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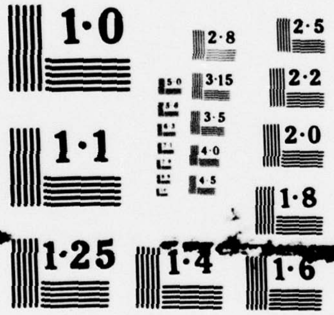
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SASPRO II--SPARE AND SERVER PROVISIONING PROGRAM

by

Donald Gross
Man-Yuen Wong

Serial T-391
2 May 1979

The George Washington University
School of Engineering and Applied Science
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SASPRO II--SPARE AND SERVER PROVISIONING PROGRAM

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SASPRO II is a versatile FORTRAN package designed to determine the level of spares inventory and number of repair channels necessary to provide a guaranteed service level at minimum cost for a population of stochastically failing, but completely repairable, items. The problem environment is first discussed, the program options are explained, and sample runs are provided.

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SASPRO II--SPARE AND SERVER PROVISIONING PROGRAM

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1. Introduction

SASPRO II, an acronym for *S*pare *a*nd *S*erver *Pro*visioning (model two), is a versatile FORTRAN package that gives provisioning levels of spares inventory and repair capacity required to support a population of randomly failing items which, upon failure, are (1) dispatched to the repair facility, and (2) replaced by a spare if one is available. This paper describes in detail the problem environment, the program options, the input required to run the program, and the output provided by the program. Sample runs are also shown for each of the program options.

2. Problem Environment

Consider a population of items containing certain significant parts; for example, a fleet of aircraft containing key avionics gear, a fleet of ships with modular engine components, or a group of milling machines, where the entire machine itself is the key "part." These "parts" randomly fail and require repair. Spare parts are also needed so that upon failure, the spare can be utilized to replace the failed part and the item put back into service. It is desired to determine how many spares and how many repair channels are required to support the system at a desired service level while minimizing costs.

The system is shown schematically in Figure 1. We consider only a single part-type at a time, which has its own spares pool and dedicated repair channels. For example, for a fleet of gas turbine propelled ships, the gas turbine engine has two components--a gas generator and a power turbine. Each must have dedicated repair channels and its own spares pool. Thus SASPRO II would treat each component in turn, being utilized to provision first for a population of gas generators and then for a population of power turbines.

When a unit in the operating population fails, a spare is requested at the same time the unit is dispatched for repair. If a spare is not available, the request is backlogged and units coming out of repair are used in removing the backlog. When there is no backlog of requests for spares, units coming out of repair go into the spares inventory. Repair times as well as failure times are treated as random variables and with the proper assumptions (to be mentioned below), this stochastic process can be readily modeled as a finite source queueing system, often referred to as "the machine repair problem with spares," which, in addition, also fits a two-stage cyclic queueing model. Thus SASPRO II uses a standard queueing model for the stochastic process [see GROSS, KAHN, and MARSH (1977)].

The assumptions required for using SASPRO II are that times to failure and repair times are exponentially distributed random variables. These assumptions allow the employment of the standard finite source

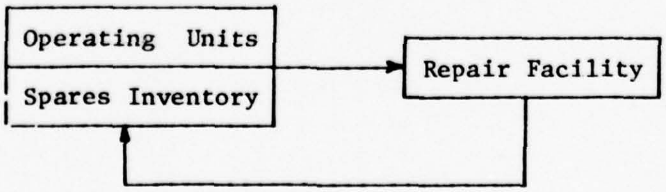

Figure 1.--Problem environment.

queueing theory to determine probabilities of various numbers of units in repair at any given time. From this, system service levels (number of units operating, availability of spares, etc.) can readily be computed. In order to achieve a specified service level, certain combinations of spares and servers (repair channels) are required. Using costs associated with purchasing and holding spares, and costs associated with building and operating repair channels, SASPRO II, through a heuristic optimization routine, finds the "best" combination of spares and servers that meets the service level constraint. While the optimization algorithm is heuristic, it does guarantee a feasible solution and also calculates the exact cost of the solution so that the user can "manually" perturb the heuristic solution to find better ones if they exist.

3. Modes of Operation

The program has two modes of operation, dynamic and static. The former is advised for initial year provisioning when population sizes, failure rates, and repair times may be changing significantly. Population size changes may occur because units are put into operation gradually, thus building up to a full strength population over a period of several years. For example, it was anticipated to build a fleet of 256 gas turbine powered ships, starting in the first year with ten ships and building up to full strength over a ten-year period. Because of new technology, engines on ships introduced in the later years were expected to have smaller failure rates (be more reliable) while due to learning, repair times were also expected to be smaller in the later years.

In designing support systems for which it is necessary to determine the number and location of depots the static mode is useful [see GROSS and PINKUS (1978)]. In this situation the population is at full strength, technological advances and learning are complete, and conditions are very close to static. Running times and input requirements are greatly reduced when operating in the static mode.

The dynamic mode allows for changing population sizes, failure rates, and repair times, as well as for changing costs on a year by year basis. A set of input information is required for each year in the planning horizon. An item repaired and placed back into spares inventory (or operation) in year i is assumed to have the same failure rate as a new item introduced in year i.

All costs are turned into an equivalent beginning of year payment and then discounted according to where the year is in the planning horizon, so that at any year i the program gives the present worth of the cumulative sum of the discounted costs up to and including year i. The final value for the last year is then the present worth of the sum of discounted costs over the entire planning horizon.

The costs that are considered in SASPRO II are purchase costs; salvage values; and annual holding and operating costs associated with spares and repair channels, respectively; unit transportation and repair costs; and component improvement program (CIP) investment costs. Purchase costs and salvage values are in dollars per spare or repair channel. Operating costs of each channel and holding costs for spares are in dollars per year per spare or repair channel. Transportation and repair costs are in dollars per unit per repaired item and component improvement program costs are in dollars per year.

In determining the discounted algorithm costs, salvage values are not realizable until the end of the planning horizon, even though spares or repair channels are retired prior to that; also, operating costs and holding costs are assumed to be incurred every year until the end of the planning horizon, even if spares or channels are retired earlier. Transportation repair and CIP costs are not explicitly considered by the algorithm.

The assumptions that salvage values are not received until the end of the planning horizon and that operating or holding costs are not reduced when spares or repair channels are retired early are necessitated by the heuristic optimization algorithm employed. Further, if a spare or repair channel is retired during the planning horizon and is required again a few years later, it must be repurchased. Again, this assumption is required because of the nature of the heuristic optimization algorithm.

Once the heuristic optimal values of spares and repair channels are obtained, the true cost and true present worth can then be determined. The true costs are the actual annual costs. In calculating these, the assumptions on salvage values, and operating and holding costs are no longer required; that is, the salvage values are received whenever spares or repair channels are retired, and the operating or holding costs are being incurred only for those spares or repair channels actually present each year. Transportation, repair, and CIP costs are also included. The true present worth at any year i is the cumulative sum of the discounted true costs up to and including year i. The final value for the last year is then the true present worth of the sum of discounted true costs over the entire planning horizon.

In the static mode fewer problems arise since spares and channels are not added or retired. Costs for this mode of operation are converted to expected equivalent end-of-year payments over the planned life of the system.

Details of the algorithm cost calculations and the true cost calculations are provided in Section 10.

4. Service Level Constraint Options

There are two options available for specifying service performance. The first, referred to as *spares availability*, sets a limit on the percentage of requests for spares that are met from on-shelf spares inventory (also called fill rate); that is,

$$\frac{\text{Number of Requests for Spares per Year Honored Immediately}}{\text{Number of Requests for Spares per Year}} \geq A \, , \qquad (1)$$

where A is specified by the user and $0 < A < 1$.

