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Northwestern University

THE EFFECTS OF SHORTER, MORE FREQUENT TRAINS ON RAILROAD CLASSIFICATION YARDS: A COMPUTER SIMULATION

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ABSTRACT

The question as to whether to operate shorter, more frequent trains between nodal points in a railroad network is of increasing interest to the railroad industry today. The additional operating expense might be justified by improved freight car utilization alone. In addition, given the existence of the technology to automate road train operation and the evidence of a relaxing work rules climate, management may soon be able to substantially reduce operating costs on a per-train operated basis, thereby making the short train concept even more attractive.

Therefore, it is timely to consider the effects of the shorter train idea on the nodes of the network; specifically, the effects on classification yards. A digital computer simulation model is suggested. The development of a general model, applicable to all yards, is described. The model considers road trains from arrival through the switching process. These trains compete with other traffic for the processing facilities. The general model can be applied to any yard by specifying the proper physical and traffic characteristics. For a specific yard, delay times to traffic are compared when road trains are input to the model with various frequencies and train lengths while total traffic is held constant.

INTRODUCTION

The Network Concept of Railroads

A railroad system can generally be thought of in terms of a spatial network, whether it is viewed at a national, regional or corporate level. Traffic may enter a network at various points and progress to its destination by traveling over the links and through the nodes of the network. In general, then, railroad traffic movements can be categorized in two ways: 1) inter-nodal; 2) intra-nodal. Obviously, the former consists of movements over the links of the network. Such movements occur in discrete units commonly called road trains. Intra-nodal activities basically consist of a sorting process known as switching which results in traffic exiting from the node over the proper link toward its destination. Other activities exist, but they are of a peripheral or supporting nature. Switching occurs on a interest to railroad management in terms of today's environment. First, the railroads no longer enjoy the virtual monopoly on freight transportation that once existed. In order to compete with other modes, customer-oriented service policies have become a necessity. As a result, a number of technological and procedural innovations have been implemented over the last decade, e.g., specialized high-capacity cars, high speed schedules, new rate-making concepts. Frequency of service may be another means of attracting traffic which now uses a competing mode (19). It is clear that more frequent service over the links of a network implies a shorter average transit time between any two points, other things being equal and providing that the capacity of any portion of the network is not a constraining factor. Not only may additional traffic be attracted, but utilization of the freight car fleet would improve. Car utilization is of considerable importance; in 1963 the average freight car was in motion only 10% of the time (24). Koomanoff and Pritsker (12) point out that in 1958 at any moment 550,000 freight cars representing an investment of $5.5 billion by United States railroads were not under load and were unavailable for loading by reason of not being at points of demand. Empty car movements are extensive; in 1962 38.8% of total car-miles resulted from empty movements (21). Furthermore, because of competition, the trend in recent years has been toward more expensive, highly specialized cars:

"...today...we are not talking about cars that can be purchased for $5,000 or $6,000 but cars that are ranging in price from $15,000 to $35,000." (2)

Therefore, even a small reduction in transit time from origin to destination may improve utilization enough to justify the added expense of more frequent service.

This added expense may be reduced substantially in the next decade as the opportunity for automating inter-nodal train movements becomes a real possibility. The technology for automation now exists; a number of such systems have been developed (17) (18). The major obstacle is in the form of union work rules. However, this constraint shows signs of weakening in view of the 1964 agreement to reduce train crews from five to four men (7). In some cases, state laws which regulate minimum crew size would have to be changed (6) (22).

In summary, then, greater frequency of service means additional operating expense. This expense has to be compared to the additional traffic attracted and improvements in freight car utilization. When automation finally occurs, per-train operating expense would be reduced, thereby making the short frequent train idea even more attractive.

Study Organization

This study examines some of the effects of shorter, more frequent road trains on classification yards through a digital computer simulation model. The IBM General Purpose Systems Simulator II (8) for the IBM

7090 computer system was used. The study itself can be broken down into three phases:

1. Development of a general model.
2. Adapting the general model to a specific yard.
3. Studying the effects of more frequent trains on the specific model.

In the first phase a general model was built in order to get some feeling for the level of detail needed and the demands that would be placed on the input data. Various assumptions as to the nature of certain phenomena had to be made. The second phase consisted of collecting the necessary information and interpreting it in a manner that would allow the general model to validly represent a specific yard. In the final phase computer runs of the model were made in order to compare the effects of shorter and more frequent trains against normal operating policy.

The paper is divided into five main sections. First, a brief literature survey is presented in order to review some of the previous work on railroad phenomena. Articles were selected for mention on the basis of general importance and pertinence to this study. Some discussion on the advantages of the simulation technique is included. The second section describes the development of a general model on the basic classification yard activities. The General Purpose Systems Simulator II is described, followed by a statement of output requirements, important assumptions, interesting features of the model and the data requirements. In the third section the general model is applied to a specific yard, data collection procedure, data weaknesses, additional assumptions and comments on model validity are presented. The fourth section gives the results of testing certain combinations of train size and frequency and the conclusions drawn. Areas for future investigation are discussed in the fifth section. Finally, the appendix contains supplementary material, including a block diagram of the simulation model, a listing of the General Purpose Systems Simulator II program, a sample of the computer output and a sample data record.

LITERATURE SURVEY

Classification Yard Phenomena

With the exception of a few papers presented at the Symposium on the Application of Cybernetics in the Railways in Paris in 1963 (5), the literature on railroad classification yard phenomena is quite scanty. The only published simulation study is a 1955 effort by Crane, Brown and Blanchard (4). They describe a manual simulation which involved generating random arrivals, random train lengths, and random service times by sampling empirically determined probability distributions. Two processes (inspection and switching) actually done in series were simulated in parallel with a resulting decrease in average delay time to traffic from 337 min. (empirical) to 243 min. (simulated) for an estimated savings of $100,000 annually. Also, queue lengths formed by arriving trains were examined under varying assumptions of the randomness of the distributions of input and service times.

No other published results of yard simulations appear to exist. However, the Battelle Memorial Institute is nearing completion of an industry-funded project to provide a set of four general simulation models for digital computers which could be applied to specific situations by the user (11). One of the models is a classification yard simulator. Koomanoff, et. al., (13) report the findings of a Battelle pilot study which established the applicability of a total system approach to the railroad industry. This study was a forerunner of the three-year program at Battelle which is providing the industry with the set of simulation models mentioned. Koomanoff (10) and Koomanoff and Pritsker (12) have two other papers which emerged from the pilot project. Both are very general in nature with the emphasis on describing the advantages of a total systems approach. Simulation is offered as a logical tool for studies of complex systems. Freight car utilization is suggested as an area where systems simulation could achieve large benefits.

Among the assortment of papers presented at the Symposium of the Application of Cybernetics in the Railways in 1963, was a manual simulation by E. de Cock (3) of the Netherlands Railway which looks into the cost of supplying a given level of service for a particular type of traffic over a given route. Output would give schedule-makers some idea of what switching should be done at each yard to minimize operating costs within the existing time and capacity constraints.

In terms of non-simulation models, Koutoukova and Markov (14) of the USSR Institute of Rail Transport Scientific Research also investigate the problem of how to allocate switching work among the yards in a railroad network so as to improve car utilization. The simpler problem of a direct route with several intermediate yards is investigated. A mathematical expression is presented but no general solution has been found. Various methods of successive approximations are discussed. Some comments are made on usefulness of a digital computer in applying these methods.

Wynne (25) describes the development of a mathematical model for predicting the number of switch engines and crews required for a specific yard based on the amount and type of work to be done and the physical layout of the yard. Mansfield and Wein (15) relate a simular study. Linear decision rules are developed for use by yard supervisors in estimating the number of crews and switch engines needed to handle the next day's work. Comparisons are made between theoretical predictions, the supervisor's "educated guess" and actual work load experienced.

