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A STUDY OF IMPLEMENTATION AND EVALUATION TECHNIQUES OF ADVANCED GUIDED VEHICLE SYSTEMS

by

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INTRODUCTION

In the early 50's Advanced Guided Vehicle Systems (AGVSs) were introduced in the United States. The early systems were used for automating warehouse transportation operation of materials by providing a link between the storage, receiving, and shipping departments.

The Europeans were the first to recognize the potential of AGVSs and created a demand for new vehicle types and new applications. Recently AGVSs have developed the ability to deliver parts and materials to the entry points of production and the transport of fixtured workpieces and tools to computer controlled machining centers in a flexible manufacturing process.

The United States has now become more involved in the use of AGVSs systems. This increased involvement is shown by the yearly industry growth of 5 to 6 % from the 1950's to the 1970's, to what is expected to be a yearly increase rate of 30 % in the 1980's.

BACKGROUND

There are three basic situations in which today's AGVSs are applied. The first application is to interface work-in-process automatic storage and retrieval systems and link them with manufacturing floor systems. This provides a link for the possible real-time material tracking throughout a facility.

The second application is in flexible manufacturing systems. The AGVSs are used to deliver material to computer numerical control machines. In this case a central control system links the vehicles with the computer numerical control machine for material tracking.

The third application is for distribution environments. The vehicles are used to move large volumes of materials great distances. For example, the movement of materials from bulk storage to receiving and shipping docks and vice versa.

Within AGVSs there are basically five types of vehicles which are used: automated towing vehicles, pallet trucks, unit-load carriers, automated forklift vehicles and specialty trucks (sideloading trucks, for example).

The power sources for these vehicles are lead-acid batteries which have 24 to 48 volt and 80 to 500 amp-hour capacity. These batteries remain charged for approximately 8 to 16 hours.

The vehicles run on a guidepath which provides a two-way link from the vehicle to the operating device. The guidepath carries instructions from the computer to the vehicles and vehicle status information from the vehicle to the operating device.

There are two types of vehicle guidance techniques: optical guidance and magnetic guidance.

In the optical guidance method the guidepath is marked by reflective tape or painted stripes on the floor. The vehicle emits a lightbeam which is focused on the guidepath, and tracks the path by measuring the amplitude of the reflected light. Other optical paths use ultraviolet light or invisible chemicals for guidance. Optical guidepaths are used mainly in office environments or temporary guidance systems. They are not recommended for extended use in industrial environments because they have a tendency to get covered over in a dirty work area.

The other guidance technique (and most commonly used) is magnetic guidance. In a magnetic system the guidepath is generated by the electromagnetic field created by a continuous wire conductor embedded in a small slot in the floor. One or more wires are placed in the slot (1/8 to 3/8 inches wide and 1 to 1.5 inches deep), which is filled with an epoxy material to make the floor smooth. The wires are energized with a low-current, low frequency AC signal that generates a magnetic field around the wire. A sensor coil, which is on board the battery-powered vehicle, detects the magnetic field created around the wire. Any deviation in the magnetic field causes the vehicle to deviate from its present activity (to turn, stop, etc.). Magnetic guidance requires more effort to install and is more difficult to change. But upon completion of installation of the required wire system it is virtually maintenance free.

Once an AGVS is installed there are two types of system control: traffic management and system management.

Traffic management is done by three possible methods. The first is called zone control or "blocking". The guidepath system is divided into zones or blocks with separate control exercised over each zone in the system.

This is done by either distributed zone control or central zone control.

In distributed zone control, the vehicle is not permitted to enter a zone until all previous traffic in that zone has moved on to another zone. When the zone is clear of all vehicle activity a hold beacon is de-energized and the vehicle is allowed to enter the zone and approach any stop station within that zone.

In centralized zone control, there is a central controller which monitors all zones at one time versus the distributed approach where there is a monitor at each zone. When a vehicle approaches a zone entrance the central controller receives status information and signals the communication point when the vehicle is okayed to move ahead.

The second method of traffic management was made possible because the developments in the last decade in microprocessor and minicomputer technology. This technology has provided the foundation for the development of intelligent or "smart" vehicles. The development of these "smart" vehicles has allowed for the elimination of zone control. In this type of system the vehicles are equipped with onboard microprocessors. This is, of course, a very expensive system. The main advantage of this type of traffic management is that if one vehicle fails the whole system does not go down.