The second criterion for service performance, called *"fleet" availability*, sets a level for the percentage of time a certain portion of the population desired to be in operation is actually operating; that is,

$$\Pr\{\geq \beta M \text{ units are up}\} \geq A \, . \qquad (2)$$

Both β and A are specified by the user where $0 < \beta \leq 1$, and M is the population (fleet) size excluding spares.

Suppose, for example, we wish to have 100 machines in operation (M=100). When a machine fails, a spare machine is "plugged in" if one is available. We might specify that a service level constraint be (1) the percentage of requests for spare machines filled immediately from on-hand spares is at least 90% (option 1: A=.9), or (2) at least 95% of the machines are operating 85% of the time (option 2: β=.95, A=.85).

5. Population Average Failure Rate Options

Using the average failure rate for each year allows for the incorporation of changing component reliability as the years progress. There are two options available for specifying population average failure rate: averaging the failure rates and averaging the mean time between failures (or removals, denoted by MTBR).

Population average failure rate computed by averaging the failure rates is calculated by the formulae (we refer to this as rate averaging):

$$\bar{\lambda}_1 = \lambda_1$$

$$\bar{\lambda}_i = \begin{cases} \{(M_i - M_{i-1})\lambda_i + \bar{R}_{i-1}\lambda_{i-1} + (M_{i-1} - \bar{R}_{i-1})\bar{\lambda}_{i-1}\} / M_i , & M_i > M_{i-1} \\ \{\bar{R}_{i-1}\lambda_{i-1} + (M_{i-1} - \bar{R}_{i-1})\bar{\lambda}_{i-1}\} / M_{i-1} , & M_i \leq M_{i-1} \end{cases} \quad i=2,3,\ldots . \tag{3}$$

For averaging the MTBRs, the population average failure rate is given by (we refer to this as time averaging):

$$\bar{\lambda}_1 = \lambda_1$$

$$\bar{\lambda}_i^{-1} = \begin{cases} \{(M_i - M_{i-1})/\lambda_i + \bar{R}_{i-1}/\lambda_{i-1} + (M_{i-1} - \bar{R}_{i-1})/\bar{\lambda}_{i-1}\} / M_i , & M_i > M_{i-1} \\ \{\bar{R}_{i-1}/\lambda_{i-1} + (M_{i-1} - \bar{R}_{i-1})/\bar{\lambda}_{i-1}\} / M_{i-1} , & M_i \leq M_{i-1} \end{cases} \quad i=2,3,\ldots , \tag{4}$$

where

M_i = component population size, year i

λ_i = component failure rate, year i

$\overline{R}_i$ = expected number of components repaired, year i.

Which is the better averaging method to use depends on whether there are many or few machines operating simultaneously. For the many machine case, rate averaging yields more accurate results while for the few machine case, time averaging is more appropriate [see GROSS and INCE (1978)]. Note that both Equations (3) and (4) assume that the likelihood of a given item failing more than once in a time period is negligible.

6. Perturbation Options

The heuristic algorithm operates on a year-by-year basis and hence has the limitation that it does not "look ahead." Further, it treats operating costs and salvage values in a very approximate way and does not explicitly consider repair, transportation, or CIP costs at all. But it does yield a *feasible* solution; that is, one that will meet the service level constraint. When considering the entire planning horizon, the heuristic algorithm may (and probably does) not prove optimal. Therefore, after obtaining the heuristic optimal solution it may be advisable to make some perturbations by visually selecting other values. By exercising the perturbation option the program will use the perturbed solution values as if they were the optimal solution (without going through the heuristic algorithm) and will print out the availabilities and true costs, allowing comparison to those given by the heuristic optimal solution.

7. Input Data

Table I shows the data that are required as input for SASPRO II.

Most input parameters are self-explanatory but a few require further comment. The A shown in Equations (1) and (2) is AVL, while BETA is the β shown in Equation (2).

When using the algorithm (KTC = 1), initial values CO and YO must be read in for number of servers and spares, respectively. In the dynamic mode, after the first year the program uses the previous year's values for CO and YO as initial values, thus the CO and YO fields can be left

TABLE I

INPUT REQUIREMENTS

Variable Name	Description	Symbol on Printout
AVL	Desired Availability	AVL
BETA	Desired Percent of Population Up	BETA
C	Initial Value--Number of Repair Channels	CO
CIC	Carrying Cost per Spare ($/yr/spare)	CIC
CIPC	Component Improvement Cost ($/yr)	CIPC
CPSER	Repair Channel (Server) Purchase Cost ($/channel)	CPSER
CPSP	Spare Purchase Cost ($/spare)	CPSP
H	Operating Hours per Year per Item (hrs)	H
JD	Averaging Rate Option Indicator { =1: Rate Average =2: Time Average	
KEYWD	Mode Option Indicator { =1: Dynamic =0: Static	
KTC	Perturbation Indicator { =1: Heuristic Opt. Algorithm =2: Perturbation Option	
KWRITE	Intermediate Output Option Indicator { =0: Not Print =1: Print	
KZ	Service Criterion Option Indicator { =0: Spare Avail =1: Fleet Avail	
NYEARS	Planning Horizon Length (yrs)	YRS
OCPSER	Operating Cost of a Channel ($/yr/channel)	OCPSER
R	Yearly Interest Rate	RATE
RM	Population Size	M
RMTBR	Mean Time Between Removals (hrs)	MTBR
ST	Average Turn Around Time (days)	1/MU
SVPSER	Salvage Value of a Channel ($/channel)	SVPSER
SVPSP	Salvage Value of a Spare ($/spare)	SVPSP
URC	Unit Repair Cost ($/unit)	URC
UTC	Unit Transportation Cost ($/unit)	UTC
Y	Initial Value--Number of Spares	YO

blank on the card sets for every year in the planning horizon after the first. The closer the initial values are to the final values (determined by SASPRO II), the fewer iterations of the heuristic optimization algorithm are required. However, one may use CO = YO = 1 if so desired.

A set of cost inputs (CIC, CIPC, CPSER, CPSP, OCPSER, SVPSER, SVPSP, URC, UTC) is required for each year in the horizon in the dynamic mode. This allows one to account for inflation and technological innovations. The Component Improvement Program Cost (CIPC) is the annual expenditure required to achieve a given MTBR schedule (the MTBR which must be inputted for each year in the horizon) for the dynamic mode of operation, or to maintain the MTBR achieved when operating in the static mode.

The MTBR value is the actual mean time to failure of each unit when operating continuously. If items do not operate continuously but are required for, say, only H hours per year on the average, the mean failure rate actually used in the queueing model portion of SASPRO II is lowered accordingly. If items do operate around the clock, $H = 365 \times 24 = 8760$. If, for example, each unit in a population of items has an MTBR of 1000 hours but is called upon to operate, on the average, only half the time ($H = 4380$ hours), the effective MTBR used in the program is raised to 2000 hours (failure rate cut in half). The user specifies H and MTBR and SASPRO II automatically makes the adjustment. The reader is referred to BARZILY, GROSS, and KAHN (1977) for a discussion of the adequacy of this procedure to account for noncontinuous operation. The above reference also discusses the SASPRO II assumptions, when operating in the dynamic mode, that (1) the population attains instantaneous steady-state each year at average values, and (2) the population consists of non-identical units (with respect to mean time to failure), which are treated as identical by weighted averaging according either to Equation (3) or (4). Gross and Ince (1978) further discuss this latter problem.

The parameters KEYWD, KZ, JD, KTC, and KWRITE are the option flags. Setting KTC = 2 puts SASPRO II in the perturbation mode; setting KTC = 1 causes SASPRO II to operate with the heuristic optimization algorithm. Putting KEYWD = 1 sets SASPRO II in the dynamic mode; setting KEYWD = 0 allows SASPRO II to operate in the static mode. Designating KZ = 1 puts the service level constraint on fleet availability; KZ = 0 sets the service level constraint on spares availability. A β must be specified when KZ = 1. Putting JD = 2 sets the population average failure rate calculation to averaging MTBRs; putting JD = 1 averages failure rates. For KWRITE = 0, intermediate output will also be printed; for KWRITE = 1 only final output is printed.

