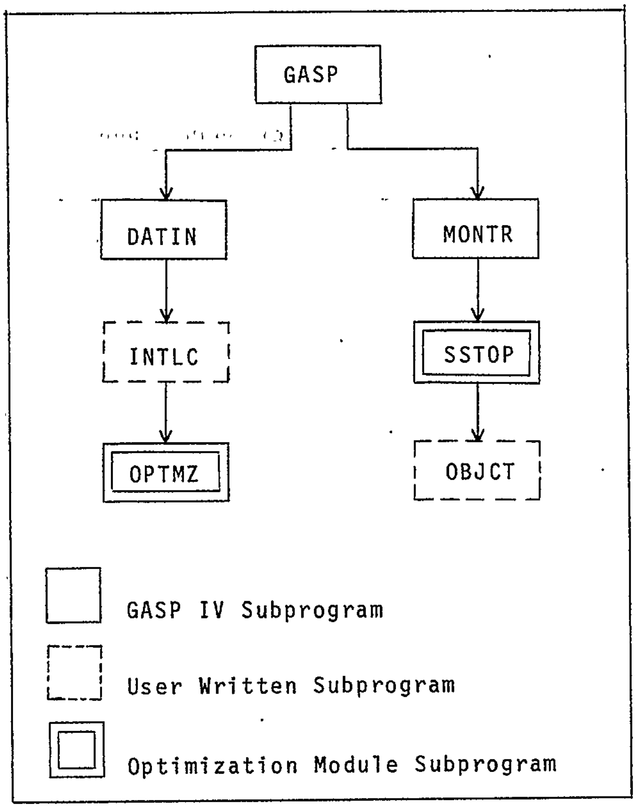

Figure 1. Relationship of Subprograms

All GASP IV output options are suppressed for all but the final simulation fun for which the decision variables are set at their presumed optimum values. The results for all other simulation runs are provided in a table summarizing the ending time of the simulation run, the mean objective function value, the standard deviation of the mean, the search point classification, and the value of each decision variable. The search point classification is denoted with a three-letter abbreviation corresponding to the terminology normally employed in describing the Hooke-Jeeves pattern search. The abbreviations are given in Table 1.

TABLE 1

SEARCH POINT CLASSIFICATION

Abbreviation	Definition
IBP	Initial Base Point
ISP	Improved Search Point
USP	Unimproved Search Point
NBP	New Base Point
UBP	Unimproved Base Point

INVENTORY EXAMPLE

To illustrate the application of the GASP IV optimization module to decision optimization of discrete event simulation models, consider the inventory problem described in detail in the GASP IV book [4]. The problem is to maximize the average weekly profit by proper choice of the following three decision variables.

Time Between Review (TBR): The time in weeks between review of the number of units in stock.

Reorder Point (RP): The stock threshold value for ordering additional units.

Stock Control Level (SCL): The level to which the inventory position is increased at the time of ordering.

To utilize the optimization module to solve this problem, the GASP IV simulation model presented in [4] must be modified to include an additional COMMON and EQUIVALENCE statement in the user written subprograms and a CALL OPTMZ must be added to subroutine INTLC. Also, four additional data cards must be prepared and subroutine OBJCT (XMN, VAR, NN) must be written to return estimates of the average weekly profit, the variance of the average profit, and the degrees of freedom plus one of the estimate.

For this example, an estimate of the variance of the average profit was obtained by batching over a four week period. The batching was accomplished in a separate event which computed the profit (PROF) for the previous four week period and then called the GASP IV subprogram COLCT (PROF, 2). This allowed easy computation of the values for XMN, VAR, and NN by accessing the standard GASP IV statistical arrays. Subroutine OBJCT for this example is relatively simple and is depicted in Figure 2.

The optimization parameters and the initial base point used for this example is summarized in the echo check depicted in Figure 3.

