A UTILITY PROGRAM FOR SYSTEMATIC LAYOUT PLANNING

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Abstract

This paper presents the results of an attempt to develop a utility simulation program for studying the system characteristics of a loading terminal under various terminal configurations. The simulation program was written in the IBM 360/GPSS simulation language.

Introduction

The use of Monte Carlo simulation (via the computer) as a problem solving technique has been in existence for over a decade. During this time a variety of simulation languages have emerged to assist the user. These languages cover the complete spectrum, from the very general purpose languages to the very specific application oriented languages.

However, during this time very few application programs have been developed which could be classified as general purpose simulation programs. Instead, almost all application programs have been highly specialized to solve one specific problem. The underlying thought behind the development of these specialized programs has been that these programs are only going to be used once so why worry about making them general purpose.

Because of this lack of general purpose application programs, the authors, who were in the process of developing a truck loading simulation model, decided to attempt to make the program as general purpose as possible. The results of this effort to develop such a general purpose program, or commonly referred to as a utility program, are the context of this paper.

Description of the Physical System

The simulation program presented in this paper simulates the physical system depicted in Figure 1. The physical system consists of a loading terminal with multiple loading facilities. The problem is to study the system characteristics of the terminal as a function of the number of loading facilities. Some of the significant system characteristics under study are the utilization of the loading facilities; the associated delays and the amount of overtime, if any; the time the facilities are in use; and the time to load all vehicles which arrive in a day.

Empty vehicles arrive at the terminal for a load of goods. The arrival of the vehicles follows a Poisson distribution. The mean arrival rate of the vehicles is dependent on the time of day. Therefore, the day is divided into hourly increments, starting at 7 AM and ending at 4 PM. Each hourly increment has its own mean arrival rate.

All arriving vehicles form a single queue. The queue discipline is on a first-in first-out basis. Vehicles exiting from the queue enter the first available loading facility. The loading facilities are polled starting with facility one and then continuing with facility two, three, etc. Therefore, the lower numbered loading facilities should have higher utilizations.

The servicing of the vehicles (i.e., the loading) is dependent on the required load (i.e., the size of the load). The time to load a vehicle can be either normally or exponentially distributed as determined by the collected sample statistics.

The loading crews break for lunch from 11 AM to 12 AM. During this hour vehicles still arrive; however, the vehicles enter the queue and are serviced after the lunch break.

After the vehicles are serviced (i.e., loaded) the vehicles exit from the loading terminal. It may be possible that at 4 PM there are vehicles still waiting for service or being serviced. If vehicles are still in the system at 4 PM, the loading crews work overtime until all the vehicles have been loaded.

Desirable Characteristics of the Program

In an attempt to make the program a utility program, a list was prepared of the desirable characteristics that such a program should possess. These characteristics are:

1. A relative simple and easy method of data input.
2. A choice of several theoretical distributions for the service times.
3. A relative simple method of altering the number of facilities within the configuration.
4. The ability to change model logic during the simulation run.
5. The execution of multiple configurations within one computer run.

These desirable characteristics of a utility program were kept in mind during the development of the simulation program.

Model Description

In describing the simulation model the following areas will be discussed: model assumptions, programming language and computer requirements, unique features, model input, model output, and model execution. Each of these areas will be discussed in the following paragraphs.

Model Assumptions

The following assumptions have been made in the development of the vehicle loading simulation model:

1. The following time periods have been defined

   7AM - 8AM
   8AM - 9AM
   9AM - 10AM
   10AM - 11AM
   11AM - 12AM
   12AM - 1PM
   1PM - 2PM
   2PM - 3PM
   3PM - 4PM.

2. Any vehicles which have not been loaded by 4PM will be loaded before the loading crews are dismissed for the day.

3. A loading crew exists for each loading facility.

4. All arriving vehicles form a single queue. The polling sequence starts with facility one and then continues with facility two, three, etc., to a maximum of five facilities. If no empty facilities are found the polling sequence is repeated.

5. The time between arrival of vehicles within a given time period follows a negative exponential distribution.

6. The distribution of the size of the load can be divided into "size" classes such as

Class	Load (size) range	Frequency
1	1 - 2 units	f_1
2	2 - 3 units	f_2
3	3 - 4 units	f_3
4	4 - 5 units	f_4.