Table II and Figure 2 give the card layout required for the input information. There are eleven cards needed for the static mode and nine plus two cards for each year in the planning horizon required for dynamic mode operation. The input requirements for static mode operation are similar to those required for a one-year planning horizon dynamic run. However, the output cost values given in the static mode are the expected end of year payments adjusted over an NYEARS life, while the costs of a single year dynamic mode run are the present worth of expenditures for that year.

8. Output from SASPRO II

SASPRO II gives the heuristic optimum combination of spares and repair channels needed to meet the service level constraint (or the actual service level for an inputted set of spares and repair channels) and also provides the costs associated with this solution. For the static operation mode there is a single line of output with all cost values being the expected equivalent annual expenditure over the NYEAR system life. For the dynamic mode of operation there is a line of output for each year, the costs outputted being the expected present worth of the cumulative sum of discounted costs up to and including that year as well as the costs for that particular year, as given by both the algorithm and exact calculation. Also given as output are the heuristic optimum combinations of servers and spares (when operating in the optimization mode); the average system failure rate, which in the static mode is the same as the inputted failure rate calculated from the MTBR and H values read in, and in the dynamic mode is a weighted average [according either to Equation (3) or (4)] of the units in the population which were introduced and repaired in various years at different values; the average number of units repaired; and the actual availability achieved (always $\geq$ AVL when using the heuristic algorithm). Another output quantity shown is ASTAR, the percentage of time the population is called upon to operate (ASTAR = H/8760); this serves as a check on the H value put in. The output quantities with definitions are shown in Table III.

TABLE II

CARD LAYOUT FOR INPUT

Card Number	Input Data Parameter(s)	Format	Columns
1	Title (any desired by user)	--	1-80
2	NYEARS	I2	1-2
3	R	F8.5	1-8
4[a]	AVL, BETA	F8.5, F8.5	1-8, 9-16
5[b]	KZ	I2	1-2
6[c]	KEYWD	I2	1-2
7[d]	JD	I2	1-2
8[e]	KTC	I2	1-2
9[f]	KWRITE	I2	1-2
10 } 11 }	See Figure 2: One set required for each year in dynamic planning horizon; one set only for static mode.		

[a] For Spares Avail Option, BETA may be set at any value.

[b] $\text{KZ} = \begin{cases} 0 \rightarrow \text{Spares Availability} \\ 1 \rightarrow \text{Fleet Availability} \end{cases}$

[c] $\text{KEYWD} = \begin{cases} 0 \rightarrow \text{Static Mode} \\ 1 \rightarrow \text{Dynamic Mode} \end{cases}$

[d] $\text{JD} = \begin{cases} 1 \rightarrow \text{Averaging Failure Rates} \\ 2 \rightarrow \text{Averaging MTBRs} \end{cases}$

[e] $\text{KTC} = \begin{cases} 1 \rightarrow \text{Heuristic Algorithm} \\ 2 \rightarrow \text{Perturbation Option} \end{cases}$

[f] $\text{KWRITE} = \begin{cases} 0 \rightarrow \text{Not Print Intermediate Output} \\ 1 \rightarrow \text{Print Intermediate Output} \end{cases}$

M	CO	YO	MTBR	1/MU	H	CIPC	CPSER	CPSP	URC	UTC
1 8	9 16	17 24	25 32	33 40	41 50	51 58	59 63	64 70	71 75	76 80
F8.0	F8.0	F8.0	F8.0	F8.0	F10.0	F8.0	F5.0	F7.0	F5.0	F5.0

SVPSER	SVPSP	OCPSER	CIC
1 5	6 12	13 17	18 26
F5.0	F7.0	F5.0	F5.0

Figure 2.--Format for card set 10,11.

TABLE III

OUTPUT QUANTITIES

Name	Description
YR	Actual year represented
M	Population size year i (from input)
FR	Failure rate of a unit purchased or repaired in year i [failures/day = (1/MTBR) • (H/8760) • 24]
FRBAR	Average failure rate of a typical unit (failures/day = weighted average of various units purchased or repaired in all years up to and including i)
ASTAR	Average percent of time population is called upon to operate (H/8760)
C	Heuristic optimum number of repair channels required in year i
Y	Heuristic optimum number of spares required in year i
AVAIL	Availability achieved
RBAR	Average number of units repaired in year i
COST	Costs, as considered by the heuristic algorithm, expended in year i dynamic mode or equivalent yearly average expenditure in static mode
PR-WORTH	Present worth of sum of discounted algorithm costs up to and including year i, dynamic mode; same as COST for static mode
TRUE-COST	True costs expended in year i dynamic mode or true equivalent yearly average expenditure in static mode
TRUE-PW	True present worth of sum of discounted costs up to and including year i, dynamic mode; same as TRUE-COST for static mode

9. Sample Runs

We illustrate the model options by presenting eight sample runs as given below in Table IV.

TABLE IV

SAMPLE RUNS

Sample Run No	Options			
	Planning Horizon	Mode	Failure Rate Computation	Service Level Constraint
1	Dynamic	Heur. Opt.	Rate Avg.	Fleet Avail.
2	Dynamic	Heur. Opt.	Rate Avg.	Spares Avail.
3	Dynamic	Heur. Opt.	Time Avg.	Fleet Avail.
4	Dynamic	Heur. Opt.	Time Avg.	Spares Avail.
5	Static	Heur. Opt.	--	Fleet Avail.
6	Static	Heur. Opt.	--	Spares Avail.
7	Dynamic	Heur. Opt.	Rate Avg.	Fleet Avail.
8	Dynamic	Perturb.	Rate Avg.	Fleet Avail.

A listing of the input cards for these runs is given in Figure 3. For the eight cases, there is a total of 196 data input cards (6[9 + (2 × 10)] + 2[11]).

The associated output for the first six cases (Sample Runs 1 to 6) is given in Figure 4. In Figure 5, output for the last two cases (Sample Runs 7 and 8) is shown. Run 7 is similar to Run 1 but the spare purchase cost in the initial year is reduced from 617 to 400. The heuristic algorithm solution does not change. However, by inspection it seems that perturbing the 1979 and 1980 Y values from 3 and 4, respectively, to 6 should give a better solution since the initial spare purchase cost is relatively cheap. Exercising the perturbation mode (KTC=2) in Sample Run 8 shows this to be true by comparing the TRUE-PW values for the final year. The input requirements for Sample Run 8 would be identical to those for

```
SAMPLE RUN 1
10
0.10
0.95      0.95
 1
 1
 1
 1
 1
     10.      1.       1.    3500.     65.   1880.30       0.  90.  616.5  49.   0.
  32. 123.3   10.  82.2
     28.                     3500.    62.5   1947.61       0.  90.  708.8  49.   0.
  32.  141.8  10.  94.5
     50.        .            4250.     60.   2121.60       0.  90.  815.3 37.8   0.
  32.  163.1  10. 108.7
     82.        .            5500.    57.5   1989.45       0.  90.  880.5  40.   0.
  32.  176.1  10. 117.4
    121.        .            6500.     55.   1958.95       0.  90.   951.  42.   0.
  32.  190.2  10. 126.8
    158.        .            7500.     55.   1966.37       0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
    182.        .            8500.     55.   1976.27       0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
    208.        .            9000.     55.   2001.90       0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
    229.        .            9000.     55.   2027.65       0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
    251.        .            9000.     55.   2046.44       0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
```