The output from the optimization module for the inventory problem is depicted in Figure 4. The optimization required a total of 18 separate simulation runs varying in length from 150 to 624 weeks. Note also that the Hooke-Jeeves pattern search would have resulted in eight redundant simulation runs if additional logic had not been incorporated to avoid repetitions of previously search points. The presumed optimum was obtained on run number 13, however, five additional runs were required in order to verify that there were no search directions yielding improvement.

```
      SUBROUTINE OBJCT(PAVG, PVAR,NNSAM)
      COMMON /GCOM6/ EENQ(100),IINN(100),KKRNK(100),MMAXQ(100),QQTIM(100GCOM6
     1),SSOBV(25,5),SSTPV(25,6),VVNQ(100)                               GCOM6
C
C*****THIS SUBROUTINE PROVIDES THE PROFIT,ITS VARIANCE AND SAMPLE SIZE
C
      XS=SSOBV(2,1)
      XSS=SSOBV(2,2)
      XN=SSOBV(2,3)
      PAVG=XS/XN
      NNSAM=XN+0.00001
      IF(NNSAM .LE. 1) RETURN
      PVAR=(XSS-XS*XS/XN)/(XN-1.0)
      RETURN
C
      END
```

Figure 2. Subroutine OBJCT

```
                    *****INITIAL OPTIMIZATION DATA*****

THE PURPOSE OF THIS OPTIMIZATION IS TO MAX THE OBJECTIVE FUNCTION.

THE FOLLOWING   3 DECISION VARIABLES ARE USED.

  DECISION            RANGE OF
  VARIABLE        DECISION VARIABLE                   RANGE OF
   NAME     INITIAL   MINIMUM    MAXIMUM         SEARCHING INTERVAL
                                           INITIAL   MINIMUM   MAXIMUM    EXPAND
 REOR PNT  .2000+02  .0000      .1000+03  .4000+01  .1000+01  .8000+01  .1000+01
 S.C. LVL  .3000+02  .0000      .1000+04  .4000+01  .1000+01  .8000+01  .1000+01
 TM BT RV  .2000+01  .2000+01   .4000+01  .1000+01  .1000+01  .1000+01  .1000+01
ALL ARRAYS ARE CLEARED AT  .0000    TO REDUCE THE EFFECT OF INITIAL TRANSIENTS.

THE STOPPING CONDITION IS INITIALIZED AT  .1500+03 TIME UNITS,AND
CHECKED AT AN INTERVAL OF  .1000+03 TIME UNITS.

THE CONFIDENCE INTERVAL FOR THE OPTIMIZATION IS     .196000+01
```

Figure 3. Optimization Parameters

TANKER EXAMPLE

A variant of the tanker problem described in the GASP IV book [4] is presented to illustrate the application of the optimization module to GASP IV combined simulation models. We have extended the original tanker problem statement to include three decision variables and a cost function to be minimized. The three decision variables are:

1) The number of 8 hour shifts per day,
2) The storage tank size,
3) The number of tankers.

The cost function consists of refinery start-up cost, refinery downtime cost, dock operating cost, tanker waiting cost, and storage tank cost. The costs are summarized as follows:

Refinery start-up cost	$100,000
Refinery down cost	$5,000/hr
Tanker waiting cost	$1,000/hr
Dock operating cost-1 shift	$1,200/hr
Dock operating cost-2 shifts	$1,000/hr
Dock operating cost-3 shifts	$800/hr