7. The time to load a vehicle is dependent on the load "size" and can follow a normal or an exponential distribution.

8. The maximum number of loading facilities is five. Each bay can load only one vehicle at a time.

9. The loading crews break for lunch between 11AM and 12AM. Vehicles still arrive during the break.

Programming Language and Computer Requirements

A generalized flow diagram of the simulation program is presented in Figure 2. The program is written in the IBM/GPSS (General Purpose Simulation System) language. The program consists of one MACRO, four FUNCTIONS, eighteen variables, and twelve TABLES. After the MACRO has been inserted into the appropriate logic, the length of the program approaches 250 blocks.

The program is setup to run in a 128K partition on the IBM 360 series computers. However, it should be possible to run the program in a 64K partition on the IBM 360 series computers. To do this would require the use of the GPSS REALLOCATE feature. Approximate compilation time on the IBM 360/65 is 13 seconds.

Unique Features of the Program

In developing this relative simple simulation program it became apparent that the MACRO feature of GPSS offered great potentials in making the program a utility program. Since the arrival patterns were variable and depended on the time of day, the majority of the program logic could be defined in a MACro. As a result, the "main-line" of the program appeared as shown below:

```
*
*        TIME PERIOD 8 AM TO 9 AM
*
         SPLIT      1,TIME9
 TRUCK   MACRO      X72,V22,2,EIGHT,BACK9,ARVL9
 TIME9   ADVANCE    60
*        TIME PERIOD 9 AM TO 10 AM
*
         SPLIT      1,TIM10
 TRUCK   MACRO      X73,V23,3,NINE,BACK2,ARVL2
 TIM10   ADVANCE    60
*
*        TIME PERIOD 10 AM TO 11 AM
*
         SPLIT      1,TIM11
 TRUCK   MACRO      X74,V24,4,TEN,BACK3,ARVL3
 TIM11   ADVANCE    60
```

Another unique feature is that all input to the program is through the use of the INITIAL and the FUNCTION cards. A brief description of the input procedures is presented in a later paragraph.

To assist in making the program a utility program, the logic included the feature of inputting via an INITIAL card the selection of either the normal or the exponential distribution for the service time.

Another unique feature of the program is the use of the redefinition feature of GPSS. This feature permitted the changing of selected logic blocks, after starting a number of transactions, without manually modifying the cards (i.e., blocks) and then reassemblying.

Model Input

In keeping with one of the previously defined desirable characteristics of a utility program, all input to the program is through the INITIAL and the FUNCTION cards.

It has been assumed that the mean arrival rate of the vehicles is dependent on the time of day. Therefore, the program has been divided into nine hourly increments starting at 7AM and ending at 4PM. Since the number of arrivals in an hourly increment follows a Poisson distribution, the time between arrivals follows a negative exponential distribution. The mean time between arrivals is equal to the reciprocal of the mean arrival rate. Therefore, the mean time between arrivals is inputted via the INITIAL cards. For the truck loading problem (see the sample problem in a later section), these INITIAL cards were defined as:

```
*
*     MEAN TIME BETWEEN TRUCKS ARRIVING
      BETWEEN TIME I AND TIME J
*
*     7AM - 8AM
      INITIAL     XH21,15
*     8AM - 9AM
      INITIAL     XH22,11
*     9AM - 10AM
      INITIAL     XH23,43
*     10AM - 11AM
      INITIAL     XH24,25
*     11AM - 12AM
      INITIAL     XH25,43
*     12AM - 1PM
      INITIAL     XH26,38
*     1PM - 2PM
      INITIAL     XH27,43
*     2PM - 3PM
      INITIAL     XH28,13
*     3PM - 4PM
      INITIAL     XH29,20
```

The size (i.e., load) of a vehicle's load is inputted via a discrete distribution. The size is divided into classes with the class number and the cumulative frequency inputted via a FUNCTION card. For example, in the truck loading problem the tonnage distribution was:

Class	Tonnage	Cumulative Frequency
1	1 - 2 tons	0.17
2	2 - 3 tons	0.41
3	3 - 4 tons	0.65
4	4 - 5 tons	0.74
5	5 - 6 tons	0.89
6	>6 tons	1.00

The discrete function was then inputted via the FUNCTION card as:

```
*
*
 3       FUNCTION     RN1,D6
0.17,1/0.41,2/0.65,3/0.74,4/0.89,5/1.0,6
*
*
```

The time to load a vehicle is dependent on the vehicle's load (see above). Therefore, each size class has its own loading time distribution. The loading time distributions for the sample problem are normally distributed. Therefore, SAVEVALUE XH1 was initialized to 1, signifying the use of the normal distribution. The corresponding means and standard deviations are then inputted via the INITIAL cards. For the sample problem the INITIAL cards were defined as:

```
*
*     MEAN TIME TO LOAD TRUCK WITH TONNAGE
      RANGE OF I TO J TONS
*
*     1 - 2 TONS
      INITIAL     XH31,24
*     2 - 3 TONS
      INITIAL     XH32,30
*     3 - 4 TONS
      INITIAL     XH33,28
*     4 - 5 TONS
      INITIAL     XH34,29
*     5 - 6 TONS
      INITIAL     XH35,48
*     GREATER 6 TONS
      INITIAL     XH36,60
```

```
*
*     STANDARD DEVIATIONS OF TIME TO LOAD
      TRUCK WITH TONNAGE RANGE OF I TO J TONS
*
*     1 - 2 TONS
      INITIAL     XH37,14
*     2 - 3 TONS
      INITIAL     XH38,20
*     3 - 4 TONS
      INITIAL     XH39,20
*     4 - 5 TONS
      INITIAL     XH40,16
*     5 - 6 TONS
      INITIAL     XH41,20
*     GREATER 6 TONS
      INITIAL     XH42,20
*
```

It should be noted that if the loading times were exponentially distributed, SAVEVALUE XH1 would have been initialized to zero. Then only the mean service times would be inputted via the INITIAL cards. The INITIALS for the standard deviations would be ignored.

Model Outputs

The output from the simulation program consists of the following:

1. Loading facility utilizations.
2. Queue statistics before the vehicles were serviced.
3. The distributions of times (1) between 7AM and 4PM and (2) after 4PM that the loading facilities were in use.
4. The distributions of (1) the length of time to load all vehicles and (2) the amount of overtime to load all vehicles which arrive during a day.

The use of these standard GPSS outputs is more fully illustrated in the truck loading problem presented in a later paragraph.

Model Execution

The program has been setup to simulate a nine hour day starting at 7AM and ending at 4PM. If vehicles are still in the system at 4PM, the program will continue execution until all the vehicles have been loaded. Multiple nine hour days are simulated by varying the argument of the START card. For example to simulate ten days the START card would be defined as:

```
START     10
```

It may be of interest to study the loading terminal's characteristics with fewer than five loading facilities. A feature of the program is that these changes may be made to the simulation program without directly changing the basic program. Instead, the program is indirectly changed by the use of the GPSS redefinition feature. These indirect changes can best be described by an example.

If in the truck loading problem it was of interest to study the terminal's characteristics under five, four, three, and two loading facilities, the following cards would be added to the simulation program:

```
        START      50
        RMULT      1,31
        CLEAR      XH21-XH42,XH1
CHG     TRANSFER   ALL,BAYN1,BAYN4,14
        START      50
        RMULT      1,31
        CLEAR      XH21-XH42,XH1
CHG     TRANSFER   ALL,BAYN1,BAYN3,14
        START      50
        RMULT      1,31
        CLEAR      XH21-XH42,XH1
CHG     TRANSFER   ALL,BAYN1,BAYN2,14
        START      50
```

The first START 50 card causes the program to simulate fifty days of operation with five loading bays. The RMULT 1,31 card resets the random number multipliers to 1 and 31. The CLEAR XH21-XH42,XH1 "zeroes-out" the output statistics; however, savevalues XH21-XH42 and XH1 are not reset to zero. These savevalues contain the mean time between arrivals and the means and standard deviations of the loading times. The TRANSFER block modifies the TRANSFER block which is labeled CHG in the simulation program. This modification to the TRANSFER block will cause the program to transfer only between loading facility one and facility four (block BAYN1 and block BAYN4). The START card will cause the program to simulate another fifty days.