Suitability of the Simulation Technique

No general analytic models of classification yards appear in the literature. One might infer that difficulties exist in mathematical formulations of the phenomena involved. In the study described by Wynne (25), it is stated that:

> "It was shocking in the early days of the research effort to discover that an adequate description of the traffic had to contemplate so many variables. There was no precedent in the literature of Operations Research."

Koomanoff and Pritsker (12) concur:

> "The railroad industry is one of the largest and most complex of existing systems....Each year the over-all railroad system becomes more complex."

More specifically, in the manual simulation study reported by Crane, Brown and Blanchard (4) it was found that:

> "The statistics of train arrivals and the statistics of train processing could not be approximated by any simple analytical form. Consequently it was necessary in the analysis to apply numerical methods."

Morgenthaler (16) gives a number of reasons why simulation might be chosen as a tool in a particular case. Directly applicable would be the inability to construct an analytic model. Furthermore, simulation might contribute something:

> "Simulation of a complex system may provide an indication of which variables are important and how they relate. This may lead to later successful analytic formulations."

Also, a simulation model requires the analyst to explicitly define the logical structure of the system. The advantages are related by Morgenthaler (16):

> "It makes necessary a broad education in the process or operation being simulated...analysts are forced into an appreciation and understanding of all facets of the system with the result that final conclusions are less apt...to be unworkable within the system framework."

Koomanoff and Pritsker (12) stress that a simulation model in effect establishes an experimental laboratory featured by the ability to control time. The model can then be manipulated at will and the effects of changes studied while the real system is undisturbed. Koomanoff, _et. al._, (13) agree that it would be far too costly and time-consuming to interrupt the daily operating of a railroad system for real-life experimentation.

Finally, a simulation model is generally far more convincing in conveying to management the essence and implications of proposed policy changes than an analytic model (16). The simulation model is at least one degree of abstraction closer to reality.

DEVELOPING THE GENERAL MODEL

Classification Yard Activities

In order to obtain a useful model the relevant activities must be identified. As was mentioned in the introduction, the basic function of the nodes of a railroad network is to process arriving traffic in such a manner that it leaves the node on the proper link. This requires switching, a physical process conducted by specialized locomotives known as switch engines. Generally, the end result of switching is that traffic is sorted into groups homogeneous with respect to destination. These groups are known as blocks. Outbound trains are then made up of one or more blocks with destinations along the same link of the network.

It is necessary to add another degree of detail to the discussion. Classification yards can be categorized into two basic types: hump yards and flat yards. The former type is common in modern, high volume installations. Switching is accomplished with a switch engine slowly pushing a string of cars over an actual hill or hump in the yard. At the crest of the hump, cars are uncoupled and allowed to roll freely downgrade singly or in small groups. In most cases, the cars travel through a complex of semi-automatic or computer-controlled switches and speed control devices (retarders) which guide the cars to the proper track at a safe speed. A single-track hump may sort cars into as many as thirty tracks with processing capacities as great as 3000 cars per day.

Flat yards are usually found in older and/or low volume locations. Generally, switch engines take short groups of cars and switch them by accelerating rapidly and then slowing down while the cars are uncoupled and allowed to roll free to the proper track. The impetus is provided by the "kick" of the switch engine instead of the force of gravity. Processing rates are slower and switches are controlled manually, but the capital investment and maintenance costs are lower than in a hump yard.

Whichever style of yard exists, the switching technique depends on the ability of the individual freight car to roll freely. Because of the air brake system employed on freight cars, brakes are locked on when cars are uncoupled. Thus it is impossible to switch cars with an operative brake system. To overcome this, all freight cars awaiting switching undergo a process known as bleeding. Physically this is done when the train arrives in the yard by a man walking along the cars, pausing at each car to pull a lever which "bleeds" the air pressure from the brake system, rendering the brake system inoperative.

Furthermore, it is normal practice to subject each car to a mechanical inspection. Any defects are noted and when the car is switched it is routed to the repair [illegible], instead of a destination track. In some yards the inspection is conducted in parallel with the bleeding process. However, it is usually more feasible to conduct the inspection in parallel with the switching process. In hump yards inspectors are often stationed in enclosed under-track pits on the hump approach so that defects can be noted as cars are pushed toward the crest. This method contributes zero delay time to traffic, i.e., the inspection process is faster than the switching process.

Another event which must be mentioned is the physical location of a train that has arrived and is awaiting processing. In some yards track space is a very real constraint and in peak periods trains may be queuing up for entry to the yard. Track assignments must be made on the basis of the size of the train as compared to the capacities of the various tracks available in the receiving area. If no one track can accomodate the train, the traffic is split to two tracks or held out of the yard until space is available.

At the level of detail described, classification yard activities experienced by incoming road trains can simply be represented as a series of successive events with respect to time. These events can be summarized as follows:

1. Arrival of the train
2. Search for track space
3. Enter queue for bleeding process
4. Bleeding process

5. Enter queue for switching process
6. Switching process
7. Enter queue for assembly into outbound train
8. Assembly process
9. Train leaves

This is the level of detail employed in the model. The assumption is made that operating rules can be given for each of these events; this would satisfy the feasibility of simulation condition proposed by Johnson, Conway and Maxwell (9):

> "...a system, however complex, can be simulated if it can be broken down into a set of elements for which operating rules can be given."

The great majority of traffic undergoes the above sequence of events at most yards. The basic processes represented are typical of all yards. Of course, some traffic arrives in specialized trains, _e.g._, all piggy--back trains, single-destination trains. Such traffic may be handled separately with little or no switching done. These activities will be considered secondary in importance and will not be included in the model. In addition, the typical supporting functions such as car and locomotive maintenance facilities, piggy-back loading areas, and switching of local pick-up and delivery traffic will be assumed to have negligible effect on the basic activities.

The General Purpose Systems Simulator

The model was developed using the IBM General

Purpose Systems Simulator II (GPSS) computer language (8). The language is designed for use on the IBM 7090 under the IBSYS/FORTRAN systems.

GPSS is especially suited for studying large systems in that the user need only describe the system in block diagram form. Given the block diagram, the GPSS program can be written directly. The appendix contains the specific block diagram and a listing of the GPSS program used in this study.

GPSS is applicable where the various portions of the system can be characterized by the flow of some discrete entities (traffic). In essence, a GPSS model contains a clock which creates units of traffic and progresses them through the system. It is then possible to observe the flow of traffic and the results of the competition among traffic units for the various processing facilities of the system. The entire logical structure of the system is displayed by the block diagram format of the program. Interdependence of various system variables and complex logical decisions can also be included to control traffic flow. Importance of particular units of traffic can be modelled through assignment of priorities. Statistical distributions can be employed to govern the entrance and progress of traffic through the system. Any stochastic properties of system variables can be included by using random numbers as the independent variables of statistical distributions. An important feature is that the system configuration can be changed easily and the simulation repeated.

GPSS model outputs normally can include the following information:

1. Traffic volumes throughout the system.
2. Statistical distributions of elapsed travel times for traffic between points in the system.
3. Average utilization of storage and processing facilities.
4. Distribution of queue lengths.
5. Values of any system variables sampled at particular instants in time.

The appendix includes a sample of typical output from a computer run.

Error analysis of block diagram logic is performed by the program during the run. Upon detection of an error, execution is terminated and appropriate diagnostic error condition comments are printed.

Size limitations for a standard GPSS program include an upper limit of 800 blocks for the block diagram and 1000 traffic units in the system at any one time. No more than 4,500 words of core storage may be used by the block diagram.

Output Requirements

A basic measurement of classification yard performance is the average delay time to traffic, that is, the total elapsed time from arrival to departure. Excessive delay time causes poor freight car utilization and, of course, can cause a loss of business. In this study, average delay time to traffic was considered as the primary measure. The GPSS program was organized so that a distribution of transit times was collected at each stage of the basic event sequence. This allowed checks of model validity by comparing empirical elapsed times to simulated elapsed times. In addition, routines were written to record the actual clock times each train passed through the particular events in the model. Statistics for queues were maintained before each basic process.