Figure 3.--Input card listing for sample runs.

```
SAMPLE RUN 2
10
0.10
0.90       1.00
 0
 1
 1
 1
 0
      10.        1.       1.    3500.      65.    1880.30      0.  90.  616.5  49.    0.
   32.  123.3   10.  82.2
     28.                        3500.    62.5    1947.61      0.  90.  708.8  49.    0.
   32.  141.8   10.  94.5
     50.                        4250.      60.    2121.60      0.  90.  815.3 37.8    0.
   32.  163.1   10. 108.7
     82.                        5500.    57.5    1989.45      0.  90.  880.5  40.    0.
   32.  176.1   10. 117.4
    121.                        6500.      55.    1958.95      0.  90.   951.  42.    0.
   32.  190.2   10. 126.8
    158.                        7500.      55.    1966.37      0.  90. 1026.8  44.    0.
   32. 205.35   10. 136.9
    182.                        8500.      55.    1976.27      0.  90. 1026.8  44.    0.
   32. 205.35   10. 136.9
    208.                        9000.      55.    2001.90      0.  90. 1026.8  44.    0.
   32. 205.35   10. 136.9
    229.                        9000.      55.    2027.65      0.  90. 1026.8  44.    0.
   32. 205.35   10. 136.9
    251.                        9000.      55.    2046.44      0.  90. 1026.8  44.    0.
```

Figure 3.--continued

```
SAMPLE RUN 3
10
0.10
0.95        0.95
 1
 1
 2
 1
 1
    10.       1.       1.   3500.     65.    1880.30     0.  90.  616.5  49.   0.
  32.  123.3  10.  82.2
    28.                     3500.     62.5   1947.61     0.  90.  708.8  49.   0.
  32.  141.8  10.  94.5
    50.                     4250.     60.    2121.60     0.  90.  815.3 37.8   0.
  32.  163.1  10. 108.7
    82.                     5500.     57.5   1989.45     0.  90.  880.5  40.   0.
  32.  176.1  10. 117.4
   121.                     6500.     55.    1958.95     0.  90.   951.  42.   0.
  32.  190.2  10. 126.8
   153.                     7500.     55.    1966.37     0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
   182.                     8500.     55.    1976.27     0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
   208.                     9000.     55.    2001.90     0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
   229.                     9000.     55.    2027.65     0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
   251.                     9000.     55.    2046.44     0.  90. 1026.8  44.   0.
  32. 205.35  10. 136.9
```

Figure 3.--continued

```
SAMPLE RUN 4
10
0.10
0.90       1.00
 0
 1
 2
 1
 0
     10.      1.       1.   3500.      65.   1880.30      0.  90.  616.5  49.    0.
  32.  123.3  10.   82.2
     28.                    3500.     62.5   1947.61      0.  90.  708.8  49.    0.
  32.  141.8  10.   94.5
     50.                    4250.      60.   2121.60      0.  90.  815.3 37.8    0.
  32.  163.1  10.  108.7
     62.                    5500.     57.5   1989.45      0.  90.  880.5  40.    0.
  32.  176.1  10.  117.4
    121.                    6500.      55.   1958.95      0.  90.   951.  42.    0.
  32.  190.2  10.  126.8
    158.                    7500.      55.   1966.37      0.  90. 1026.8  44.    0.
  32. 205.35  10.  136.9
    182.                    8500.      55.   1976.27      0.  90. 1026.8  44.    0.
  32. 205.35  10.  136.9
    208.                    9000.      55.   2001.90      0.  90. 1026.8  44.    0.
  32. 205.35  10.  136.9
    229.                    9000.      55.   2027.65      0.  90. 1026.8  44.    0.
  32. 205.35  10.  136.9
    251.                    9000.      55.   2046.44      0.  90. 1026.8  44.    0.
  32. 205.35  10.  136.9
```

Figure 3.--continued

```
SAMPLE RUN 5
20
0.10
0.95        0.95
 1
 0
 1
 1
 0
   256.        8.      11.    9000.      55.    2046.44        0.  90. 1026.8  44.    0.
  32. 205.35  10. 136.9
```

```
SAMPLE RUN 6
20
0.10
0.90        1.00
 0
 0
 1
 1
 0
   256.        8.      11.    9000.      55.    2046.44        0.  90. 1026.8  44.    0.
  32. 205.35  10. 136.9
```

Figure 3.--continued

```
SAMPLE RUN 7
10
0.10
0.95        0.95
 1
 1
 1
 1
 1
    10.        1.       1.   3500.      65.    1380.30      0.  90.  400.0  49.    0.
  32.  123.3  10.   82.2
    28.                      3500.     62.5    1947.61      0.  90.  708.3  49.    0.
  32.  141.8  10.   94.5
    50.                      4250.      60.    2121.60      0.  90.  815.3 37.8    0.
  32.  163.1  10. 108.7
    82.                      5500.     57.5    1989.45      0.  90.  880.5  40.    0.
  32.  176.1  10. 117.4
   121.                      6500.      55.    1958.95      0.  90.   951.  42.    0.
  32.  190.2  10. 126.8
   158.                      7500.      55.    1966.37      0.  90. 1026.8  44.    0.
  32. 205.35  10. 136.9
   182.                      8500.      55.    1976.27      0.  90. 1026.8  44.    0.
  32. 205.35  10. 136.9
   208.                      9000.      55.    2001.90      0.  90. 1026.8  44.    0.
  32. 205.35  10. 136.9
   229.                      9000.      55.    2027.65      0.  90. 1026.8  44.    0.
  32. 205.35  10. 136.9
   251.                      9000.      55.    2046.44      0.  90. 1026.8  44.    0.
  32. 205.35  10. 136.9
```

Figure 3.--continued

```
SAMPLE RUN 8
10
0.10
0.95         0.95
 1
 1
 1
 2
 1
    10.        3.       6.    3500.      65.    1880.30      0.   90.  400.0  49.    0.
 32.  123.3   10.   82.2
    28.        7.       6.    3500.     62.5    1947.61      0.   90.  706.8  49.    0.
 32.  141.8   10.   94.5
    50.        3.       6.    4250.      60.    2121.60      0.   90.  815.3 37.8    0.
 32.  163.1   10.  108.7
    82.       10.       6.    5500.     57.5    1989.45      0.   90.  880.5  40.    0.
 32.  176.1   10.  117.4
   121.       10.       6.    6500.      55.    1958.95      0.   90.   951.  42.    0.
 32.  190.2   10.  126.8
   158.       14.       5.    7500.      55.    1966.37      0.   90. 1026.8  44.    0.
 32. 205.35   10.  136.9
   182.       13.       4.    8500.      55.    1976.27      0.   90. 1026.8  44.    0.
 32. 205.35   10.  136.9
   208.       13.       4.    9000.      55.    2001.90      0.   90. 1026.8  44.    0.
 32. 205.35   10.  136.9
   229.       13.       3.    9000.      55.    2027.65      0.   90. 1026.8  44.    0.
 32. 205.35   10.  136.9
   251.       13.       3.    9000.      55.    2046.44      0.   90. 1026.8  44.    0.
 32. 205.35   10.  136.9
```