To further reduce the number of loading facilities requires a similar sequence of cards. Note that the only difference in the subsequent sequences is the TRANSFER block where the argument BAYN4 is changed to BAYN3 and to BAYN2, thereby resulting in the simulation of only three and two loading facilities, respectively.

Truck Loading Simulation

The truck loading problem for which the simulation program was initially written consisted of studying the system characteristics of a loading terminal with four, three, and two loading facilities. The system corresponded to the previously defined assumptions, with the service times being normally distributed. The data input has been previously presented in the model input section.

Some of the data used in the analysis of the truck loading problem is presented in Figure 3 through Figure 7. Figure 3 presents the utilization of the loading bays for the three terminal configurations. Figure 4 gives an indication of the maximum queue size which developed during the simulation. Figure 5 presents the average delays for those trucks which had to wait.

Figures 6 and 7 were of primary interest since they presented an indication of the amount of overtime required to load the trucks and of the time the crews were idle.

Analysis

Considerable care was taken in setting up the simulation runs to insure the maximum validity of the data with the minimum sample size. Several problem areas which exist in most Monte Carlo simulations and which are often ignored are (1) when should measurements be collected from a simulation (i.e., when has equilibrium been approached), (2) what should be the initial starting conditions of the simulation, (3) what should be the stopping conditions of the simulation, and (4) what should be the sample size.

Equilibrium is a limiting condition which is approached but actually never attained. This means that there is no single point in the simulation beyond which the system is in equilibrium. The difference between the present distribution of the simulation and the limiting distribution decreases with time during the simulation. Therefore, the user tries to find that point beyond which he is willing to neglect the error that is made by considering the system in equilibrium. Since the assumption was made that all trucks would be loaded before the crews are dismissed for the day, the problem of determining when the system has reached equilibrium could be ignored.

The length of time required to obtain the state probability distribution which is independent of the starting conditions must certainly depend on the starting conditions of the system. One of the most common ways of starting a Monte Carlo simulation is in the empty and idle condition. That is, at the start of execution, all queues are empty and all facilities are idle. Therefore, it is obvious that if the model is started in a state other than zero, the time for the system to reach equilibrium should be reduced. Based on the previous assumption for the truck loading simulation, the starting conditions for each simulated day were "empty and idle." That is, all queues were empty and all loading facilities were idle at the start of each day.

A similar problem exists for stopping a simulation run as for determining equilibrium at the beginning of the run. Many times a simulation run is terminated by stopping the creation of new events for the system and by allowing the system to return to an empty and idle condition. By including the measurements collected from the time following termination of new events will likewise introduce a bias which can be serious, especially if the total run is not long. Based on the previous assumption, the stopping conditions for each simulated day were when all the trucks which arrived during the day had been loaded; therefore leaving the system empty and idle at the end of the day.

A problem which was considered is that of the variability associated with the measurements from the model. Fortunately, a large portion of the real world problems only require a comparison of alternatives. This is one of the real benefits of simulation. The simulation model can be used to produce relative results much more efficiently than absolute results. The relative approach was used in studying the various terminal configurations in this problem.

By reproducing the same sequence of random numbers for each alternative (i.e., terminal configuration), it is possible to reproduce the identical sequence of events. This increases the contrast between terminal configurations by reducing the residual variation in the differences in the total performance of the system; therefore, smaller samples are required to detect any statistically significant differences.

The procedure for comparing two alternatives is to pair the results regarding the performance of the system that were produced by the same events. Since these pairs of events are obtained under the same conditions, the differences between them become the relevant sample observations. This sample is used to test the hypothesis that the mean of these differences is zero and to obtain a confidence interval of the mean. This test indicates whether there is a significant difference between the means of the performance of the system for the two alternatives.

