# SIMULATION: A CASE APPROACH

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## INTRODUCTION

Certain real-world situations can prove to be effective learning experiences. Indeed it is possible for more learning to take place as a consequence of this pedagogical style than from any other style.

In the last several years management science has moved toward an emphasis on application: How can this problem be modeled? How can this model be used in the decision process? What implementation problems might be encountered?

As a consequence of this shift in emphasis, many instructors have turned toward real-world problems in the form of projects or cases. These vehicles, they feel will not only make the course more relevant, but also raise some important issues and questions that might otherwise be left for "on the job training."

The purpose of this paper is to explore the use of the case method in capturing the real-world environment and in adding an applied flavor to the topic of simulation. In the paper the process of developing, writing, and presenting a case will be discussed, as well as the instructor's role in a case discussion. Finally, as an example, a case study and its analysis is included.

## CASES AND PROBLEMS

The difference between a textbook "problem" and a "case" is that a case often involves a description of a complex operational environment, a decision problem which may not be trivial to define, incomplete information, a certain degree of ambiguity, some structure, and the need to make a decision. Problems on the other hand are generally well structured and lead to one "right" answer.

## BENEFITS

Several benefits can be associated with the case method. First, those skills which have been acquired must be applied to an ambiguous situation. The intention is that this situation more closely parallels the real-world than does a simple textbook problem.

Second, the student often sees the case experience as a very relevant learning experience.

Third, the case experience frequently generates a high level of class interest.

## WHERE ARE THE CASES

Indeed a perusal of the ICCH (Intercollegiate Case Clearing House at Harvard) bibliography of cases suggests that countless cases have already been developed. But a closer examination reveals that a small percentage lend themselves to the use of quantitative techniques. Fewer yet lend themselves to the development of simulation models. In some situations a simulation model might be indicated, but the data are infrequently supplied.

Consequently if we find it advantageous to include simulation cases as part of a simulation or management science course, there are few from which to choose.

That good cases are still needed comes as no surprise. They are difficult to develop. They must be researched, written, tested in class, rewritten, tested again, and so on. And before a case can become an effective pedagogical vehicle many hours of development are required.

## SUGGESTIONS ON CASE DEVELOPMENT

Several suggestions, however, may make this process less difficult. The first is size. It is not necessarily true that "bigger is better." Short cases, especially at the introductory level, are often more desirable. In fact it may be even more effective to divide a longer case into several parts. The first part could include the basic information and data to develop a simple model. Subsequent parts could add layers of complexity to the basic system.

The second suggestion treads on a controversial area: should the case be based on a factual real-world situation, fiction, or some combination of both.

If a case is based on a real-world situation, there is always the temptation to "put as much into the case" as possible. Often this strategy boggs the case down with masses of irrelevant as well as near-relevant information. The sheer volume of the case may mask the very learning objectives it was designed to achieve.

A case based on fiction may, on the other hand, be too superficial. It may not be a convincing exercise in real-world application.

An interesting approach is to compromise. First a real-world situation is selected, studied and analyzed. Then the educational objectives of the case are developed and finally the case is written to include those aspects which will capture a reasonable representation of the real-world flavor. Compromises may be necessary in order to keep the case simple, on the track, and not too bogged down. In its final stage the case may be half fact and half fiction. But this compromise should only be made in the interest of meeting the educational objectives of the case and providing the student with a cohesive learning module from which generalizations can be drawn.

The third suggestion implies that a case is never completed...and indeed this may be true. Most cases should be revised over and over again. Since it is unusual for a case to have a "right" answer, it is very possible that new ways of thinking about the problem may surface during a classroom discussion. Often those new insights are worth incorporating into the case. As a result the case becomes stronger and stronger.

The final suggestion is to develop a teaching note for the case which might include the results of manual or computer simulations, GPSS programs, general case information and analysis, and finally any conclusions that might reasonably be drawn. Again this should be updated as more experience is gained in leading the case discussion.

## LEADING THE CASE DISCUSSION

In the beginning, leading a case discussion may be more difficult than lecturing on the same topic. The reason for this, perhaps, is that there is no predetermined schedule or structure to the class period. Discussion may shift direction several times before the case starts to take its final form. Familiarity with this process takes several class sessions after which most instructors become comfortable with the process.