The third method of traffic management is sensor control. In this method, each vehicle is equipped with on-board sonic or optical sensors. These sensors emit signals and record the reflected response. When something is in the vehicle's proposed path, whether a foreign object or another vehicle, the vehicle will stop a specified distance from the obstruction and will not proceed until it is removed. Sensor control is most effective on a straight and unvarying guidepath.

The second type of system control is system management. There are three types of system management: on board call, off board call, and central computer control.

On board call or dispatch is typified by a panel being on board the vehicle and the station operator using this panel to dispatch the vehicle to a desired destination. This method is the simplest and cheapest but is heavily dependent on the operator.

The second method of system management is off board call or remote dispatch system. In this system the operator interacts with a remote dispatch instead of directly with the vehicle and "calls" a vehicle to his station. This method increases efficiency by providing a buffer between the vehicles and the system's operators. However, this system provides no material tracking capabilities and is still dependent on the station operators.

The third method of system management is central computer control. In this approach the operator control on the system is eliminated. All vehicles in the system are monitored by a central controller and respond to his commands only. If the vehicle controller is interfaced with the user's host computer it is possible to have real-time tracking and inventory control. In most cases these systems are connected with automatic load/unload devices which further reduce the operator involvement which in turn eliminates potential idle time of the vehicle. Central computer control is more complex and expensive (as much as twice that of remote dispatch) but in proper circumstances can pay for itself in increased efficiency and system flexibility.

There are many possible benefits to the installation of a AGVS, some of which include:

(1) materials are more closely controlled as a result of more accurate inventory information,

(2) reduction of work-in process inventory,

(3) a more efficient use of personnel, which produces significant labor savings,

(4) a more efficient work environment (workers don't have to keep up with a line),

(5) elimination of manual material handling between manufacturing sections,

(6) the flexibility afforded by guidepaths that can be readily changed,

(7) increase in production space because the guidepath requires minimal area,

(8) more efficient use of floor space since the guidepath provides no obstruction to material flow off the path,

(9) overall adaptability to automation and AGVSs' effectiveness in operating with other computer controlled systems.

As the benefits increase so does the price of AGVSs. But still it is a worthwhile investment for industry. In fact, four times as many AGVSs were sold in 1984 than in 1983.

Because of the increasing cost, development of pre-installation simulation procedures are needed to be able to accurately predict system performance before installation of the actual physical system.

The purpose of this thesis is to develop procedures that can be used during the design and evaluation of the proposed AGVS systems.

OBJECTIVE

Because of the ever increasing demand for AGVSs, it has become necessary to make a thorough design and evaluation of facility plans before large capital investments can be made. This can be done by developing different designs and evaluating them by computer simulation. The evaluation of AGVSs can be done with simulation languages, in this case GPSS-H. The use of GPSS-H provides the opportunity, without having to use physical hardware, to emulate an actual system with the manipulation of mathematical equations. This can produce design criteria for the implementation of a AGVS.

This thesis will be concerned with the development of design and evaluation techniques for AGVSs. Macros, using GPSS-H, will be developed which emulate the unique sections which make up AGVSs. By piecing these "unique sections" together like building blocks the AGVS, whether real or proposed, can be simulated and hence evaluated.

Three AGV systems will be evaluated, one which is in existance and two that are being proposed by a local manufacturer.

The first system, which is already in use, will be simulated and then evaluated. The evaluation will consist of a study of the number of vehicles needed, vehicle utilization, vehicle efficiency, job completion, and block analysis.

The second and third systems, which are being proposed, will be first designed and then optimized, by development of material handling techniques. Simulation will then be used to evaluate the designs and give insights for possible design improvements.

MODELING

The depiction of the AGVSs will be done using the General Purpose Simulation System computer language. The version used is GPSS/H.

Macros were developed to emulate the following unique parts of a AGVS: travel block, input block, output block, park block, refuel block, loop block, and the cross block. The program statements which are used to call these macros are individualized by a set of operands which are used in the called macro. The main program statements call the desired macro and place it in its place in the main program. The operands which are attached to the main program statement individualize each macro into separate pieces of track. These main program statements are pieced together to form a representation of the actual AGVS.