To make such a statistical comparison for this problem, the run, under each terminal configuration, was divided into five equal portions of ten days each. The GPSS logic was:

```
          START     10
          RESET
          START     10
          RESET
          START     10
          RESET
          START     10
          RESET
          START     10
          RMULT     1,31
          CLEAR     XH21-XH42,XH1
CHG       TRANSFER  ALL,BAYN1,BAYN3,14
          START     10
          RESET
          START     10
          RESET
          START     10
          RESET
          START     10
          RESET
          START     10
          RMULT     1,31
          CLEAR     XH21-XH42,XH1
CHG       TRANSFER  ALL,BAYN1,BAYN2,14
          START     10
          RESET
          START     10
          RESET
          START     10
          RESET
          START     10
          RESET
          START     10
```

The appropriate statistic was selected of the performance of the system. Therefore, from each alternative, five observations were collected: s_1, s_2, s_3, s_4, and s_5. By taking the difference for each of the five portions for two alternatives the average difference

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{5} (s_i \text{ alt1} - s_i \text{ alt2}),$$

and the sample standard deviation of the difference

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{5} \left[(s_i \text{ alt1} - s_i \text{ alt2}) - \bar{d}\right]^2}$$

were obtained, where the sample size is 5. Hence, the estimate of the standard deviation of the mean difference is $s/\sqrt{n}$. The corresponding t-statistic is $t = \bar{d}/(s/\sqrt{n})$. The value of the t-distribution with $\alpha = 0.05$ and $(n - 1) = 4$ degrees of freedom can be obtained from standard tables. If $t < t_{\alpha = 0.05}\,(n - 1 = 4)$, the hypothesis is accepted that there is no significant difference in the mean differences for the two alternatives. A similar test can then be made for comparing the remaining alternatives.

Conclusions

In conclusion, the simulation program for the systematic layout planning of a loading terminal works well as a utility program when the physical system under study has the following characteristics:

1. Arrival rates vary throughout the day.
2. Multiple service facilities exist.
3. Service times are dependent on the type of arrival (e.g., in the truck loading problem service time depended on the size of the load).
4. Poisson arrivals and normal or exponential service.
5. A lunch hour during which arrivals still occur.
6. No arrivals are left in the system at the end of the day. Arrivals are processed during overtime if necessary.

The utility program has been successfully used to simulate a truck loading terminal as indicated by the previous text. The program should be applicable to various types of similar shipping/receiving problems.

Also the program has value as a teaching aid to college students in teaching them (1) a simulation language, (2) the formulation of a simulation model, (3) efficient execution of the simulation, and (4) the required statistical analysis to verify the problem output.

References

1. General Purpose Simulation System (GPSS)/360 Users Manual, H20-0326-2, IBM, White Plains, N.Y., 1968.
2. General Purpose Simulation System (GPSS)/360 OS Operators Manual, H20-0311-1, IBM, White Plains, N.Y., 1967.