Additional Notes

Perhaps most important was the decision to omit from the model events seven through nine of the basic event sequence. Upon completion of the switching process, traffic exits from the model. This simplification was felt justified since the activities omitted appear to be highly situation-bounded. The particular schedules and operating policies being employed determine when particular blocks of cars are assembled. The assembly process normally takes place as close to the departure time of the outbound train as possible so that all traffic which has been switched up to that time can be included. Typically, for each outbound train there exists a "cut-off time" which designates the time of day the assembly process will begin. Including the assembly process in the model would require distributions of traffic by block and programming a separate decision rule for each outbound train, thus adding considerably to the complexity of the model. By omitting these events the model then shows when traffic is available for assembly and outbound movement. Any time that elapses after the switching process and before the assembly process is essentially under management control. Thus, benefits of including this phenomenon in the model are doubtful.

Another assumption involved the cyclical properties of railroad traffic volumes. Daily, weekly, monthly, and seasonal cycles affecting the level and nature of traffic are known to exist. It was assumed that the daily repetitiveness of traffic phenomena was the important cyclical characteristic of yard operations. The model was designed so that a single run could easily cover several daily cycles without excessive use of computer time. The statistical distributions used for the various model inputs were then based on a daily cycle.

Features of the Model

By basing the model inputs on a daily cycle some interesting programming features were possible. All arriving trains are input to the model through "batch generator" routines which create a number of trains at the beginning of the daily cycle and then distribute their arrival times throughout the cycle by random sampling of the appropriate empirical distribution. The number of trains created is the average number of trains per day from the empirical data. Similarly, certain types of traffic may have train sizes which appear to vary with the time of day. Also, delays to the switching process resulting from switch engines being used for miscellaneous work elsewhere in the yard are distributed according to the hour of the day.

To avoid clogging the model with unnecessary traffic units, the basic unit was designated as a train, rather than the individual freight car. Each train introduced into the system carries train size with it as one of the eight parameters allowable in a GPSS model. Other parameter fields are employed for convenience at various points in the model. For output purposes, dummy traffic units are split off from the main program at critical points and sent to statistical routines to signal the need to record current clock time.

The basic GPSS clock unit was set equivalent to one minute of simulated time. It was felt that a faster model would suffer from inaccuracies, while a slower model would use excessive amounts of computer time in return for any benefits in accuracy.

Input Requirements

To apply the general model to a specific yard, there are essentially two types of information required.

A. The specific physical characteristics of the yard being studied.

B. The actual operating data from the yard over a period of time.

Specific characteristics involve the following items:

1. Size of the receiving area (no. of tracks, capacity of each).

2. No. of trains which can be processed simultaneously.

3. Processing criteria employed, e.g., any priority system, logical decision rules.

The following operating data are required:

1. Distribution of road train arrival times.

2. Distribution of road train lengths.

3. Distributions of arrivals of other traffic which competes for processing facilities.

4. Distribution of train lengths of other traffic.

5. Process times per train as a function of the size of the train (bleeding and switching).

6. Distribution of delays to switching process as a function of the time of day.

THE SPECIFIC MODEL

Description of the Yard

The actual yard studied contained a sixteen track receiving area with a total capacity of 1339 cars. Individual track capacities ranged from 40 to 118 cars. These tracks funnel into a single track hump facility equipped with remote-controlled switches and car retarders. Control over operations is provided by supervisory personnel located in a tower at the crest of the hump. A "general yardmaster" is stationed at the upper level of the control tower. Among his duties are decisions as to what track arriving trains will be assigned and the sequence in which trains will be switched.

The direction of flow in the yard is from west to east. Incoming trains from the west enter the receiving area directly from the west end. Incoming trains from the east can enter the receiving area from two tracks, one on each side of the hump, with each track allowing access to half of the tracks in the receiving area. Such arrivals may or may not interfere with switching that is underway, depending on what track is being switched.

As a result of the location of this yard in the Chicago area at the eastern end of the subject railroad's lines, there existed definite contrasts in the characteristics of the traffic flow when separated by direction of flow. Traffic from the west arrives in typical road trains. The movements are relatively infrequent and large in size. However, traffic from the east consists mainly of deliveries of traffic from other railroads (transfers) with yards in the Chicago area and cars from local industries. These movements are generally shorter and more frequent than road train movements. The data collected covered the handling of 226 trains with a total of 11,425 cars over a seven-day period. A breakdown by direction is shown in Table 1.

TABLE 1.

TRAFFIC FOR SEVEN-DAY PERIOD

direction	no. of trains	total cars	average cars/train
From the east[1] (transfers and locals)	175	8252	47.2
From the west[2] (road trains)	51	3173	62.2

[1]Local traffic may be destined either west or east, but is included in the above figure to keep local and transfer movements separate from road train movements.

[2]Excludes twelve trains which bypassed the receiving area and hump facility and were switched separately.

Since the purpose of this study is to examine the effects of changes in road train operating policies, transfer and local traffic was included in the model only to the extent that it competed for processing facilities with the road trains.

In addition to processing the trains arriving in the yard, consideration must be given to an activity which might be termed residual switching. This involves the switching of cars already processed once. For example, cars sent to the repair track are now ready to continue to destination or empties being held for disposition might be subject to reprocessing. During the seven-day period a total of 2610 cars were reswitched. Again, this activity must be included in the model because the traffic involved competes with other traffic for the switching processors.

Another phenomena which became apparent was the time period that elapses after one train is switched until switching of the next train begins. This delay is of two basic types. First, there exists an amount of miscellaneous work which must be done by the switch engines in a manner which interferes with the switching process. Some examples might be retrieving a car which was switched to the wrong track, pushing cars which stopped rolling too soon, or taking cars requiring maintenance to the maintenance area. Second, because of the physical layout of the yard, there is a period from the time the last train is switched until the next train can be pushed from the receiving area into position at the crest of the hump. Both of these factors are taken into account in the model.

Data Collection and Handling

Three midwestern railroads with major yards in the Chicago area were asked to make their facilities available for this study. Two of the companies responded favorably by making data from company records available and allowing the necessary supplementary information to be furnished. However, one company did not have available all of the necessary data and the attempt to model that pzrticular yard had to be terminated. The remaining company furnished operating data for a seven-day period and permitted observation of the operations in the yard and discussions with company personnel. A sample of the data record furnished is in the appendix.

Process times for the bleeding and switching activities were assumed to be linearly dependent on train size since every car has to undergo the same process. A three-day sample of elapsed times vs. train lengths was taken for both processes. Least--square equations were computed and then entered in the GPSS model as continuous functions. The equations used:

$$Y = 3.27 + .371X \qquad N = 48$$

$$Z = 0.05 + .307X \qquad N = 143$$

Where Y = estimated bleeding time (in minutes)
Z = estimated switching time
X = number of cars in train
N = sample size

The smaller sample taken for the bleeding process was caused by insufficiencies in the data. There was no definite way to determine whether bleeding was or was not begun immediately upon arrival. An arbitrary judgment had to be made; only in forty-eight cases did it appear that bleeding was begun upon arrival.