Figure 3.--continued

```
                         SAMPLE RUN 1
                         OPTIONS : DYNAMIC, HEURISTIC OPT, RATE AVG, FLEET AVAIL
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100    10. .950 0.95   1.   1.   3500.  65.000   1880.   90.   617.  49.       0.  0.0    32.   123.    10.  82.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
79  10   0.00147186   0.00147186  0.214646    3     3  0.97552   5.4   3809.42     3809.42    2658.47     2658.47
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100    28. .950 0.95   0.   0.   3500.  62.500   1948.   90.   709.  49.       0.  0.0    32.   142.    10.  95.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
80  28   0.00152455   0.00150573  0.222330    7     4  0.95095  15.3   1806.43     5451.63    2265.48     4717.99
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100    50. .950 0.95   0.   0.   4250.  60.000   2122.   90.   815.  38.       0.  0.0    32.   163.    10. 109.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
81  50   0.00136767   0.00145073  0.242192    8     6  0.95815  26.3   2887.98     7838.38    3447.17     7566.89
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100    82. .950 0.95   0.   0.   5500.  57.500   1989.   90.   881.  40.       0.  0.0    32.   176.    10. 117.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
82  82   0.00099101   0.00124468  0.227106   10     6  0.95716  36.8    254.26     8029.42    2457.82     9413.49
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100   121. .950 0.95   0.   0.   6500.  55.000   1959.   90.   951.  42.       0.  0.0    32.   190.    10. 127.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
83 121   0.00082569   0.00103241  0.223624   10     6  0.95090  44.9       0.0     8029.42    2748.66    11290.86
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100   158. .950 0.95   0.   0.   7500.  55.000   1966.   90.  1027.  44.       0.  0.0    32.   205.    10. 137.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
84 158   0.00071831   0.00090005  0.224471   14     5  0.95176  51.0    447.32     8307.16    3221.22    13290.99
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100   182. .950 0.95   0.   0.   8500.  55.000   1976.   90.  1027.  44.       0.  0.0    32.   205.    10. 137.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
85 182   0.00063699   0.00081447  0.225602   13     4  0.95973  52.9       0.0     8307.16    2766.99    14852.88
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100   208. .950 0.95   0.   0.   9000.  55.000   2002.   90.  1027.  44.       0.  0.0    32.   205.    10. 137.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
86 208   0.00060941   0.00074372  0.228527   13     4  0.96488  55.2       0.0     8307.16    3108.07    16447.81
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100   229. .950 0.95   0.   0.   9000.  55.000   2028.   90.  1027.  44.       0.  0.0    32.   205.    10. 137.
OUTPUT DATA
YR  M          FR        FRBAR      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-P[illegible]
87 229   0.00061725   0.00069972  0.231467   13     3  0.95377  57.0       0.0     8307.16    2843.60    17774.[illegible]
INPUT DATA
YRS RATE      M  AVL BETA   CO   YO    MTBR    1/MU      H CPSER   CPSP  URC     CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 10 .100   251. .950 0.95   0.   0.   9000.  55.000   2046.   90.  1027.  44.       0.  0.0    32.   205.    10. 137.
OUTPUT DATA
YR  M          FR        FRBAH      ASTAR     C     Y   AVAIL   RBAR     COST     PR-WORTH  TRUE-COST     TRUE-PW
88 251   0.00062296   0.00067426  0.233612   13     3  0.95079  60.2       0.0     8307.16    3189.34    19126.97
```

Figure 4.--Sample run output.

```
                         SAMPLE RUN 2
                         OPTIONS : DYNAMIC, HEURISTIC OPT, RATE AVG, SPARES AVAIL
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100    10. .900  1.00    1.    1.   3500.  65.000    1880.   90.   617.   49.       0.   0.0    32.    123.   10.   82.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
79   10   0.00147186   0.00147186  0.214646    3     3   0.92299    5.4    3809.42       3809.42      2658.47       2658.47
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100    28. .900  1.00    0.    0.   3500.  62.500    1948.   90.   709.   49.       0.   0.0    32.    142.   10.   95.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
80   28   0.00152455   0.00150573  0.222330    5     6   0.92344   15.3    4021.50       7465.33      3675.37       5999.71
INPUT DATA
YRS  RATE      M   AVL  BETA   CC    YC    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100    50. .900  1.00    0.    0.   4250.  60.000    2122.   90.   815.   38.       0.   0.0    32.    163.   10.  109.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
81   50   0.00136767   0.00145076  0.242192    8     8   0.91496   26.4    3155.49      10073.17      3849.12       9160.80
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100    82. .900  1.00    0.    0.   5500.  57.500    1989.   90.   881.   40.       0.   0.0    32.    176.   10.  117.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
82   82   0.00099101   0.00124457  0.227106   10    10   0.91325   37.2    3091.94      12396.19      4702.89      12714.15
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   121. .900  1.00    0.    0.   6500.  55.000    1959.   90.   951.   42.       0.   0.0    32.    190.   10.  127.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
83  121   0.00082569   0.00103161  0.223624   12    11   0.90538   45.5    1690.80      13551.03      4557.44      15826.94
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   158. .900  1.00    0.    0.   7500.  55.000    1966.   90.  1027.   44.       0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
84  158   0.00071831   0.00089892  0.224471   15    12   0.90113   51.8    1805.64      14672.19      5368.92      19160.62
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   182. .900  1.00    0.    0.   8500.  55.000    1976.   90.  1027.   44.       0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
85  182   0.00063699   0.00081297  0.225602   13    13   0.91697   54.0    1363.89      15442.07      5247.01      22122.42
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   208. .900  1.00    0.    0.   9000.  55.000    2002.   90.  1027.   44.       0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
86  208   0.00060941   0.00074187  0.228527   14    13   0.90290   56.3      93.31      15489.95      4486.17      24424.53
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   229. .900  1.00    0.    0.   9000.  55.000    2028.   90.  1027.   44.       0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
87  229   0.00061725   0.00069788  0.231467   13    14   0.90969   58.3    1118.44      16011.72      5606.01      27039.78
INPUT DATA
YRS  RATE      M   AVL  BETA   CO    YO    MTBR    1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   251. .900  1.00    0.    0.   9000.  55.000    2046.   90.  1027.   44.       0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR   M          FR          FRBAR      ASTAR     C     Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST       TRUE-PW
88  251   0.00062296   0.00067259  0.233612   15    14   0.90349   61.6     141.82      16071.86      4956.21      29141.70
```

Figure 4.--continued

```
                            SAMPLE RUN 3
                            OPTIONS : DYNAMIC, HEURISTIC OPT, TIME AVG, FLEET AVAIL
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100    10. .950  0.95     1.     1.    3500.  65.000     1880.    90.    617.    49.        0.   0.0    32.     123.    10.   82.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
79   10  0.00147186     0.00147186  0.214646       3       3  0.97552       5.4   3809.42         3809.42       2658.47        2658.47
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100    28. .950  0.95     0.     0.    3500.  62.500     1948.    90.    709.    49.        0.   0.0    32.     142.    10.   95.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
80   28  0.00152455     0.00150530  0.222330       7       4  0.95100      15.3   1806.43         5451.63       2265.27        4717.80
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100    50. .950  0.95     0.     0.    4250.  60.000     2122.    90.    815.    38.        0.   0.0    32.     163.    10.  109.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
81   50  0.00136767     0.00144682  0.242192       8       6  0.95878      26.2   2887.98         7838.38       3444.56        7564.55
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100    82. .950  0.95     0.     0.    5500.  57.500     1989.    90.    881.    40.        0.   0.0    32.     176.    10.  117.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
82   82  0.00099101     0.00120769  0.227106       9       6  0.95122      35.7    127.13         7933.90       2314.06        9303.14
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   121. .950  0.95     0.     0.    6500.  55.000     1959.    90.    951.    42.        0.   0.0    32.     190.    10.  127.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
83  121  0.00082569     0.00099505  0.223624      11       5  0.95826      43.2    239.69         8097.61       2549.37       11044.39
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   158. .950  0.95     0.     0.    7500.  55.000     1966.    90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
84  158  0.00071031     0.00086802  0.224471      12       5  0.95085      49.2    111.83         8167.05       3058.81       12943.67
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   182. .950  0.95     0.     0.    8500.  55.000     1976.    90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
85  182  0.00063699     0.00078614  0.225602      12       4  0.95978      51.1       0.0         8167.05       2710.40       14473.63
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   208. .950  0.95     0.     0.    9000.  55.000     2002.    90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
86  208  0.00060941     0.00071875  0.228527      12       4  0.96230      53.4       0.0         8167.05       3018.29       16022.49
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   229. .950  0.95     0.     0.    9000.  55.000     2028.    90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
87  229  0.00061725     0.00068003  0.231467      12       4  0.96320      55.7       0.0         8167.05       3116.25       17476.24
INPUT DATA
YRS  RATE      M   AVL  BETA    CO     YO     MTBR    1/MU         M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   251. .950  0.95     0.     0.    9000.  55.000     2046.    90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M           FR          FRBAR     ASTAR       C       Y    AVAIL      RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
88  251  0.00062296     0.00065985  0.233612      12       4  0.95248      59.1       0.0         8167.05       3268.58       18862.43
```