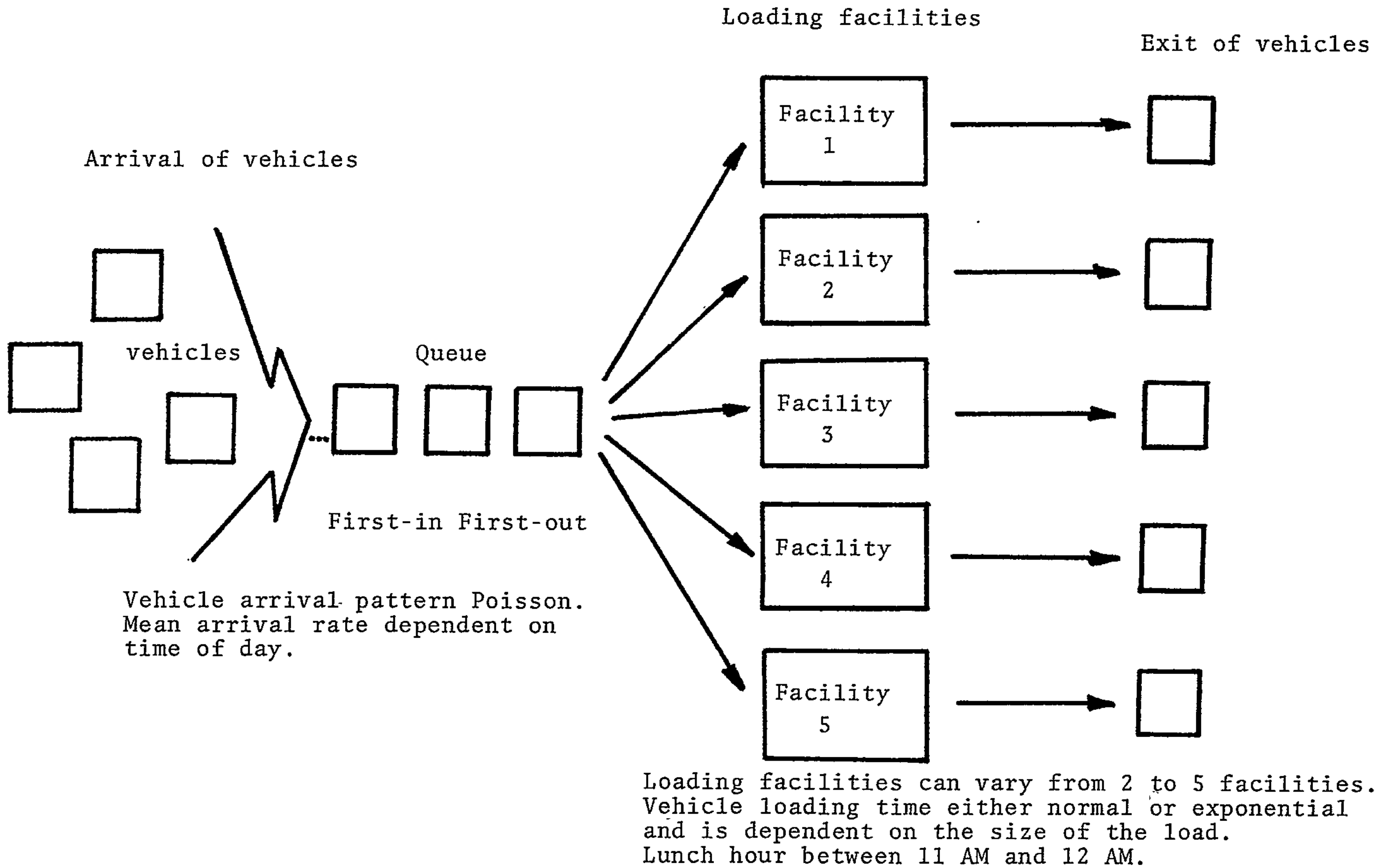

Figure 1. Vehicle Loading Terminal Configuration

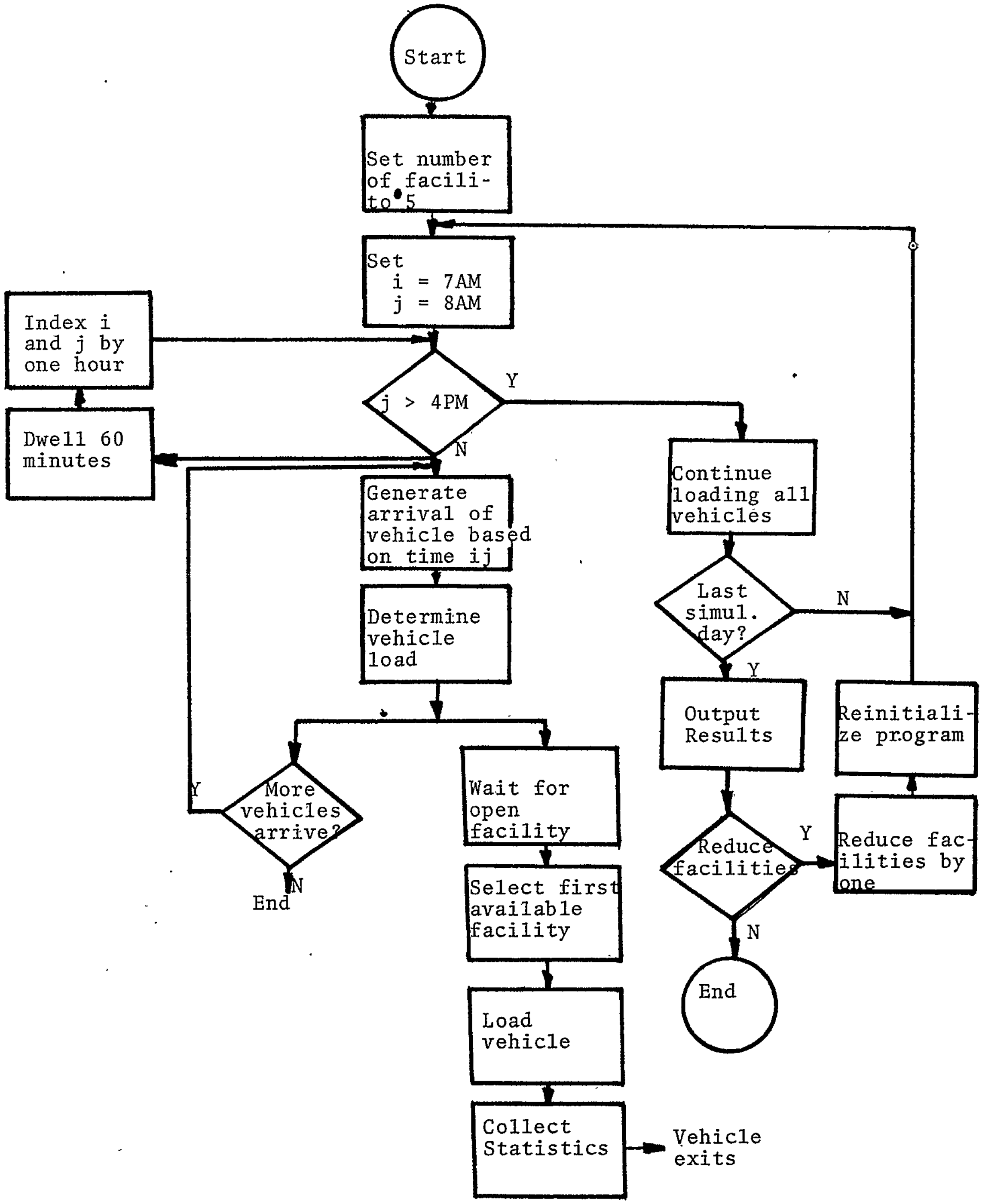

Figure 2. Generalized Program Logic

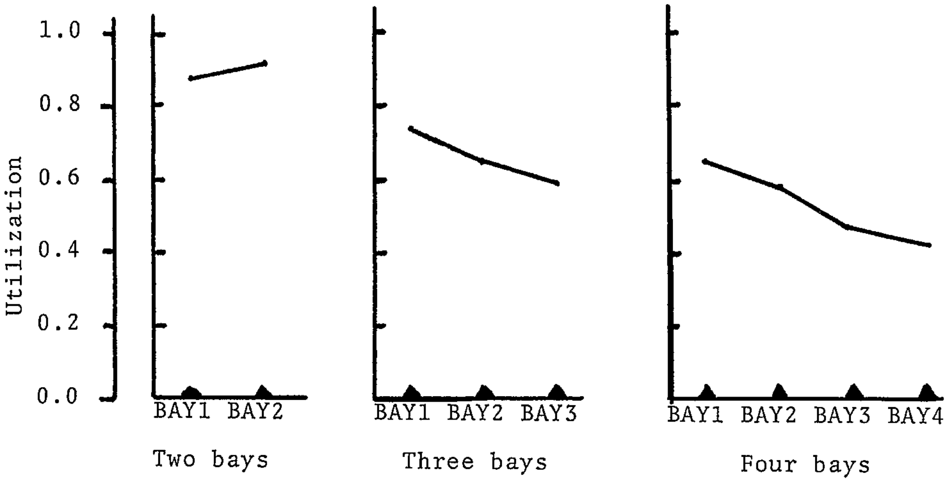