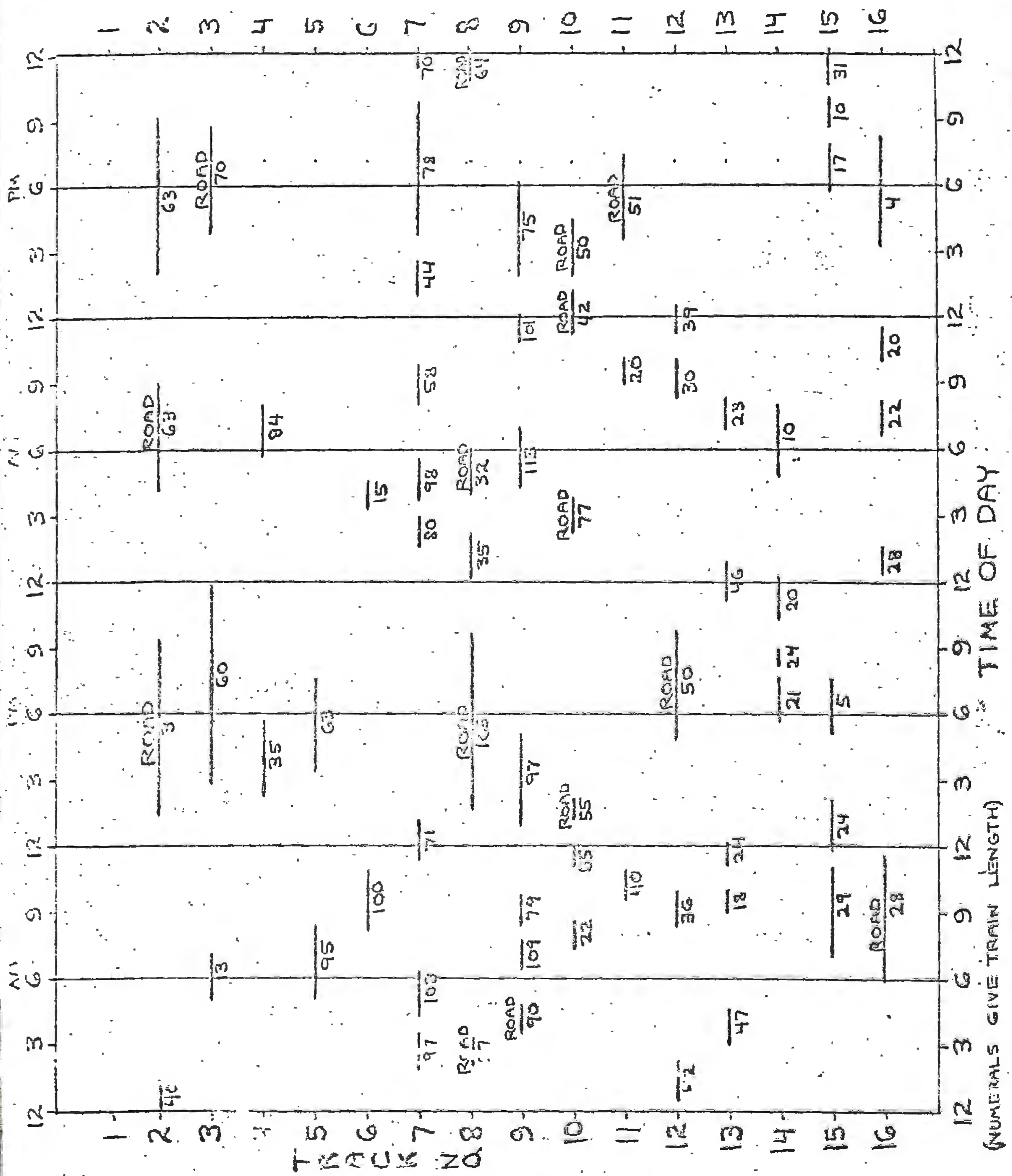
All data with regard to train arrival times, train size, residual switching traffic and switching delays were tabulated on a twenty-four hour basis in twelve two-hour divisions. Given the average number of occurrences over the data period, the probability of an occurrence in each of the two-hour divisions could be calculated. These distributions were then inserted in the model. Road train size did not appear to be time-dependent; the argument for this distribution was a simple random number.

Additional Assumptions

Road trains and other traffic compete not only for processing facilities but also for track space in the receiving area. An average of thirty-four trains arrived daily (eight road trains, twenty-six transfers and locals) seeking space in the sixteen track receiving area. If the non-road train traffic could be eliminated from the model, except for processor competition, considerable computer time could be saved. To pursue this question, a Gantt chart was used to study empirical track occupancy (Fig. 1). It was immediately evident that the capacity of the receiving area was far above the demand being placed on it. Thus there was little

FIGURE 1.

RECEIVING AREA TRACK OCCUPANCY - FOR 48-HOUR PERIOD



justification for modelling the entire competition for track space. Ten of the sixteen tracks could easily handle all of the transfer and local traffic. These tracks were then eliminated from the model; six tracks remained for use by road trains.

As a result of difficulties encountered in determining the actual decision rule used in assigning arriving trains to receiving area tracks, a hypothetical decision rule had to be constructed. Incoming trains are assigned to the empty track which minimizes the difference between the size of the train and the capacity of the track:

> $\min_i (c_i - x)$ subject to $c_i \geq x$.
> where c_i is the capacity of track i and x is the size of the arriving train.

When no empty tracks are available ($c_i < x$ for all i), trains are split up and assigned whatever open space exists. In the event that all tracks are full, trains queue up outside the yard and search for open track space every five minutes of simulated time. This rule would appear to be the most rational way to allocate track space to arriving trains. In the actual case it was apparent that there was no explicit decision rule; mistakes in judgement could be cushioned by the excess capacity of the receiving area tracks.

There was no explicit data available with regard to the unavoidable delay occurring between the switching of trains. In cases where the delay was small, i.e., less than seven or eight minutes, it was impossible to discriminate between delays caused by miscellaneous work and the unavoidable delay while the next train is pushed to the crest of the hump. Since the purpose of the simulation is to study the effects of more frequent trains, it is desirable to separate the delays dependent on the number of trains to be switched from other delays. From the records furnished, the minimum period between any two trains was three minutes. An arbitrary judgement of an average of five minutes delay per train was made. Miscellaneous work delays were assumed to be dependent on the total number of cars handled. Since total cars handled is held constant throughout the study, the total minutes of miscellaneous work is held constant over the daily cycle.

Model Validity

Before the effects of more frequent road trains can be examined, there must be some assurance that the model validly represents the yard being studied. Since it has been stated that overall elapsed time from train arrival through the switching process will be the primary measure of yard performance, comparison of simulated vs. empirical elapsed times is the logical measure of model validity.

When making a computer run of a simulation model, an important decision is the length of the run. According to Tocher (23):

> "This should be related to the purpose of the simulation and is rarely settled by statistical considerations...plants with long runs can be dealt with by shifts, days, or weeks."

Railroad yard operations are continuous; considering the assumption of the importance of the daily cycle characterizing yard activities, it was felt that a run should consist of several daily cycles, in order to obtain reliable results.

Five runs of four weeks each were made. Initial conditions were the same for each run; the model represented the actual conditions at the beginning of the period for which data had been obtained. Since GPSS random numbers are in fact "pseudo-random" numbers in that given a particular seed (initial random number) the same sequence of random numbers is always produced, the seed was changed for each run. New seeds were made up from random number tables (1). During the five runs a total of 955 road trains passed through the model. The results for each run are shown in Table 2.

The program tabulated the transit times in a frequency distribution (see Table 3). This allowed a goodness-of-fit test of the simulated times to the empirical distribution. Since the distributions did not appear to be normal, a non-parametric test was needed. The χ^2 one-sample test (20) was chosen. For this test the statistic $\chi^2 = \sum_{i=1} \frac{(S_i-E_i)^2}{E_i}$ is computed where S_i is the simulated value for the i^{th} category,

TABLE 2.

TOTAL TRANSIT TIME

run	mean	std.dev.	N
#1	168.1	105.3	192
#2	147.2	84.3	192
#3	197.0	126.0	190
#4	144.5	103.4	191
#5	139.4	80.7	190
Average:	159.2	99.9	191
Empirical:	158.2	111.4	45

TABLE 3.