Incorporation into the program of logical code is needed to make decisions at path division points. When a vehicle reaches a decision point its destination is checked and the correct route is chosen.

To depict accurately any AGVS with simulation programming the following factors must be imitated.

(1) Blocking - Blocking is a signalling system which divides the work route into zones and allows only one vehicle into that zone at one time.

(2) Routing - Routing is chosing the route to the destination that has the shortest possible path.

(3) Dispatch and scheduling algorithms - D/S is a method of assigning empty vehicle destinations.

(4) Status - The status of the input stations, output stations, and vehicles must be kept for decision making processes through the system

(5) Parking stations - Emulation of these are necessary to have a place where the vehicle can go when there are no jobs to be performed; otherwise the vehicle will travel the circuit and obstruct vehicles doing work.

Blocking is accomplished by allowing only one vehicle into any macro at one time. If a vehicle attempts entry into a macro which is already in use it waits and the waiting time is recorded.

Routing is accomplished by providing the proper tests at path divisions. For example, if a vehicle must travel from point A to B, the incorporated test logic will "steer" the vehicle on the appropriate path to its destination.

Five approaches were considered in constructing the dispatch and scheduling algorithm: set distribution, queue sizing, first-in-first-out, minimum distance locator, and combined queue sizing and minimum distance locator.

The set distribution algorithm can be used when destinations from points are surveyed over a period of time and then categorized into a distribution. This is a simple algorithm which uses a random number generator to pick the next vehicle destination.

The queue sizing algorithm is merely the checking of all possible destinations and the picking of the one with the longest job queue.

The first-in-first-out algorithm ranks with queue sizing for complexity. The algorithm picks the destination which has the oldest job. This method is useful when time limits are set on job fulfillment.

These first three approaches can cause much lost time for a AGVS. All are common in the fact that they may require the AVG to travel long distances to destinations when alternatives are shorter.

This leads into the fourth approach which is the minimum distance locator algorithm (MDLA). In the MDLA, all possible destinations are scanned and the destination which is the closest is chosen. Because a vehicle round trip consists of travelling empty to an input station and travelling loaded to an output station, the MDLA reduces empty vehicle travel time by directing the vehicles from the outputs to the closest inputs that have jobs to be done. The problem with this algorithm is that job queues can back up at input stations simply because of their great distance from destination assignment points.

The fifth, and most complex, algorithm is the queue sizing and MDLA combination. This algorithm first checks all job queues for any which are above a "queue full" status. If any are above that level the vehicle is dispatched to that destination. Note that there should be at most one job queue exceeding this level at a time. There is no logic in the algorithm to accommodate multiple job queue overloads, for in the properly running system there should not be more than one. In an inadequate system where two or more overloads may occur, one is chosen without regard to distance. If there is no overload of the job queues the vehicle is dispatched to the closest possible vehicle requesting destination. This alleviates queue buildup and at the same time reduces empty vehicle travel.

The dispatch and scheduling algorithm is contained within the output, input, park, and refuel macros, in which a vehicle has reached its destination and requires a new one.

The recommended algorithm to dispatch vehicles from the output stations, park area, and refuel area is the queue sizing and MDLA combination. Destinations consist of input stations, the park area and the refuel area (obviously you can not dispatch to your own location e.g. park-to-park). Because of this, before entering the D/S algorithm the fuel level must be checked and if below a prescribed level, the refuel area is assigned as destination. Similarly, after the D/S algorithm, if no destination has been chosen, the vehicle is dispatched to a park area.

The algorithm for dispatching vehicles from the input stations is the set distribution. Since the destination from an input station is always an output, distributions can be developed which provide desired patterns.

The status of input and output stations are accounted for in the macro sequence as either in use or not in use. Since each is represented by a macro, when the station is in use no other vehicle may enter.

Other status values which are associated with each input are a buffer value and an assigned job value. The buffer value is the number of jobs that are at the input station but have not been assigned to a certain vehicle for pickup. When a vehicle is assigned the destination of a particular input (see dispatch/scheduling), one job is subtracted from the buffer value and added to the assigned job value (which is decremented when the vehicle picks up the job).