The first impulse when leading the discussion is to treat it like a problem session. Avoid the impulse to structure the session completely. Guide the session but try not to lead it. The preferred pattern is to act as a catalyst during the student-centered development of the case.

In a student-centered discussion the instructor may start the session by calling on one person and asking that person to describe the background of the case. The next student may be asked to identify the key issues. From this point the case should carry itself.

After one person has suggested a method of analysis others can be asked to critique it. At this point the instructor has the option of supporting or rejecting the analysis. The trick is to keep the discussion on the right track without leading the discussion.

At the end of the discussion the instructor may volunteer an analysis.

## CASE STUDY/AN EXAMPLE

Somerville Fabrication Company

"Sorry," said the voice over the intercom system, "the overhead crane is backlogged with requests and will be unable to pick up your job for at least 15 minutes." Marie LeBlanc, a machinist for the Somerville Fabrication Company, lit up a cigarette and prepared for the long wait.

This condition was becoming more frequent lately. The shop was so busy that the crane was unable to keep pace with the demands for service.

## THE PROBLEM

Somerville Fabrication Company specializes in the machining of large castings which generally weigh from 100 pounds to several tons. It is therefore impossible for these jobs to be moved or positioned by hand. Instead an overhead mobile crane is used.

The crane runs on tracks and is positioned 100 feet above the shop floor. The operator sits inside the cab and receives instructions through a mobile radio which keeps him in contact with the central dispatcher on the shop floor. The dispatcher, on the other hand, receives requests for crane service from the 135 machinists who are scattered throughout the 40,000-square-foot shop floor. Unless the machinists receive prompt service from the crane, they are unable to perform any additional work on their current job or other jobs. An unavailable crane always means lost production time.

## THE ALTERNATIVES

The manager of the machine shop, Dan Gurney, has been concerned about these delays for several months and has collected some information from two sales representatives who specialize in materials handling equipment. The first recommended that the use of the present crane be discontinued and that it be replaced by a new one capable of performing the jobs 50 percent faster. The present crane is leased for $5000 per year; the faster one could be leased for $12,000 per year. The present crane has an annual operating cost including fuel, maintenance, and labor of $30,000. It is expected that the new crane would incur the same costs. The shop is on a two-shift schedule, each one 8 hours long, and the company is open 200 days per year.

The second sales representative recommended that a second crane identical to the present one be used. He felt that this would meet the needs of the shop more than adequately. The cost of leasing the second crane would be the same as the present one.

## PRIORITY CALLS

The demand for crane service is initiated when a machinist places a call to the dispatcher. The call is then put into one of two categories. The first is the routine category, and as calls arrive, they are scheduled on a first come, first served basis. The second is a priority category, consisting of all calls whose jobs are behind schedule. All priority jobs are taken ahead of routine jobs, but a job which is already being serviced cannot be interrupted for a priority job. The priority job, however, would be next.

## RELEVANT COST SAVINGS

Dan Gurney met with the accounting department for the purpose of determining the possible savings that could be accrued by the addition of crane capacity. Working together, they estimated that it cost the company $1 for every minute of waiting time on routine jobs and $2 for every minute on priority jobs.

## DISCUSSION OF PROBLEM

Dan Gurney was presenting this information to the vice president of finance, Betty Wilson. "Betty, it's very difficult to determine the total cost associated with either of these alternatives because there doesn't seem to be any pattern associated with calls for service. Sometimes calls arrive one right after the other and a large backlog occurs. Why, on Wednesday of last week one routine job had to wait 1 hour for the crane. On other occasions the crane is idle. I just can't seem to uncover any pattern."

Betty Wilson added, "It looks to me as if you already have enough crane capacity on the average, but I think this is one of those situations where the averages don't tell the whole story."

They were both silent for a moment, and then Betty Wilson continued, "Dan, I'll bet that our management science group can help us with some estimates. Why don't you familiarize them with this problem and ask them to report to us in 2 weeks with some preliminary comparisons?"

## DATA COLLECTION

The management science group decided that the easiest way to compare the costs of the various alternatives was to simulate the process. To do this, they needed some data.

The crane operators on both shifts were asked to record the time it took to service each call. Early during this data collection process it was determined that service times seemed to be independent of arrival rates, the time of day, or the shift. The results of 200 calls for service are given in Exhibit A.