Figure 3. Loading Bay Utilizations

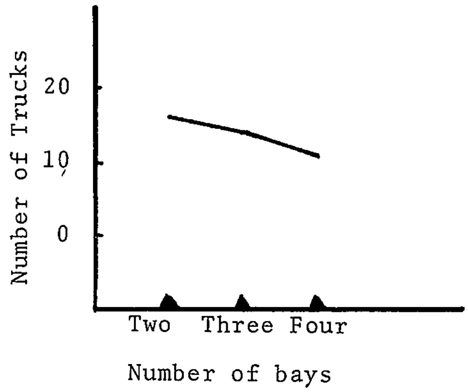

Figure 4. Maximum Queue Contents

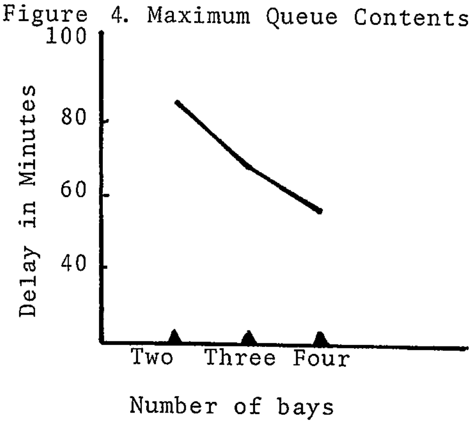

Figure 5. Average Delay for Those Trucks Which Had To Wait

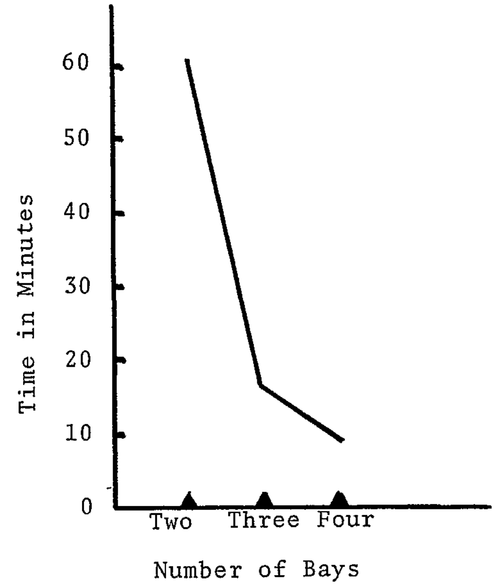