DISTRIBUTION OF TRANSIT TIMES

total time	run #1	run #2	run #3	run #4	run #5	total	avg
1-60	26	20	20	37	25	128	26
61-120	55	77	43	66	71	312	62
121-180	38	40	39	36	41	194	39
181-240	25	24	32	23	34	138	28
241-300	26	17	16	14	11	84	17
301-360	9	11	11	6	4	41	8
361-420	9	3	12	3	2	29	5
421 +	4	0	17	6	2	29	6
total	192	192	190	191	190	955	191

E_i is the empirical value and k is the total number of categories. Table 4 shows the computations and tabulations for the χ^2 test.

TABLE 4.

TABULATIONS FOR χ^2 TEST

transit time[b]	empirical (E_i)	simulated (S_i)	$\frac{(S_i-E_i)^2}{E_i}$
1-60	4	6	1.00
61-120	16	15	.06
121-180	10	9	.10
181-300	10	11	.09
301 +	5	4	.20
totals	45[a]	45	2 = 1.45

a - To equalize sample size, average simulated values (from Table 3) are divided by 4.24.

b - Some combining of categories necessary to satisfy χ^2 test requirement that not more than 20% of frequencies 5.

χ^2 = 1.45 for four degrees of freedom fails to reject the null hypothesis at the .05 level of significance. In fact, $.90 > p > .80$ where p is the lowest level of significance at which a significant difference can be inferred. In other words the null hypothesis cannot be rejected for any level of significance less than .80.

Therefore, in view of the many simplifying assumptions made, it can be concluded that the model represents the actual yard reasonably well.

<u>RESULTS & CONCLUSIONS</u>

Following the tests for model validity, five runs were made with road trains arriving twice as frequently with half as many cars per train. The length of the runs was cut in half to hold the total number of trains equal with the previous series of runs. The same set of random number seeds was used. Initial conditions were the same as before and all statistical distributions remained unchanged. A total of 953 road trains passed through the model during the five runs. The results are compared in Table 5 with the earlier runs.

TABLE 5.

COMPARISON OF TOTAL TRANSIT TIMES

	Short Trains			Long Trains[1]	
run	mean	std.dev.	run	mean	std.dev.
#1	180.3	131.1	#1	168.1	105.3
#2	146.5	89.1	#2	147.2	84.3
#3	130.0	79.3	#3	197.0	126.0
#4	136.1	96.7	#4	144.5	103.4
#5	127.0	89.9	#5	139.4	80.7
Average:	144.0	97.2		159.2	99.9

[1] As in Table 2.

Table 6 shows the frequency distribution tabulations from the five runs for shorter and more frequent trains. To test for the significance of any differences between the two samples, the χ^2 test is applicable here, too.

TABLE 6.

DISTRIBUTION OF TRANSIT TIMES - SHORT TRAINS[1]

total time	run #1	run #2	run #3	run #4	run #5	total	total for long trains[2]
1-60	46	32	50	46	49	223	128
61-120	44	56	50	53	68	261	312
121-180	32	43	47	38	27	187	194
181-240	22	31	24	26	20	123	138
241-300	14	16	13	11	14	68	84
301-360	24	9	5	6	9	53	41
361-420	11	3	1	7	3	25	29
421 +	9	1	1	2	0	13	29
totals:	192	191	191	189	190	953	955

[1]Twice the normal frequency and one-half the normal length.

[2]As in Table 3.

However, the Kolmogorov-Smirnov two-sample test is considered to have a higher power-efficiency (20). This test considers whether two independent samples have been drawn from the same population. The one-tailed test is used to check differences in central tendency while the two-tailed test is sensitive to higher-order differences also. The Kolmogorov-Smirnov tests are concerned with the agreement between cumulative frequency distributions of the two samples. Table 7 gives these cumulative distributions; for large samples (n_1 and $n_2 > 40$) and a

TABLE 7.

CUMULATIVE DISTRIBUTIONS - TWO SAMPLES

transit time	long trains (S_{i1})	short trains (S_{i2})	(S_{i2}-S_{i1})
60 or less	.133	.234	.101
120 or less	.461	.508	.047
180 or less	.665	.704	.039
240 or less	.808	.834	.026
300 or less	.897	.905	.008
360 or less	.941	.961	.020
420 or less	.971	.987	.016
over 420	1.000	1.000	----

$n_1 = 955 \quad n_2 = 953$

one-tailed test, the statistic $\frac{4D^2 \quad n_1 n_2}{n_1 \; + \; n_2}$ is computed where $D = \max_i (S_{i1}-S_{i2})$, i.e., the maximum difference between the two distributions over all i categories. This statistic can be approximated by the χ^2 distribution with two degrees of freedom. For the distributions in Table 7 the Kolmogorv-Smirnov two-sample one-tailed test shows that transit time for shorter and more frequent trains is significantly lower at the .001 level.

A comparison could also be made between the distribution for shorter, more frequent trains and the empirical distribution. The χ^2 goodness-of-fit test would apply here again. The tabulations are given in Table 8. A χ^2 value = 13.81 for four degrees of

TABLE 8.

TABULATIONS FOR χ^2 TEST

transit time	empirical (E_i)	simulated (S_{12})	$\frac{(S_{12}-E_i)^2}{E_i}$
1-60	4	11	12.25
61-120	16	13	.56
121-180	10	9	.10
181-300	10	9	.10
300 +	5	3	.80
totals	45	45	χ^2 = 13.81

freedom rejects the null hypothesis at the .01 level of significance. However, this test does not give any clues as to what the nature of the difference might be; the Kolmogorov-Smirnov two-sample one-tailed test showed a significant reduction in average transit time for the case of shorter trains.

In summary, the simulation shows that a policy of operating road trains with twice the frequency and half the normal train length results in elapsed time from arrival through switching being reduced about 10% in the yard studied. This is shown to be a statistically significant reduction at the .001 level by the Kolmogorov-Smirnov two-sample test.

Additional runs were made with road trains input at three and four times the normal frequency and one--third and one-fourth the normal train lengths, respectively. Further reductions in elapsed time from arrival through switching occurred. Table 9 summarizes the mean times for all sets of runs.

TABLE 9.

SUMMARY OF MEAN TRANSIT TIMES - ALL RUNS

times normal frequency	mean transit time	stand. dev.	no. trains in sample
1	159.2	99.9	955
2	144.0	97.2	953
3	141.5	96.0	940
4	131.8	88.6	936

AREAS FOR FURTHER INVESTIGATION

Given the results of the simulation of the specific yard considered in this study, a number of questions arise: 1) Does the conclusion that shorter, more frequent trains result in a reduction of elapsed time from arrival through switching apply for all yards? (Other yards could easily be considered through use of the general model.) 2) What would be the effects of still other combinations of input frequencies and train lengths; is there an optimum? If a short train policy is adopted, there may be opportunities for reduction in fixed plant. In the extreme cases, each car would be self-propelled and would arrive separately, or in small batches, proceeding directly toward final destination; no yard facilities would be needed. 3) In the yard studied, only about 25% of the total traffic arrived in road trains. Would yards with a higher percentage of road train movements show a larger reduction in transit time when under a short train policy? 4) It would be interesting to investigate the effects of the short train policy on the assembly process. If twice as many trains are being handled, the number of blocks to be assembled over a period of time may increase (though the total volume of traffic is constant). The costs associated with the additional work would have to be considered by a rational, profit-maximizing management. 5) From a management viewpoint, the logical next step would be to attempt to convert the time savings for a particular yard into dollars. This figure would have to be weighed against the additional costs associated with the short train policy.