In addition, the dispatcher was asked to record the time between calls. After careful analysis it was determined that the pattern was the same throughout the day and on each shift. It was also discovered that approximately 30 percent of all calls were in the priority category. There was no pattern to these priority calls; they seemed to occur on a random basis. The results of the 200 calls which the dispatcher recorded are given in Exhibit B.

With the data collected, the next step was to simulate each of the alternatives and determine the cost of each of them.

EXHIBIT A SERVICE TIMES

| Service times, minutes | Number of observations |
|---|---|
| 3 | 40 |
| 4 | 80 |
| 5 | 50 |
| 6 | 30 |
| | 200 |

Note: Service times include the length of time it takes for the crane to travel from one job to the next.

EXHIBIT B TIME BETWEEN ARRIVALS

| Time between arrivals, minutes | Number of observations |
|---|---|
| 2 | 4 |
| 3 | 20 |
| 4 | 100 |
| 5 | 40 |
| 6 | 20 |
| 7 | 10 |
| 8 | 6 |
| | 200 |

## QUESTIONS

1. Simulate the crane process for 1 hour, given the current situation of one crane. (Assume that the plant opens at 8 a.m.)
2. Simulate the crane process using an additional crane identical to the present one. Simulate the process for 1 hour. (Assume that the plant opens at 8 a.m.)

3. Simulate the crane process using a crane which is 50 percent faster - one that will do the job in two-thirds of the time presently required. Simulate the process for 1 hour. (Assume that the plant opens at 8 a.m.)
4. Compute the total yearly costs associated with each of these alternatives. What will be the saving associated with a faster crane? With an additional crane?
5. Suppose the volume of jobs which the shop must process will double in 5 years. Will any of these alternatives be capable of handling this new level of demand or will new strategies have to be considered?

## TEACHING NOTE

| Service Times | Probability | 2 Digit Numbers |
|---|---|---|
| 3 | .20 | 00-19 |
| 4 | .40 | 20-59 |
| 5 | .25 | 60-84 |
| 6 | .15 | 85-99 |
| | 1.00 | |

| Time Between Arrivals | Probability | 2 Digit Numbers |
|---|---|---|
| 2 | .02 | 00-01 |
| 3 | .10 | 02-11 |
| 4 | .50 | 12-61 |
| 5 | .20 | 62-81 |
| 6 | .10 | 82-91 |
| 7 | .05 | 92-96 |
| 8 | .03 | 97-99 |
| | 1.00 | |

Two digit numbers between 00 and 24 are used to identify a priority call.

SIMULATION OF PRESENT CRANE

| Random Number | Time Between Arrival of Calls | Clock Time at Arrival | Random Number | Priority Call | Random Number | Service Time | Service Begins | Service Ends | Waiting Time Priority | Waiting Time Routine |
|---|---|---|---|---|---|---|---|---|---|---|
| 98 | 8 | 8:08 | 11 | yes | 39 | 4 | 8:08 | 8:12 | 0 | 0 |
| 66 | 5 | 8:13 | 02 | yes | 42 | 4 | 8:13 | 8:17 | 0 | 0 |
| 77 | 5 | 8:18 | 36 | | 32 | 4 | 8:18 | 8:22 | 0 | 0 |
| 52 | 4 | 8:22 | 73 | | 05 | 3 | 8:22 | 8:25 | 0 | 0 |
| 40 | 4 | 8:26 | 66 | | 06 | 3 | 8:26 | 8:28 | 0 | 0 |
| 49 | 4 | 8:30 | 76 | | 51 | 4 | 8:30 | 8:34 | 0 | 0 |
| 39 | 4 | 8:34 | 42 | | 99 | 6 | 8:34 | 8:40 | 0 | 0 |
| 06 | 3 | 8:37 | 01 | yes | 49 | 4 | 8:40 | 8:44 | 3 | 0 |
| 21 | 4 | 8:41 | 36 | | 70 | 5 | 8:44 | 8:49 | 0 | 3 |
| 33 | 4 | 8:45 | 36 | | 10 | 3 | 8:49 | 8:52 | 0 | 4 |
| 71 | 5 | 8:50 | 07 | yes | 56 | 4 | 8:52 | 8:56 | 2 | 0 |
| 90 | 6 | 8:56 | 80 | | 76 | 5 | 8:56 | 9:01 | 0 | 0 |
| 83 | 6 | | 36 | | 66 | 5 | | | | |