Figure 6. Average Time Required After 4PM to Load Those Trucks Still Waiting

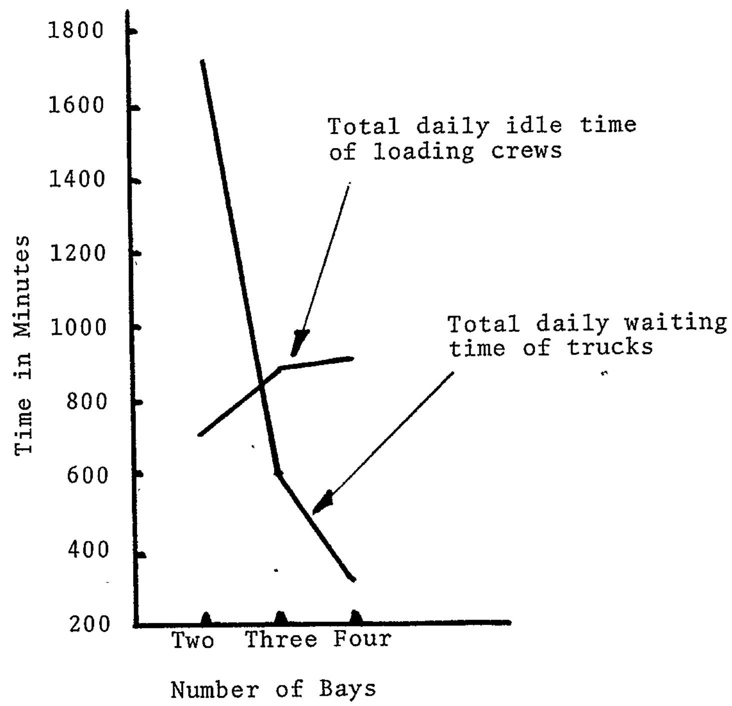

Figure 7. Total Daily Waiting Time of Trucks vs Total Daily Idle Time of Loading Crews