Figure 4.--continued

```
                    SAMPLE RUN 4
                    OPTIONS : DYNAMIC, HEURISTIC OPT, TIME AVG, SPARES AVAIL
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100    10.  .900   1.00   1.    1.    3500.   65.000    1880.   90.   617.   49.       0.   0.0   32.    123.   10.   82.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
79   10   0.00147186   0.00147186   0.214646    3      3   0.92299    5.4     3809.42      3809.42     2658.47        2658.47
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100    28.  .900   1.00   0.    0.    3500.   62.500    1948.   90.   709.   49.       0.   0.0   32.    142.   10.   95.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
80   28   0.00152455   0.00150530   0.222330    5      6   0.92353   15.3     4021.50      7465.33     3675.16        5999.52
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100    50.  .900   1.00   0.    0.    4250.   60.000    2122.   90.   815.   38.       0.   0.0   32.    163.   10.  109.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
81   50   0.00136767   0.00144684   0.242192    8      8   0.91601   26.4     3155.49     19073.17     3846.45        9178.41
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100    82.  .900   1.00   0.    0.    5500.   57.500    1989.   90.   881.   40.       0.   0.0   32.    176.   10.  117.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
82   82   0.00099101   0.00120761   0.227106    9     10   0.90741   36.1     2964.81     12300.68     4558.16       12603.02
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   121.  .900   1.00   0.    0.    6500.   55.000    1959.   90.   951.   42.       0.   0.0   32.    190.   10.  127.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
83  121   0.00082569   0.00099453   0.223624   11     11   0.91409   43.9     1690.80     13455.51     4478.69       15662.02
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   158.  .900   1.00   0.    0.    7500.   55.000    1966.   90.  1027.   44.       0.   0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
84  158   0.00071831   0.00086719   0.224471   12     12   0.90382   50.0     1581.98     14437.80     5077.92       18815.01
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   182.  .900   1.00   0.    0.    8500.   55.000    1976.   90.  1027.   44.       0.   0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
85  182   0.00063699   0.00078511   0.225602   12     13   0.91947   52.1     1363.89     15207.68     5219.46       21761.26
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   206.  .900   1.00   0.    0.    9000.   55.000    2002.   90.  1027.   44.       0.   0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
86  206   0.00060941   0.00071745   0.228527   13     13   0.91215   54.4       93.31     15255.56     4394.66       24016.42
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   229.  .900   1.00   0.    0.    9000.   55.000    2028.   90.  1027.   44.       0.   0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
87  229   0.00061725   0.00067874   0.231467   15     13   0.90351   56.7      165.29     15332.67     4604.54       26164.47
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU       H  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   251.  .900   1.00   0.    0.    9000.   55.000    2046.   90.  1027.   44.       0.   0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C      Y    AVAIL    RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
88  251   0.00062296   0.00065875   0.233612   14     14   0.90621   60.3      977.02     15747.02     5705.07       28583.98
```

Figure 4.--continued

```
                              SAMPLE RUN 5

                              OPTIONS : STATIC, HEURISTIC OPT, FLEET AVAIL
INPUT DATA
YRS  RATE     M   AVL  BETA   CO   YO    MTBR    1/MU       M  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP UCPSER  CIC
 20  .100  256. .950  0.95    8.  11.   9000.  55.000   2046.    90.  1027.   44.       0.  0.0    32.    205.    10.  137.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C     Y    AVAIL    RBAR      COST     PR-WORTH  TRUE-COST      TRUE-PW
79  256  0.00062296   0.00062296  0.233612   17     1  0.95056    56.5    624.83       624.83    3359.43      3359.43




                              SAMPLE RUN 6

                              OPTIONS : STATIC, HEURISTIC OPT, SPARES AVAIL
INPUT DATA
YRS  RATE     M   AVL  BETA   CO   YO    MTBR    1/MU       M  CPSER   CPSP   URC     CIPC  UTC  SVPSER  SVPSP UCPSER  CIC
 20  .100  256. .900  1.00    8.  11.   9000.  55.000   2046.    90.  1027.   44.       0.  0.0    32.    205.    10.  137.
OUTPUT DATA
YR   M         FR          FRBAR       ASTAR     C     Y    AVAIL    RBAR      COST     PR-WORTH  TRUE-COST      TRUE-PW
79  256  0.00062296   0.00062296  0.233612   13    14  0.91078    58.2   4019.74      4019.74    6835.13      6835.13
```

Figure 4.--continued

```
                              SAMPLE RUN 7
                              OPTIONS : DYNAMIC, HEURISTIC OPT, RATE AVG, FLEET AVAIL
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   10. .950  0.95    1.    1.    3500.  65.000   1880.    90.   400.    49.       0.  0.0     32.   123.    10.  82.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
79   10   0.00147186   0.00147186  0.214646     3     3   0.97552     5.4   3159.92         3159.92       2008.97        2008.97
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   28. .950  0.95    0.    0.    3500.  62.500   1948.    90.   709.    49.       0.  0.0     32.   142.    10.  95.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
80   28   0.00152455   0.00150573  0.222330     7     4   0.95095    15.3   1806.43         4802.13       2265.48        4068.49
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   50. .950  0.95    0.    0.    4250.  60.000   2122.    90.   815.    38.       0.  0.0     32.   163.    10. 109.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
81   50   0.00136767   0.00145073  0.242192     8     6   0.95815    26.3   2887.98         7188.88       3447.17        6917.39
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100   82. .950  0.95    0.    0.    5500.  57.500   1989.    90.   881.    40.       0.  0.0     32.   176.    10. 117.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
82   82   0.00099101   0.00124468  0.227106    10     6   0.95716    36.8    254.26         7379.92       2457.82        8763.99
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100  121. .950  0.95    0.    0.    6500.  55.000   1959.    90.   951.    42.       0.  0.0     32.   190.    10. 127.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
83  121   0.00082569   0.00103241  0.223624    10     6   0.95090    44.9      0.0          7379.92       2748.66       10641.36
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100  158. .950  0.95    0.    0.    7500.  55.000   1966.    90.  1027.    44.       0.  0.0     32.   205.    10. 137.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
84  158   0.00071831   0.00090005  0.224471    14     5   0.95176    51.0    447.32         7657.66       3221.22       12641.49
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100  182. .950  0.95    0.    0.    8500.  55.000   1976.    90.  1027.    44.       0.  0.0     32.   205.    10. 137.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
85  182   0.00063699   0.00081447  0.225602    13     4   0.95973    52.9      0.0          7657.66       2766.99       14203.38
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100  208. .950  0.95    0.    0.    9000.  55.000   2002.    90.  1027.    44.       0.  0.0     32.   205.    10. 137.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
86  208   0.00060941   0.00074372  0.220527    13     4   0.96488    55.2      0.0          7657.66       3108.07       15798.31
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100  229. .950  0.95    0.    0.    9000.  55.000   2028.    90.  1027.    44.       0.  0.0     32.   205.    10. 137.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
87  229   0.00061725   0.00069972  0.231467    13     3   0.95377    57.0      0.0          7657.66       2843.60       17124.88
INPUT DATA
YRS  RATE     M   AVL  BETA    CO    YO     MTBR    1/MU       M  CPSER   CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 10  .100  251. .950  0.95    0.    0.    9000.  55.000   2046.    90.  1027.    44.       0.  0.0     32.   205.    10. 137.
OUTPUT DATA
YR   M         FR          FRBAR      ASTAR     C     Y     AVAIL    RBAR      COST        PR-WORTH     TRUE-COST        TRUE-PW
88  251   0.00062296   0.00067426  0.233612    13     3   0.95079    60.2      0.0          7657.66       3189.34       18477.47
```