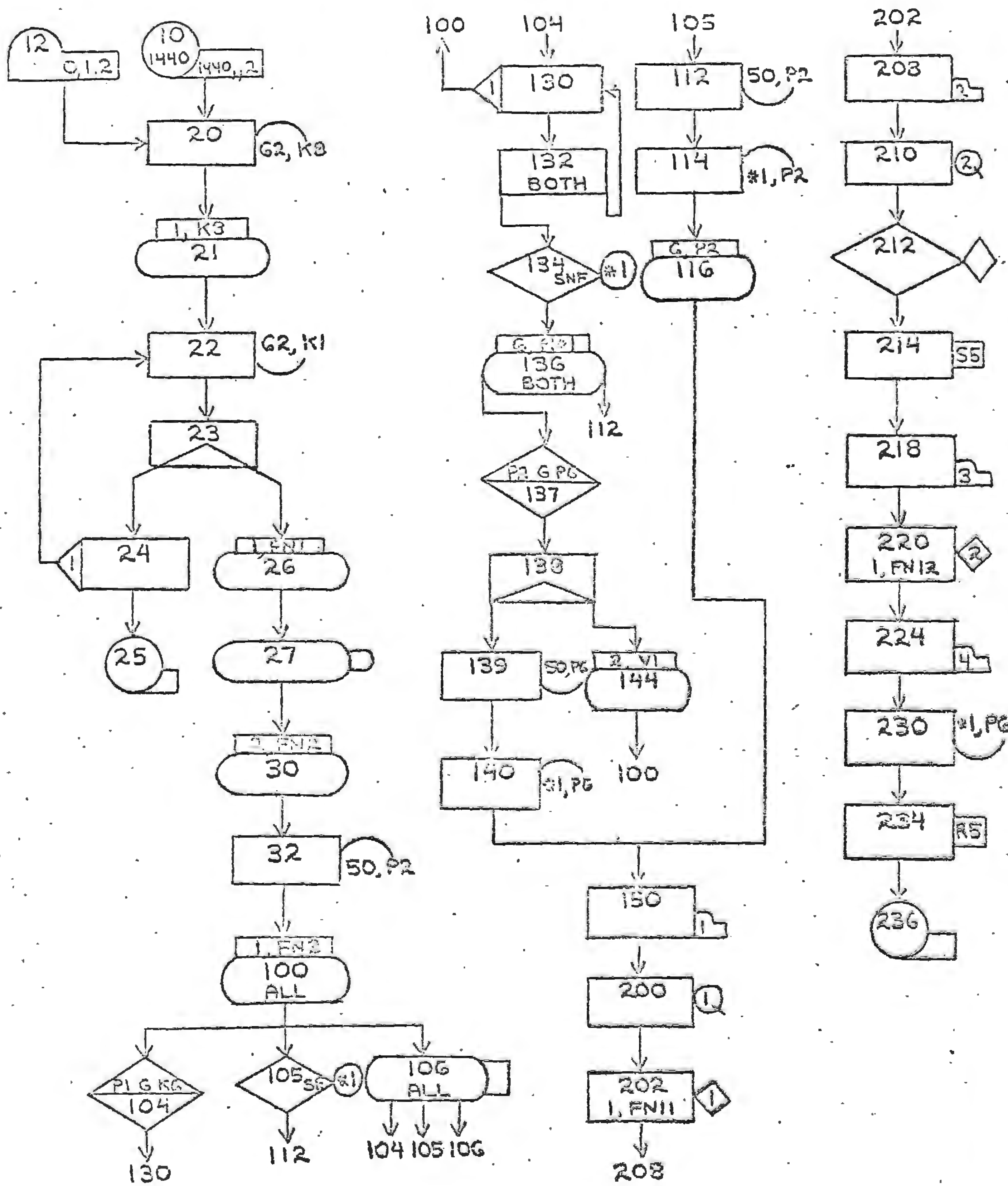
This study has not only presented some preliminary insights into the effects of the short train policy on classification yards, but the general simulation model can be used to study the effects of other kinds of changes. For example, the effects of adding or removing receiving area tracks, or adding additional or improved bleeding or switching facilities could be studied. Policy changes such as new schedules (resulting in a new input function), operating the yard on two shifts instead of three, or setting up a priority system for processing could also be tested.

When a new yard is being designed the general model could be of great value in testing various alternative configurations of tracks and facilities against expected traffic volumes. Furthermore, the sensitivity of a particular design to changes in traffic characteristics could also be observed.

APPENDIX

GPSS Block Diagram

Shown below is a typical portion of the GPSS block diagram of the general model. There are 63 additional blocks in the model - for a total of 104 blocks.



Listing of GPSS Program

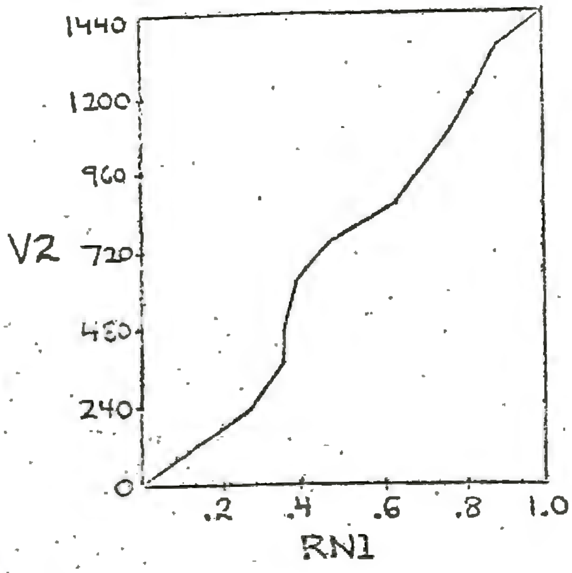
```
*         J S EHRHARDT   TRANSPORTATION CENTER   THESIS RESEARCH
*         BLOCKS 10 - 32 INPUT ROAD TRAINS TO MODEL
 10       ORIGINATE     1440          2            20            1440
 11       GENERATE      0      1      2            20
 20       ENTER         62     K8                  21
 21       ASSIGN        1      K3                  22
 22       LEAVE         62     K1                  23
 23       SPLIT                                    24      26
 24       LOOP          1                          22      25
 25       TERMINATE
 26       ASSIGN        1      FN1                 27             *1
1         FUNCTION      RN1    C13    ROAD TRAIN ARRIVALS - EMPIRICAL
0         1      .133   120    .289   240    .356  360    .357   480    .378   600
.467      720    .623   840    .712   960    .779  1080   .846   1200   .890   1320
1.0       1440
 27       MARK                                     30
2         VARIABLE      C1(K1440
 30       ASSIGN        2      K12                 32
2         FUNCTION      RN1    C11    ROAD TRAIN LENGTHS
0         10     .022   20     .133   30     .200  40     .289   50     .422   60
.518      70     .734   80     .867   90     .933  100    1.0    110
 32       ENTER         50     P2                  100

*         BLOCKS 40 - 44 SIMULATE DELAYS TO SWITCHING
 40       ORIGINATE     1             6            41            120
 41       GATE          LR5                        42
 42       LOGIC         S5                         43            1      FN15
15        FUNCTION      V2     D12    DELAY TO SWITCHING
120       41     240    28     360    32     480   44     600    36     720    32
840       31     960    38     1080   42     1200  50     1320   55     1440   50
 43       LOGIC         R5                         44
 44       TERMINATE

*         BLOCKS 50 -98 SIMULATE PROCESSING OF OTHER TRAFFIC
*         BLOCKS 50 - 56, 81 - 88, 70 - 79 HANDLE TRANSFERS
 50       ORIGINATE     1440          2            81            1440
 51       GENERATE      0      1      2            81
 52       ASSIGN        2      FN22                70
 22       FUNCTION      V2     D5     TRANSFER LENGTHS
 420      60     600    33     960    60     1330  20     1440   60
*         BLOCKS 55 AND 56 SET UP INITIAL CONDITIONS
 55       GENERATE      0      1      2            56
 56       ASSIGN        2      K35                 73
*         BLOCKS 60 - 69. 91 - 98 HANDLE RESIDUAL SWITCHING
 60       ORIGINATE     1440          6            91            1440
 61       GENERATE      0      1      6            91
 62       ASSIGN        2      FN24                63
 24       FUNCTION      V2     D3     RESIDUAL LENGTHS
 840      16     1200   32     1440   16
```

```
 63    QUEUE        5                         64
 64    GATE         LR5                       65
 65    LOGIC        S5                        66
 66    HOLD         2                         67              1       FN12
12     FUNCTION     P2      C3     SWITCHING TIME
3      1      13    4       113    36
 67    ADVANCE                                68
 68    LOGIC        R5                        69
 69    TERMINATE

 70    QUEUE        3                         71
 71    HOLD         1                         73              1       FN11
11     FUNCTION     P2      C3     BLEEDING TIME
0      3      10    7       118    47
 73    QUEUE        4                         74
 74    GATE         LR5                       75
 75    LOGIC        S5                        76              5
 76    HOLD         2                         78              1       FN12
 78    LOGIC        R5                        79
 79    TERMINATE

 81    ENTER        60      K26               82
 82    ASSIGN       1       K26               83
 83    LEAVE        60      K1                84
 84    SPLIT                                  85      88
 85    LOOP         1                         83      86
 86    TERMINATE
 88    ASSIGN       1       FN31              52              *1
31     FUNCTION     RN1     C13    TRANSFER ARRIVALS - EMPIRICAL
0      1     .070   120     .160   240   .218   360   .246   480     .538   600
.609   720   .660   840     .769   960   .814   1080  .846   1120    .910   1320
1.0    1440

 91    ENTER        61      K15               92
 92    ASSIGN       1       K15               93
 93    LEAVE        61      K1                94
 94    SPLIT                                  95      98
 95    LOOP         1                         93      96
 96    TERMINATE
 98    ASSIGN       1       FN32              62              *1
32     FUNCTION     RN1     C13    RESIDUAL ARRIVALS - EMPIRICAL
0      1     .043   120     .117   240   .191   360   .202   480     .203   600
.266   720   .362   840     .564   960   .724   1080  .862   1200    .936   1320
1.0    1440

*      BLOCKS 100 - 150     SIMULATE ROAD TRAIN SEARCH FOR TRACK SPACE
100    ASSIGN       1       FN3          ALL  104     106
3      FUNCTION     P2      D7     LOGIC FOR FIRST TRACK CHOICE
73     1      78    2       95     3     100   4      108     5       118    6
200    7
104    COMPARE      P1      G      K6          130
105    GATE         SE*1                       112
106    INDEX        1       1            ALL  104     106
112    LEAVE        50      P2                 114
```