SIMULATION OF TWO CRANES

| Random Number | Time Between Arrival of Calls | Clock Time at Arrival | Random Number | Priority Call | Random Number | Service Time | Crane 1 Service Begins | Crane 1 Service Ends | Crane 2 Service Begins | Crane 2 Service Ends | Priority Waiting Time | Routine Waiting Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 98 | 8 | 8:08 | 11 | yes | 39 | 4 | 8:08 | 8:12 | | | 0 | 0 |
| 66 | 5 | 8:13 | 02 | yes | 42 | 4 | 8:13 | 8:17 | | | 0 | 0 |
| 77 | 5 | 8:18 | 36 | | 32 | 4 | 8:18 | 8:22 | | | 0 | 0 |
| 52 | 4 | 8:22 | 73 | | 05 | 3 | 8:22 | 8:25 | | | 0 | 0 |
| 40 | 4 | 8:26 | 66 | | 06 | 3 | 8:26 | 8:28 | | | 0 | 0 |
| 49 | 4 | 8:30 | 76 | | 51 | 4 | 8:30 | 8:34 | | | 0 | 0 |
| 39 | 4 | 8:34 | 42 | | 99 | 6 | 8:34 | 8:40 | | | 0 | 0 |
| 06 | 3 | 8:37 | 01 | yes | 49 | 4 | | | 8:37 | 8:41 | 0 | 0 |
| 21 | 4 | 8:41 | 36 | | 70 | 5 | 8:41 | 8:46 | | | 0 | 0 |
| 33 | 4 | 8:45 | 36 | | 10 | 3 | | | 8:45 | 8:48 | 0 | 0 |
| 71 | 5 | 8:50 | 07 | yes | 56 | 4 | 8:50 | 8:54 | | | 0 | 0 |
| 90 | 6 | 8:56 | 80 | | 76 | 5 | 8:56 | 9:01 | | | 0 | 0 |
| 83 | 6 | | 36 | | 66 | 5 | | | | | 0 | 0 |

| Random Number | Time Between Arrival of Calls | Clock Time at Arrival | Random Number | Priority Call | Random Number | * Service Time | Service Begins | Service Ends | Waiting Time Priority | Waiting Time Routine |
|---|---|---|---|---|---|---|---|---|---|---|
| 98 | 8 | 8:08 | 11 | yes | 39 | 2.67 | 8:08 | 8:10.67 | | |
| 66 | 5 | 8:13 | 02 | yes | 42 | 2.67 | 8:13 | 8:15.67 | | |
| 77 | 5 | 8:18 | 36 | | 32 | 2.67 | 8:18 | 8:20.67 | | |
| 52 | 4 | 8:22 | 73 | | 05 | 2 | 8:22 | 8:24 | | |
| 40 | 4 | 8:26 | 66 | | 06 | 2 | 8:26 | 8:28 | | |
| 49 | 4 | 8:30 | 76 | | 51 | 2.67 | 8:30 | 8:32.67 | | |
| 39 | 4 | 8:34 | 42 | | 99 | 4 | 8:34 | 8:38 | | |
| 06 | 3 | 8:37 | 01 | yes | 49 | 2.67 | 8:38 | 8:40.67 | 1 | |
| 21 | 4 | 8:41 | 36 | | 70 | 3.33 | 8:41 | 8:44.33 | | |
| 33 | 4 | 8:45 | 36 | | 10 | 2 | 8:45 | 8:47 | | |
| 71 | 5 | 8:50 | 07 | yes | 56 | 2.67 | 8:50 | 8:52.67 | | |
| 90 | 6 | 8:56 | 80 | | 76 | 3.33 | 8:56 | 8:59.33 | | |
| 83 | 6 | | 36 | | 66 | 3.33 | | | | |

*Note: Since the faster crane completes the service in two-thirds of the original time, the figures in the service distribution must be multiplied by 2/3.

| | Service Time | Probability | 2 Digit Numbers |
|---|---|---|---|
| 2/3 (3) = | 2 | .20 | 00-19 |
| 2/3 (4) = | 2.67 | .40 | 20-59 |
| 2/3 (5) = | 3.33 | .25 | 60-84 |
| 2/3 (6) = | 4 | .15 | 85-99 |

Cost Comparisons

A) One Crane:

Yearly waiting cost

(5 X 2) + (7 X $1) X 8 hrs/day X 200 days/year

= $27,200

Maintenance & operating costs

= $30,000

Lease costs

= $5,000

TOTAL = $62,200

B) Two Cranes:

Waiting cost

= 0

Maintenance & operating costs

= $30,000 X 2 = $60,000

Lease costs

= $5,000 X 2 = $10,000

TOTAL = $70,000

C) Fast Crane:

Waiting costs

= (1 X $2) X 8 X 200

= $3,200

Maintenance and operating costs

= $30,000

Lease costs

= $12,000

TOTAL = $45,200

## GPSS MODEL

Simulation results can be obtained for this problem using relatively simple GPSS models. A basic single server queuing model (see model 1) is modified into seven variations. In all of them, the implicit time unit is one minute.

Model 2 involves only changing the SERV function. The "fifty percent faster" is interpreted to mean

$$\frac{\text{average service rate for slow crane}}{\text{average service rate for fast crane}} = \frac{100}{150} = 2/3.$$

To maintain the same implicit time unit under the integer restrictions of GPSS the distribution of service times for the faster crane was derived as follows:

| slow crane dist$^h$ | X 2/3 = fast crane dist$^h$ | fast crane integer dist$^h$ | prob. |
|---|---|---|---|
| 3 | 2 | 2 | .33 |
| 4 | 2 2/3 | 3 | .44 |
| 5 | 3 1/3 | | |
| 6 | 4 | 4 | .23 |

Two slow cranes were introduced into model 3 by changing the facility to a STORAGE with capacity 2.

To test the importance of priority in the models validity all three models were modified to include statistical TRANSFER and PRIORITY blocks. These are models 1P, 2P, and 3P.

All six models were run for one tenth of a year or 12,000 implicit time units.

The models and relevant output appear below.

Analysis of increment effects can be accomplished by calculating total waiting time. This equals the number of non-zero entries times the average waiting time for non-zero entries.

(Total entries − Zero entries) X $ Average time/tran

| | (1) | (2) | 3=(1-2) | (4) | (3 X 4) |
|---|---|---|---|---|---|
| Model | Total | Zero | Non-Zero | AVGtime | Total Time |
| 1 | 2647 | 600 | 2047 | 6.83 | 1398 |
| 2 | 2642 | 2535 | 107 | 1.09 | 117 |
| 3 | 2642 | 2641 | 1 | 1.00 | 1 |
| 1P | 2640 | 619 | 2021 | 5.58 | 11277 |
| 2P | 2659 | 2552 | 107 | 1.16 | 124 |
| 3P | 2659 | 2657 | 2 | 1.00 | 2 |

Inspection of total waiting time reveals the consideration of priorities is not necessary. The ratio of incremental improvement of an additional slow crane to that of replacement by one fast crane is $\frac{1398 - 11.7}{1398 - 1} \approx 1.$

The cheaper alternative, an additional slow crane, is preferrable.

The future growth will translate directly to a fifty percent increase in total waiting time even with two slow cranes (model 5).

```
GPSS ASSEMBLY    GPSS10 7(53) 16:44 24-SEP-78     PAGE 1
CRN1     GPS     24-SEP-78 16:29

                                  SIMULATE
                        *         MODEL 1   ONE SLOW CRANE WITH OUT PRIORITY
                        SERV1     FUNCTION RN1,D4
                        .2,3/.6,4/.85,5/1.,6
                        ARRV1     FUNCTION RN1,D7
                        .02,2/.12,3/.62,4/.82,5/.92,6/.97,7/1.,8
      1                           GENERATE FN$ARRV1
      2                           QUEUE     WAIT
      3                           SEIZE     CRANE
      4                           DEPART    WAIT
      5                           ADVANCE FN$SERV1
      6                           RELEASE CRANE
      7                           TERMINATE
                        *                   TIMER
      8                           GENERATE           12000
      9                           TERMINATE          1
                        *                   CONTROL
                                  START     1
                                  END
```

| QUEUE | MAXIMUM CONTENTS | AVERAGE CONTENTS | TOTAL ENTRIES | ZERO ENTRIES | PERCENT ZEROS | AVERAGE TIME/TRAN | $AVERAGE TIME/TRAN |
|---|---|---|---|---|---|---|---|
| WAIT | 6 | 1.16 | 2647 | 600 | 22.667 | 5.28 | 6.83 |