RUN NBR	TNOW	OBJECTIVE VALUE	STANDARD DEVIATION	PT TYPE/ LAST OPT PT NR	DIFFERENCE FROM LAST/ NEW OPTIMUM	REOR PNT	S.C. LVL	TM BT RV
1	624.	.706955+02	.243159+01	IBP/ 1	.000000	.2000+02	.3000+02	.2000+01
2	250.	.804576+02	.347962+01	ISP/ 2	.976216+01	.2400+02	.3000+02	.2000+01
3	624.	.843614+02	.233061+01	ISP/ 3	.390381+01	.2400+02	.3400+02	.2000+01
4	624.	.871668+02	.268929+01	ISP/ 4	.280533+01	.2400+02	.3400+02	.3000+01
5	150.	.985326+02	.458155+01	NBP/ 5	.113659+02	.4000+02	.5000+02	.3000+01
6	624.	.980218+02	.246776+01	USP/ 5	-.510891+00	.4400+02	.5000+02	.3000+01
7	624.	.101151+03	.235142+01	ISP/ 7	.261842+01	.3600+02	.5000+02	.3000+01
8	624.	.104969+03	.238454+01	ISP/ 8	.381835+01	.3600+02	.5400+02	.3000+01
9	624.	.104645+03	.219510+01	USP/ 8	-.324822+00	.3600+02	.5400+02	.4000+01
10	450.	.962845+02	.255753+01	USP/ 8	-.868492+01	.3600+02	.5400+02	.2000+01
11	624.	.100523+03	.241289+01	UBP/ 8	-.444642+01	.8400+02	.1340+03	.3000+01
		.104969+03	POINT PREVIOUSLY SEARCHED RUN 8.			.3600+02	.5400+02	.3000+01
12	624.	.104372+03	.238233+01	USP/ 8	-.597310+00	.3700+02	.5400+02	.3000+01
13	624.	.105440+03	.239253+01	ISP/ 13	.470967+00	.3500+02	.5400+02	.3000+01
14	624.	.105224+03	.241456+01	USP/ 13	-.216553+00	.3500+02	.5500+02	.3000+01
15	624.	.104975+03	.236192+01	USP/ 13	-.465543+00	.3500+02	.5300+02	.3000+01
16	624.	.104137+03	.218874+01	USP/ 13	-.130380+01	.3500+02	.5400+02	.4000+01
17	450.	.967909+02	.259813+01	USP/ 13	-.864947+01	.3500+02	.5400+02	.2000+01
18	624.	.105007+03	.242543+01	UBP/ 13	-.433837+00	.3400+02	.5400+02	.3000+01
		.105440+03	POINT PREVIOUSLY SEARCHED RUN 13.			.3500+02	.5400+02	.3000+01
		.104969+03	POINT PREVIOUSLY SEARCHED RUN 8.			.3600+02	.5400+02	.3000+01
		.105007+03	POINT PREVIOUSLY SEARCHED RUN 18.			.3400+02	.5400+02	.3000+01
		.105224+03	POINT PREVIOUSLY SEARCHED RUN 14.			.3500+02	.5500+02	.3000+01
		.104975+03	POINT PREVIOUSLY SEARCHED RUN 15.			.3500+02	.5300+02	.3000+01
		.104137+03	POINT PREVIOUSLY SEARCHED RUN 16.			.3500+02	.5400+02	.4000+01
		.967909+02	POINT PREVIOUSLY SEARCHED RUN 17.			.3500+02	.5400+02	.2000+01

```
    THE OPTIMUM IS      1.05440383+02
DECISION VARIABLE( 1)-REOR PNT =    .3500000+02  DEL( 1)=    .1000000+01
DECISION VARIABLE( 2)-S.C. LVL =    .5400000+02  DEL( 2)=    .1000000+01
DECISION VARIABLE( 3)-TM BT RV =    .3000000+01  DEL( 3)=    .1000000+01
```

Figure 4. Inventory Optimization Results

*****INITIAL OPTIMIZATION DATA*****

THE PURPOSE OF THIS OPTIMIZATION IS TO MIN THE OBJECTIVE FUNCTION.

THE FOLLOWING 3 DECISION VARIABLES ARE USED.

DECISION VARIABLE NAME	RANGE OF DECISION VARIABLE INITIAL	MINIMUM	MAXIMUM	RANGE OF SEARCHING INTERVAL INITIAL	MINIMUM	MAXIMUM	EXPAND
SHIFTS	.2000+01	.1000+01	.3000+01	.1000+01	.1000+01	.1000+01	.1000+01
TANK-SIZ	.1000+04	.1500+03	.5000+04	.2000+03	.1000+03	.2000+03	.1000+01
TANKERS	.1500+02	.1500+02	.1500+02	.1000+01	.1000+01	.1000+01	.1000+01

ALL ARRAYS ARE CLEARED AT .0000 TO REDUCE THE EFFECT OF INITIAL TRANSIENTS.

THE STOPPING CONDITION IS INITIALIZED AT .3650+03 TIME UNITS,AND
CHECKED AT AN INTERVAL OF .1000+03 TIME UNITS.

THE CONFIDENCE INTERVAL FOR THE OPTIMIZATION IS .000000

Figure 5. Optimization Parameters

The yearly storage cost is assumed to be a piecewise linear function of storage capacity as follows:

Capacity (1000 gallons)	Cost (Million $)
0	1
1000	7
2000	12
3000	15
4000	19,5
5000	22.5

The modifications required of the GASP IV model given in [4] is the addition of the optimization COMMON and EQUIVALENCE statements and the insertion of a CALL OPTMZ in subroutine INTLC. In addition, subroutine OBJCT must be included to return values of XMN, VAR, and NN for the cost function. For this example, the variance of the mean (VAR) was not computed and the first monitoring of stopping conditions was set at time TTFIN. As a result, each simulation run ended at time TTFIN with search point classification based upon a simple comparison of means.