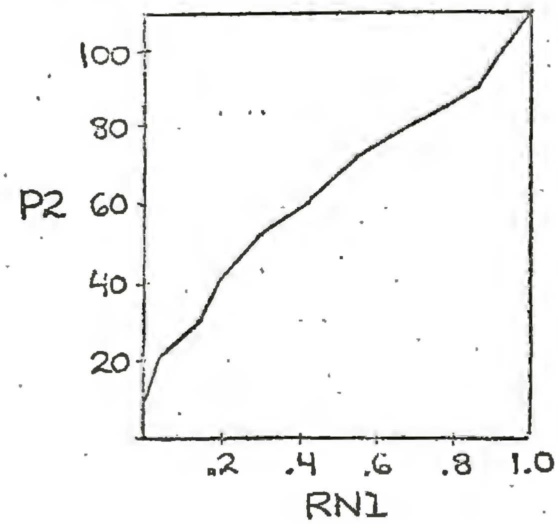
```
120      ADVANCE                                         100                5
130      LOOP          1                                 132      120
132      [illegible]                              BOTH   134      130
134      GATE          SNF*1                             136
136      ASSIGN        6        N*1               BOTH   137      112
137      COMPARE       P2       G       P5               138
138      SPLIT                                           139      144
139      LEAVE         50       P6                       140
140      ENTER         *1       P6                       150
1        VARIABLE      P2-P6
144      ASSIGN        2.       V1                       100
150      TABULATE      1                                 200

*        BLOCKS 200 - 236 PROCESS ROAD TRAINS THRU BLEEDING AND
*        SWITCHING - TRAINS LEAVE MODEL WHEN SWITCHING FINISHED
200      QUEUE         1                                 202
202      HOLD          1                                 208                1         FN11
208      TABULATE      2                                 210
210      QUEUE         2                                 212
212      GATE          LR5                               214
214      LOGIC         S5                                218                5
218      TABULATE      3                                 220
220      HOLD          2                                 224                1         FN12
224      TABULATE                                        230
230      LEAVE         *1       P6                       234
234      LOGIC         R5                                236
236      TERMINATE

*        FOLLOWING BLOCKS SET UP TABULATIONS FOR ROAD TRAINS
*        TABLE 1 HAS TRANSIT TIME THRU ENTER YARD TRACK
1        TABLE         M1       10      10      12
*        TABLE 2 HAS TRANSIT TIME THRU BLEEDING PROCESS
2        TABLE         M1       15      15      16
*        TABLE 3 HAS TRANSIT TIME THRU BEGIN SWITCHING
3        TABLE         M1       30      30      20
*        TABLE 4 HAS TRANSIT TIME THRU FINISH SWITCHING
4        TABLE         M1       30      30      20
*        TABLE 5 - 9 ARE FOR PRE-PROCESS QUEUES.
5        QTABLE        1        15      15      24
6        QTABLE        2        30      30      16
7        QTABLE        3        15      15      24
8        QTABLE        4        15      15      24
9        QTABLE        5        15      15      24
*        FOLLOWING BLOCKS DEFINE STORAGE SPACE - YARD TRACKS
1        CAPACITY      73       TRACK 11
2        CAPACITY      78       TRACK 10
3        CAPACITY      95       TRACK 3
4        CAPACITY      100      TRACK 4
5        CAPACITY      108      TRACK 6
6        CAPACITY      118      TRACK 8
```