| FACILITY | AVERAGE UTILIZATION | NUMBER ENTRIES | AVERAGE TIME/TRANS | SEIZING TRANS. NO. | PREEMPTING TRANS. NO. |
|---|---|---|---|---|---|
| CRANE | 0.9567 | 2646 | 4.34 | 4 | 0 |

```
GPSS ASSEMBLY    GPSS10 7(53) 16:50 24-SEP-78     PAGE 1
CRN2     GPS     24-SEP-78 16:30

                                  SIMULATE
                        *         MODEL 2   ONE FAST CRANE WITH OUT PRIORITY
                        SERV2     FUNCTION RN1,D3
                        .33,2/.77,3/1.,4
                        ARRV1     FUNCTION RN1,D7
                        .02,2/.12,3/.62,4/.82,5/.92,6/.97,7/1.,8
      1                           GENERATE FN$ARRV1
      2                           QUEUE     WAIT
      3                           SEIZE     CRANE
      4                           DEPART    WAIT
      5                           ADVANCE FN$SERV2
      6                           RELEASE CRANE
      7                           TERMINATE
                        *                   TIMER
      8                           GENERATE           12000
      9                           TERMINATE          1
                        *                   CONTROL
                                  START     1
                                  END
```

| QUEUE | MAXIMUM CONTENTS | AVERAGE CONTENTS | TOTAL ENTRIES | ZERO ENTRIES | PERCENT ZEROS | AVERAGE TIME/TRAN | $AVERAGE TIME/TRAN |
|---|---|---|---|---|---|---|---|
| WAIT | 1 | 0.01 | 2642 | 2535 | 95.950 | 0.04 | 1.09 |

| FACILITY | AVERAGE UTILIZATION | NUMBER ENTRIES | AVERAGE TIME/TRANS | SEIZING TRANS. NO. | PREEMPTING TRANS. NO. |
|---|---|---|---|---|---|
| CRANE | 0.6358 | 2642 | 2.89 | 4 | 0 |

```
GPSS ASSEMBLY    GPSS10 7(53) 16:56 24-SEP-78     PAGE 1
CRN3      GPS    24-SEP-78 16:30

                         SIMULATE
                *        MODEL 3  TWO SLOW CRANES WITH OUT PRIORITY
                CRANE    STORAGE 2
                SERV1    FUNCTION RN1,D4
                .2,3/.6,4/.85,5/1.,6
                ARRV1    FUNCTION RN1,D7
                .02,2/.12,3/.62,4/.82,5/.92,6/.97,7/1.,8
         1               GENERATE FN$ARRV1
         2               QUEUE    WAIT
         3               ENTER    CRANE
         4               DEPART   WAIT
         5               ADVANCE  FN$SERV1
         6               LEAVE    CRANE
         7               TERMINATE
                *                 TIMER
         8               GENERATE           12000
         9               TERMINATE          1
                *                 CONTROL
                         START    1
                         END
```

| QUEUE | MAXIMUM CONTENTS | AVERAGE CONTENTS | TOTAL ENTRIES | ZERO ENTRIES | PERCENT ZEROS | AVERAGE TIME/TRAN | $AVERAGE TIME/TRAN |
|---|---|---|---|---|---|---|---|
| WAIT | 1 | 0.00 | 2642 | 2641 | 99.962 | 0.00 | 1.00 |

| STORAGE | CAPACITY | AVERAGE CONTENTS | AVERAGE UTILIZATION | TOTAL ENTRIES | AVERAGE TIME/TRANS |
|---|---|---|---|---|---|
| CRANE | 2 | 0.96 | 0.4785 | 2642 | 4.35 |

```
GPSS ASSEMBLY    GPSS10 7(53) 16:48 24-SEP-78     PAGE 1
CRN1P     GPS    24-SEP-78 16:29

                         SIMULATE
                *        MODEL 1  ONE SLOW CRANE WITH  PRIORITY
                SERV1    FUNCTION RN1,D4
                .2,3/.6,4/.85,5/1.,6
                ARRV1    FUNCTION RN1,D7
                .02,2/.12,3/.62,4/.82,5/.92,6/.97,7/1.,8
         1               GENERATE FN$ARRV1
         2               TRANSFER           .7,,PASS
         3               PRIORITY           2
         4      PASS     QUEUE    WAIT
         5               SEIZE    CRANE
         6               DEPART   WAIT
         7               ADVANCE  FN$SERV1
         8               RELEASE  CRANE
         9               TERMINATE
                *                 TIMER
        10               GENERATE           12000
        11               TERMINATE          1
                *                 CONTROL
                         START    1
                         END
```