The optimization input data is summarized by the echo check included as Figure 5. Note that for this particular optimization run, the number of tankers was held constant at 15.

The output from the optimization module is depicted in Figure 6. A total of nine simulation runs were executed with the presumed optimum obtained on run number seven.

Note that twice the pattern search produced tentative base points which were outside the bounds specified for the decision variables. When this occurs the algorithm automatically returns to the best feasible point todate and initiates a more cautious search.

SUMMARY

In many applications of simulation, the analyst is interested in using the simulation model as a basis for selecting between alternative decisions. The optimization module described in this paper provides a needed capability for automated decision optimization in GASP IV simulation models. The key features of the optimization module are: 1) it is simple to use, 2) it has application to discrete, continuous, and combined simulation models, and 3) it reduces simulation time by automatically controlling simulation run length and number of simulation runs.

RUN NBR	TNOW	OBJECTIVE VALUE	STANDARD DEVIATION	PT TYPE/ LAST OPT PT NR	DIFFERENCE FROM LAST/ NEW OPTIMUM	SHIFTS	TANK-SIZ	TANKERS
1	365.	.388515+08	.000000	IBP/ 1	.000000	.2000+01	.1000+04	.1500+02
2	365.	.299446+08	.000000	ISP/ 2	-.890686+07	.3000+01	.1000+04	.1500+02
3	365.	.308846+08	.000000	USP/ 2	.940000+06	.3000+01	.1200+04	.1500+02
4	365.	.283837+08	.000000	ISP/ 4	-.156090+07	.3000+01	.8000+03	.1500+02
		TENTATIVE BASE POINT IS OUT OF BOUNDS AT				.3000+01	-.3920+05	.1500+02
		.283837+08	POINT PREVIOUSLY SEARCHED RUN 4.			.3000+01	.8000+03	.1500+02
			SEARCH POINT IS OUT OF BOUNDS AT			.4000+01	.8000+03	.1500+02
5	365.	.377115+08	.000000	USP/ 4	.932776+07	.2000+01	.8000+03	.1500+02
6	365.	.289538+08	.000000	USP/ 4	.570110+06	.3000+01	.9000+03	.1500+02
7	365.	.283113+08	.000000	ISP/ 7	-.723975+05	.3000+01	.7000+03	.1500+02
		TENTATIVE BASE POINT IS OUT OF BOUNDS AT				.3000+01	-.9300+04	.1500+02
		.283113+08	POINT PREVIOUSLY SEARCHED RUN 7.			.3000+01	.7000+03	.1500+02
			SEARCH POINT IS OUT OF BOUNDS AT			.4000+01	.7000+03	.1500+02
8	365.	.371415+08	.000000	USP/ 7	.883016+07	.2000+01	.7000+03	.1500+02
		.283837+08	POINT PREVIOUSLY SEARCHED RUN 4.			.3000+01	.8000+03	.1500+02
9	365.	.284077+08	.000000	USP/ 7	.963632+05	.3000+01	.6000+03	.1500+02

THE OPTIMUM IS 2.83113025+07

DECISION VARIABLE(1)-SHIFTS = .3000000+01 DEL(1)= .1000000+01

DECISION VARIABLE(2)-TANK-SIZ = .7000000+03 DEL(2)= .1000000+03

DECISION VARIABLE(3)-TANKERS = .1500000+02 DEL(3)= .1000000+01

Figure 6. Tanker Optimization Results

REFERENCES

1. Fishman, G., Concepts and Methods in Discrete Event Digital Simulation, John Wiley and Sons, Inc., N. Y., 1973.

2. Hooke, Robert and Jeeves, T. A., " 'Direct Search' Solution of Numerical and Statistical Problems," Journal of the Association for Computing Machinery, Vol. 8, No. 2, April 1961, pp. 212-229.

3. Ören, Tuncer I., "Software for Simulation of Combined Continuous and Discrete Systems: A State-of-the-Art Review," Simulation, Vol. 28, No. 2, February 1977, pp. 33-45.

4. Pritsker, A. Alan B., The GASP IV Simulation Language, John Wiley and Sons, Inc., N. Y., 1974.