Figure 5.--Illustration of perturbation option.

```
                              SAMPLE RUN A
                              OPTIONS : DYNAMIC, PERTURB MODEL, RATE AVG, FLEET  AVAIL
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100    10. .950   0.95    3.    6.    3500.   65.000     1880.   90.    400.    49.        0.   0.0    32.     123.    10.   82.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
79   10   0.00147186   0.00147186   0.214646      3       6    0.99921     5.4     5884.08       5884.08      3456.41       3456.41
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100    28. .950   0.95    7.    6.    3500.   62.500     1948.   90.    709.    49.        0.   0.0    32.     142.    10.   95.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
80   28   0.00152455   0.00150573   0.222330      7       6    0.99308    15.4      559.11       6392.37      1750.23       5047.54
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100    50. .950   0.95    6.    6.    4250.   60.000     2122.   90.    815.    38.        0.   0.0    32.     163.    10.  109.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
81   50   0.00136767   0.00145077   0.242192      8       5    0.95815    26.3      133.76       6502.91      1816.59       6548.85
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100    82. .950   0.95   10.    6.    5500.   57.500     1989.   90.    881.    40.        0.   0.0    32.     176.    10.  117.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
82   82   0.00099101   0.00124469   0.227106     10       6    0.95716    36.8      254.26       6693.94      2457.83       8395.46
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   121. .950   0.95   10.    6.    6500.   55.000     1959.   90.    951.    42.        0.   0.0    32.     190.    10.  127.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
83  121   0.00082569   0.00103241   0.223624     10       6    0.95089    44.9        0.0        6693.94      2748.67      10272.83
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   150. .950   0.95   14.    5.    7500.   55.000     1966.   90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
84  150   0.00071831   0.00090005   0.224471     14       5    0.95176    51.0      447.32       6971.69      3221.23      12272.96
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   182. .950   0.95   13.    4.    8500.   55.000     1976.   90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
85  182   0.00063699   0.00081448   0.225602     13       4    0.95973    52.9        0.0        6971.69      2767.00      13834.86
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   208. .950   0.95   13.    4.    9000.   55.000     2002.   90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
86  208   0.00060941   0.00074372   0.228527     13       4    0.96488    55.2        0.0        6971.69      3108.07      15429.79
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   229. .950   0.95   13.    3.    9000.   55.000     2028.   90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
87  229   0.00061725   0.00069972   0.231467     13       3    0.95377    57.0        0.0        6971.69      2843.60      16756.35
INPUT DATA
YRS  RATE      M   AVL   BETA   CO    YO     MTBR     1/MU        M  CPSER    CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 10  .100   251. .950   0.95   13.    3.    9000.   55.000     2046.   90.   1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M         FR           FRBAR      ASTAR      C       Y     AVAIL     RBAR       COST        PR-WORTH    TRUE-COST       TRUE-PW
88  251   0.00062296   0.00067426   0.233612     13       3    0.95079    60.2        0.0        6971.69      3189.34      18108.94
```

Figure 5.--continued

Sample Run 7 except KTC is set to 2 and all CO,YO values *must be punched in* and would be equal to the C,Y values of Sample Run 7, except for changing the 1979 and 1980 YOs to 6.

Note that there is a large difference between the algorithm costs and the true costs. Much of this is due to $(\text{URC} + \text{UTC})\overline{R}$, and while $\overline{R}$ is affected by the choices of the decision variables C and Y, the effect on optimality is of a secondary nature since $\overline{R}$ changes only very slightly for vast differences in C and Y when all else is constant (compare, for example, Sample Runs 5 and 6 or years 1979 and 1980 in Sample Runs 7 and 8). While CIPC could have a sizable effect on optimal costs because it is directly related to attainable failure rates, this can be studied via a sensitivity type of analysis; that is, rerunning with a variety of CIPC programs and their associated failure rate schedules. In the Sample Runs 1 through 8, CIPC (as well as UTC) was set to zero. In Sample Run 9, shown in Figure 6, we do a five-year dynamic horizon with conditions the same as for Run 1, except that CIPC is set at 400, 500, 600, 200, 200 and UTC is set at 5, 5, 10, 10, 10, respectively over the five-year period. Although the algorithm solution came out the same as for Run 1, the algorithm costs differ somewhat from Run 1 due to a five-year rather than a ten-year anticipated horizon. The true cost and true present worth differ to account for the added CIPC and UTC costs.

10. Intermediate Output, Cost Functions, and the Heuristic Optimization Algorithm

Also provided (if so desired by setting KWRITE=1) as output are intermediate values of Y and C which "step up" from YO and CO, showing the operation of the algorithm at each iteration. Briefly, the heuristic algorithm works as follows.

For the dynamic mode, the true present worth of the sum of discounted yearly costs over a dynamic horizon of K years is given by

```
                         SAMPLE RUN 9

                         OPTIONS : DYNAMIC, HEURISTIC OPT, RATE AVG, FLEET AVAIL

INPUT DATA
YRS  RATE     M   AVL   BETA    CO    YO     MTBR    1/MU        H  CPSER    CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
  5  .100   10.  .950  0.95    1.    1.    3500.  65.000    1880.    90.    617.    49.     400.   5.0   32.    123.   10.   82.

OUTPUT DATA
YR   M           FR           FRBAR      ASTAR     C      Y    AVAIL     RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
79   10   0.00147186    0.00147186  0.214646     3      3   0.97552     5.4    2983.60       2983.60      3085.24      3085.24

INPUT DATA
YRS  RATE     M   AVL   BETA    CO    YO     MTBR    1/MU        H  CPSER    CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
  5  .100   28.  .950  0.95    0.    0.    3500.  62.500    1948.    90.    709.    49.     500.   5.0   32.    142.   10.   95.

OUTPUT DATA
YR   M           FR           FRBAR      ASTAR     C      Y    AVAIL     RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
80   28   0.00152455    0.00150573  0.222330     7      4   0.95095    15.3    1353.50       4214.06      2841.87      5668.76

INPUT DATA
YRS  RATE     M   AVL   BETA    CO    YO     MTBR    1/MU        H  CPSER    CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
  5  .100   50.  .950  0.95    0.    0.    4250.  60.000    2122.    90.    815.    38.     600.  10.0   32.    163.   10.  109.

OUTPUT DATA
YR   M           FR           FRBAR      ASTAR     C      Y    AVAIL     RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
81   50   0.00136767    0.00145073  0.242192     8      6   0.95815    26.3    2073.54       5927.73      4310.23      9230.93

INPUT DATA
YRS  RATE     M   AVL   BETA    CO    YO     MTBR    1/MU        H  CPSER    CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
  5  .100   82.  .950  0.95    0.    0.    5500.  57.500    1989.    90.    881.    40.     200.  10.0   32.    176.   10.  117.

OUTPUT DATA
YR   M           FR           FRBAR      ASTAR     C      Y    AVAIL     RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
82   82   0.00099101    0.00124468  0.227106    10      6   0.95716    36.8     165.29       6051.91      3026.18     11504.54

INPUT DATA
YRS  RATE     M   AVL   BETA    CO    YO     MTBR    1/MU        H  CPSER    CPSP    URC     CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
  5  .100  121.  .950  0.95    0.    0.    6500.  55.000    1959.    90.    951.    42.     200.  10.0   32.    190.   10.  127.

OUTPUT DATA
YR   M           FR           FRBAR      ASTAR     C      Y    AVAIL     RBAR      COST       PR-WORTH    TRUE-COST      TRUE-PW
83  121   0.00082569    0.00103241  0.223624    10      6   0.95030    44.9       0.0        6051.91      3398.15     13825.53
```