GPSS Functions Used

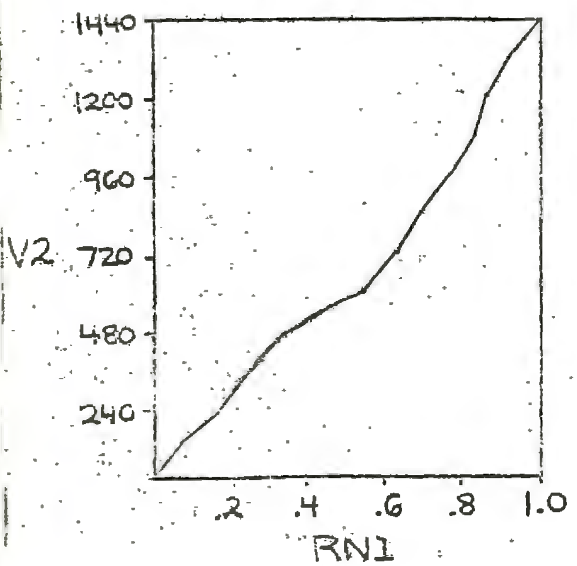
FN1 Road Train Arrivals



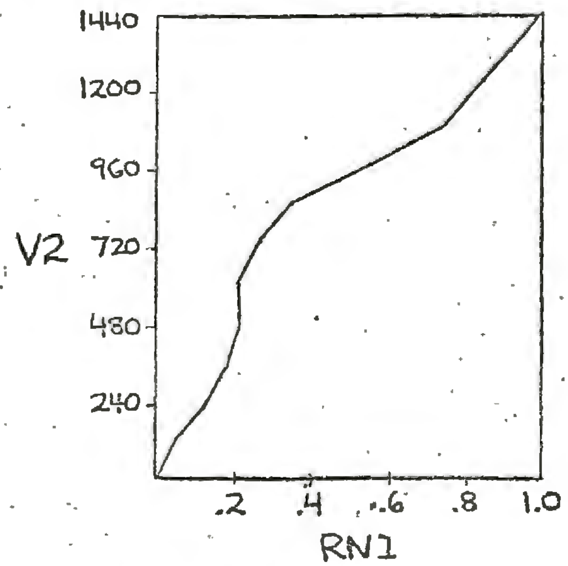
FN2 Road Train Lengths



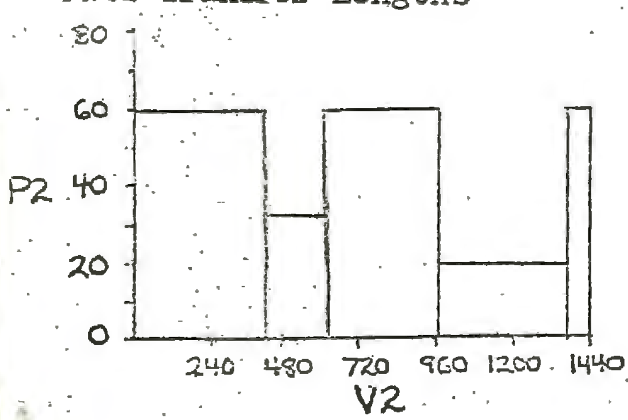
FN31 Transfer Arrivals



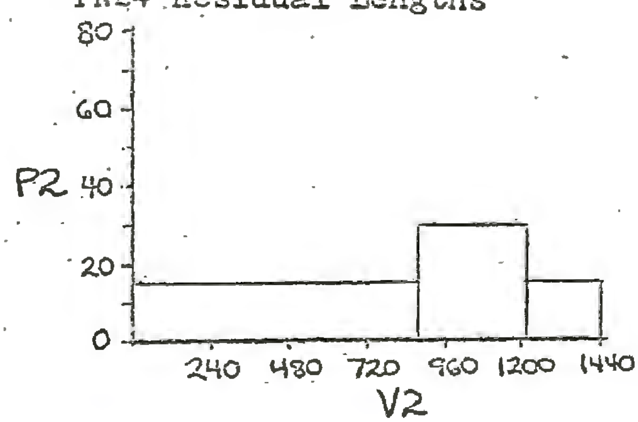
FN32 Residual Arrivals



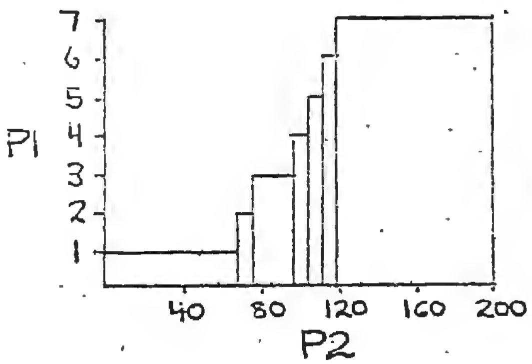
FN22 Transfer Lengths



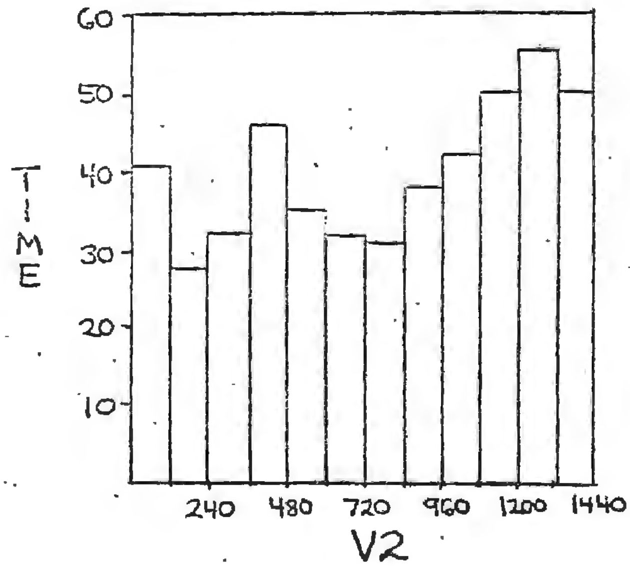
FN24 Residual Lengths



FN3 Initial Track Choice



FN15 Delays to Switching



FN11 = 3.27 + .371(P2)

FN12 = 0.05 + .307(P2)

<u>Variables Used as Function Arguments</u>

V2 = time of day (24 hour clock - in minutes)

P2 = train length (no. of cars)

RN1 = uniformly distributed random number (between 0 and 1)

P1 = initial track choice - that track which minimizes (C_i-P2) for all i where $C_i \geq$ P2 and C_i = capacity of track i. Largest track in model has 118 car capacity. In order to handle trains where P2>118, a dummy track (track 7) is named to handle such trains temporarily until it can be split up among the actual tracks in the yard.

Sample Standard GPSS Output

CLOCK TIME REL 17280 ABS 17280

TABLE NUMBER 4

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
190	126.968	89.946

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN
30	8	4.21	4.2	95.8	.236
60	41	21.58	15.8	74.2	.473
90	39	20.53	46.3	53.7	.709
120	29	15.26	61.6	38.4	.945
150	16	8.42	70.0	30.0	1.181
180	11	5.79	75.8	24.2	1.418
210	12	6.32	82.1	17.9	1.654
240	8	4.21	86.3	13.7	1.890
270	5	2.63	88.9	11.1	2.127
300	9	4.74	93.7	6.3	2.363
330	4	2.11	95.8	4.2	2.599
360	5	2.63	98.4	1.6	2.835
390	2	1.05	99.5	.5	3.072
420	1	.53	100.0	.0	3.308

REMAINING FREQUENCIES ARE ALL ZERO

(An additional column, "DEVIATION FROM MEAN", also is given)

FACILITY NR	AVERAGE UTILIZATION	NUMBER ENTRIES	AVERAGE TIME/TRANS	TRANS	$TRANS
1	.5163	504	17.72	17,H	0
2	.4157	684	10.50	53,H	0

STORAGE NR	CAPACITY	AVERAGE CONTENTS	AVERAGE UTILIZATION	NUMBER ENTRIES	AVERAGE TIME/TRANS
1	73	16.39	.2245	2755	162.35
2	78	12.57	.1612	1717	126.51
3	95	8.84	.930	1007	151.63
4	100	4.25	.0425	449	163.62
5	100	2.70	.0250	170	274.46
6	110	.67	.0056	32	360.00

QUEUE NR	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS
1	3	.10	192	100	52.1	5.89
2	5	.98	191	12	6.3	88.72
3	5	.22	312	139	44.6	12.37
4	8	1.50	313	28	8.9	82.88
5	5	.21	180	15	8.3	19.92

(For storages, there exists an additional colum; "CURRENT CONTENTS"; For queues there exists two other columns, "TABLE NUMBER" And "CURRENT CONTENTS".)

TRANS COUNTS

BLOCK	TRANS,	TOTAL	BLOCK	TRANS,	TOTAL	BLOCK	TRANS,	TOTAL
10	0	12	12	0	1	20	0	13
21	0	13	22	0	305	23	0	208
27	0	192	[illegible]	0	152	30	0	192

(The above transaction count is printed for every block of the GPSS program. "BLOCK" denotes the block number. "TRANS" shows the number of transactions currently at that block. "TOTAL" gives the total number of transactions having passed through that block during the run - including those still at that block.)

SAVEX NR,	VALUE	NR,	VALUE	NR,	VALUE	NR,	VALUE
1	191	2	527	3	648	4	722
5	808	6	908	7	1017	8	1030
9	1116	10	1125	11	1164	12	1320

("SAVEX" routines can be written into the block diagram in order to sample and record values of any systems variable at particular instants during the simulation run. "NR" denotes the "SAVEX" cell number while "VALUE" is the contents of that cell.)

Sample Company Data Record

DATE ______________ YARDMASTER ______________ ASSIGNMENT HOURS ______________

WEATHER __________ CONDITION ______________ RETARDER OPS ______________

TRAIN ARRIVALS

TRAIN	ENG NO.	NO. CARS	TRACK	TIME ARR.	TIME RELSD.	

HUMPING OPERATIONS

TRAIN	HUMPED BY ENG. NO.	FOREMAN	STARTED	COMPLETED	NO. CARS	DELAYS