| QUEUE | MAXIMUM CONTENTS | AVERAGE CONTENTS | TOTAL ENTRIES | ZERO ENTRIES | PERCENT ZEROS | AVERAGE TIME/TRAN | $AVERAGE TIME/TRAN |
|---|---|---|---|---|---|---|---|
| WAIT | 7 | 0.94 | 2640 | 619 | 23.447 | 4.27 | 5.58 |

| CILITY | AVERAGE UTILIZATION | NUMBER ENTRIES | AVERAGE TIME/TRANS | SEIZING TRANS. NO. | PREEMPTING TRANS. NO. |
|---|---|---|---|---|---|
| CRANE | 0.9546 | 2640 | 4.34 | 9 | 0 |

```
GPSS ASSEMBLY    GPSS10 7(53) 16:51 24-SEP-78     PAGE 1
CRN2P    GPS     24-SEP-78 16:30

                       SIMULATE
                *      MODEL 2P  ONE FAST CRANE WITH  PRIORITY
                SERV2  FUNCTION RN1,D3
                .33,2/.77,3/1.,4
                ARRV1  FUNCTION RN1,D7
                .02,2/.12,3/.62,4/.82,5/.92,6/.97,7/1.,8
    1                  GENERATE FN$ARRV1
    2                  TRANSFER          .7,,PASS
    3                  PRIORITY          2
    4           PASS   QUEUE    WAIT
    5                  SEIZE    CRANE
    6                  DEPART   WAIT
    7                  ADVANCE FN$SERV2
    8                  RELEASE CRANE
    9                  TERMINATE
                *               TIMER
   10                  GENERATE          12000
   11                  TERMINATE         1
                *               CONTROL
                       START    1
                       END
```

| QUEUE | MAXIMUM CONTENTS | AVERAGE CONTENTS | TOTAL ENTRIES | ZERO ENTRIES | PERCENT ZEROS | AVERAGE TIME/TRAN | $AVERAGE TIME/TRAN |
|---|---|---|---|---|---|---|---|
| WAIT | 1 | 0.01 | 2659 | 2552 | 95.976 | 0.05 | 1.16 |

| FACILITY | AVERAGE UTILIZATION | NUMBER ENTRIES | AVERAGE TIME/TRANS | SEIZING TRANS. NO. | PREEMPTING TRANS. NO. |
|---|---|---|---|---|---|
| CRANE | 0.6398 | 2659 | 2.89 | 1 | 0 |

```
GPSS ASSEMBLY    GPSS10 7(53) 16:59 24-SEP-78     PAGE 1
CRN3P    GPS     24-SEP-78 16:31

                       SIMULATE
                *      MODEL 3P  TWO SLOW CRANES WITH  PRIORITY
                CRANE  STORAGE 2
                SERV1  FUNCTION RN1,D4
                .2,3/.6,4/.85,5/1.,6
                ARRV1  FUNCTION RN1,D7
                .02,2/.12,3/.62,4/.82,5/.92,6/.97,7/1.,8
    1                  GENERATE FN$ARRV1
    2                  TRANSFER          .7,,PASS
    3                  PRIORITY          2
    4           PASS   QUEUE    WAIT
    5                  ENTER    CRANE
    6                  DEPART   WAIT
    7                  ADVANCE FN$SERV1
    8                  LEAVE    CRANE
    9                  TERMINATE
                *               TIMER
   10                  GENERATE          12000
   11                  TERMINATE         1
                *               CONTROL
                       START    1
                       END
```

| QUEUE | MAXIMUM CONTENTS | AVERAGE CONTENTS | TOTAL ENTRIES | ZERO ENTRIES | PERCENT ZEROS | AVERAGE TIME/TRAN | $AVERAGE TIME/TRAN |
|---|---|---|---|---|---|---|---|
| WAIT | 1 | 0.00 | 2659 | 2657 | 99.925 | 0.00 | 1.00 |

| STORAGE | CAPACITY | AVERAGE CONTENTS | AVERAGE UTILIZATION | TOTAL ENTRIES | AVERAGE TIME/TRANS |
|---|---|---|---|---|---|
| CRANE | 2 | 0.96 | 0.4795 | 2659 | 4.33 |