Figure 6.--Example showing component improvement and transportation costs.

$$
\begin{aligned}
\text{TRUE-PW} = \sum_{J=1}^{K}\left(\frac{1}{1+R}\right)^{J-1} \Big\{ & \text{CPSER}(J)\,[C(J)-C(J-1)]^{+} \\
& + \text{SVPSER}(J)\,[C(J)-C(J-1)]^{-} + \text{OCPSER}(J)\cdot C(J) \\
& + \text{CPSP}(J)\,[Y(J)-Y(J-1)]^{+} + \text{SVPSP}(J)\,[Y(J)-Y(J-1)]^{-} \\
& + \text{CIC}(J)\cdot Y(J) + \text{CIPC}(J) + [\text{URC}(J) + \text{UTC}(J)]\,\text{RBAR}(J) \Big\}\ , \qquad (5)
\end{aligned}
$$

where the symbols are as defined in Tables I and III, and the $[a-b]^{+}([a-b]^{-})$ indicates the maximum (minimum) of $(a-b,0)$.

Now the heuristic algorithm present worth is taken to be

$$
\text{PR-WORTH} = \sum_{J=1}^{K}\left(\frac{1}{1+R}\right)^{J-1}\Big\{C_1(J)\,[C(J)-C(J-1)]^{+} + C_2(J)\,[Y(J)-Y(J-1)]^{+}\Big\}\ , \qquad (6)
$$

where C_1 and C_2 are given by

$$
\begin{aligned}
C_1 &= \text{CPSER} + \text{OCPSER}\left[\frac{(1+R)\,[(1+R)^{K-i+1}-1]}{R(1+R)^{K-i+1}}\right] - \text{SVPSER}\left[\frac{1}{(1+R)^{K-i+1}}\right]\ , \\
C_2 &= \text{CPSP} + \text{CIC}\left[\frac{(1+R)\,[(1+R)^{K-i+1}-1]}{R(1+R)^{K-i+1}}\right] - \text{SVPSP}\left[\frac{1}{(1+R)^{K-i+1}}\right]\ .
\end{aligned}
\qquad (7)
$$

First, the C_1 and C_2 are computed, where C_1 is a function of the purchase cost, operating cost, and salvage value of a repair channel and C_2 is a function of the purchase cost, carrying cost, and salvage value of a spare as given by Equation (7) for the dynamic model. The first bracket term brings the annual costs, OCPSER and CIC, to a beginning of year i equivalent cost, while the second bracket term brings the salvage value to a beginning of year i equivalent term; that is, the bracket terms are the present worth factors for a beginning of year series payment and end of horizon payment, respectively. Note that the algorithm assumes that if a spare or repair channel is purchased in year i, the annual costs at year i values are incurred through the end of the horizon, even if removal occurs sooner.

The algorithm forms a ratio (call Δ) of C_1/C_2 or C_2/C_1, depending on the relative magnitudes in such a way that the ratio is ≥ 1. Then given a pair of values C,Y (to start year i, C_{i-1} and Y_{i-1} are used) the availability is computed. If it is below the desired level and if, for example, $\Delta = C_1/C_2$, then for an equal dollar expenditure Δ repair channels or one spare can be added. Availability is calculated for both cases (adding Δ repair channels or one spare) and the case yielding the higher availability becomes the new C,Y pair. The algorithm repeats until the desired availability is met. Upon exceeding the desired availability, a backoff procedure is utilized. If feasibility was reached by adding Δ channels, the algorithm first attempts to remove a spare and then channels are removed one at a time to see if a cheaper solution exists near the boundary. If feasibility was reached by adding a spare, again one-at-a-time removal of channels is tried. Had $\Delta = C_2/C_1$, the words channel and spare would be reversed in describing the algorithm.

When the initial values of C and Y for year i exceed the availability desired, the algorithm immediately goes into a backoff mode, trying to remove spares and channels one at a time, starting with the more expensive (larger C_i value) first.

The algorithm uses only C_1 and C_2. The other costs (URC, UTC, CIPC) are not used in the algorithm but are considered in the true cost calculations. The costs inside the braces in Equations (5) and (6) are what is given as TRUE-COST and COST, respectively, for each year in the output.

In the static mode the algorithm works in the same way, except the functions C_1 and C_2 are changed to reflect all costs as equivalent uniform series end of period expenditures over the system life. Thus, the purchase costs and salvage values are multiplied by sinking fund and capital recovery factors, and the yearly operating costs associated with spares and channels which are assumed beginning of period expenditures are multiplied by $(1+R)$. Hence,

$$\begin{aligned} C_1 &= \text{CPSER}\left[\frac{R(1+R)^K}{(1+R)^K - 1}\right] + \text{OCPSER}[1+R] - \text{SVPSER}\left[\frac{R}{(1+R)^K - 1}\right] \\ C_2 &= \text{CPSP}\left[\frac{R(1+R)^K}{(1+R)^K - 1}\right] + \text{CIC}[1+R] - \text{SVPSP}\left[\frac{R}{(1+R)^K - 1}\right]. \end{aligned} \tag{8}$$

The costs URC, UTC, and CIPC are also assumed year beginning costs and are multiplied by (1+R) to bring them to year-end expenditures, and are incorporated into the TRUE-COST calculation by adding $(\text{URC} + \text{UTC}) \cdot (1+R)\overline{R}$ and $\text{CIPC}\cdot(1+R)$ to $C_1 \times (C) + C_2 \times (Y)$. This is then the value which shows as both TRUE-COST and TRUE-PW on the output, TRUE-PW (as well as PR-WORTH, which equals COST) being redundant in the static mode.

A sample of intermediate output is shown in Figure 7 for the first year of Sample Run 1. Shown are the failure rate for year i (RLAM), average population failure rate for year i (AMTBR), average turn-around (repair) time (ST), availability for the particular combination of C and Y, average queue size at repair depot (LQ), and average number of units in repair (L).

11. Acknowledgment

The authors wish to thank Mr. Arturo Balana for his help in modifying the original SASPRO program that led to SASPRO II.

```
M=  10.0 C=  1.0 Y=  1.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.38615D 00 LQ= 0.1610D 01 L=  2.4129
M=  10.0 C=  8.0 Y=  1.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.76002D 00 LQ= 0.1538D-07 L=  0.9266
M=  10.0 C=  1.0 Y=  2.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.49112D 00 LQ= 0.2000D 01 L=  2.8293
M=  10.0 C= 15.0 Y=  1.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.76002D 00 LQ= 0.0         L=  0.9266
M=  10.0 C=  8.0 Y=  2.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.92963D 00 LQ= 0.5208D-07 L=  0.9484
M=  10.0 C= 15.0 Y=  2.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.92963D 00 LQ= 0.0         L=  0.9484
M=  10.0 C=  8.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98395D 00 LQ= 0.1332D-06 L=  0.9549
M=  10.0 C=  7.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98395D 00 LQ= 0.2655D-05 L=  0.9549
M=  10.0 C=  6.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98394D 00 LQ= 0.4001D-04 L=  0.9549
M=  10.0 C=  5.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98387D 00 LQ= 0.4669D-03 L=  0.9553
M=  10.0 C=  4.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98305D 00 LQ= 0.4328D-02 L=  0.9590
M=  10.0 C=  3.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.97552D 00 LQ= 0.3331D-01 L=  0.9868
M=  10.0 C=  2.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.93769D 00 LQ= 0.2403D 00 L=  1.1875
```

Figure 7.--Intermediate output, Sample Run 1, first year.

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