Vehicle status is "carried" by the transaction, which represents the vehicle, as it travels around the AGVS. Each vehicle is identified with a number from 1 to X (where X is the number of vehicles in the system). Fuel levels and loaded or unloaded status are also carried by each vehicle.

Parking stations are represented by macros and can be placed around the guidepath as needed. Parking stations can also have a capacity which is greater than one, i.e., more than one vehicle can be in a parking station at one time.

The following data are kept track of during the simulation process and output when prompted or at the completion of the simulation:

(1) The number of vehicle entries into each block of track, output station, input station, park

area, and refuel area and whether there are any vehicles presently in any of these.

(2) Average time (in seconds) that the vehicle remains in each block.

(3) Total number of vehicles blocked at a block of track for any time greater than zero, which is further broken down into the number of vehicles that were loaded and the number that were unloaded.

(4) For the number of blocked vehicles, the average waiting times for both the loaded and unloaded vehicles (in seconds).

(5) Status of the buffer and job waiting queues.

(6) Vehicle fuel levels.

(7) Status of each vehicle, either loaded or unloaded.

(8) Total vehicle travel time(in seconds) loaded and unloaded.

CASE 1

The first AGVS studied is one that is already in existance. The design was taken from the Newark, Delaware warehouse of Avon Products Inc. as presented in the June 1983 issue of Modern Materials Handling. The AGVS is linked to an automatic storage and retrieval system, delivering inventory to order filling lanes.

Because some of the information needed to model this system was not provided by the article some of the AGVS properties were approximated by the author. Given was the guidepath length of 2,200 feet. From this value distances between possible stop areas were determined. Also given was that 80 loads were input into the system per hour. Since no distribution was indicated the loads were allocated to the four system inputs, i.e., 20 loads input at each input station per hour. Likewise, there was no distribution of job destinations given, so each job randomly selected an output station as its destination. Since there were 10 outputs each station had a 1/10 probability of being chosen as the destination. The calculated vehicle speed, 2.3 feet/second is slower than most vehicles travel but was a convenient magnitude for the simulation. In the magazine design no park or refuel areas are shown, so the author placed each in the system at his own discretion. The purpose of the Avon study is to see the effect that the number of vehicles has on vehicle utilization, vehicle efficiency, job completion, and job analysis.

Vehicle utilization, as described by Hitchens (4), is the percentage of time that each vehicle is transporting a load in the system. This leads to system utilization being defined as

$$\text{system utilization} = \frac{\text{sum of the loaded vehicle travel time}}{\text{sum of the vehicle travel time}} .$$

This equation should be further refined to include vehicle load and unload time. Input and output stations are included in the system and thus must be represented in the utilization calculation. The new system utilization would be defined as

$$\text{system utilization} = \frac{\text{total loaded travel time} + \text{total unload time} + \text{total load time}}{\text{shift length} \times \text{no. of vehicles}} .$$

Hitchens (4) also describes vehicle efficiency as the percentage of time that a vehicle, with a job to do, is in motion. The system efficiency is defined as

$$\text{system efficiency} = \frac{\text{sum of loaded vehicle travel time} - \text{sum of loaded vehicle waiting time}}{\text{sum of loaded vehicle travel time}}$$

Since efficiency is an indicator of system blockage, Hitchens' approach must be further defined to include cars which are travelling empty to reach new loads. This would give a truer indication of system congestion. The new system efficiency equation would be defined as

$$\text{system efficiency} = \frac{\text{sum of vehicle travel time} - \text{sum of vehicle waiting time}}{\text{sum of vehicle travel time}}$$

Job completion, which is self explanatory, is the other factor studied in the Avon case. It must be studied, for if you are not processing the workload, utilization and efficiency calculations are useless.

Blocks, the signalling device used in the AGVS, can be varied and the effects on the system monitored. Blocks are sections of track which allow only one car to enter at one time. By varying the block lengths, fluctuations should be seen in the utilization, efficiency, and possibly job completion rate.

It should be noted that the Avon system is but one type of AGVS configuration. All of the inputs are placed at one end of the system and the outputs at the other end. Because of this the dispatch and scheduling algorithm was not used except to check for refuelling or park assignments. The vehicles were assigned input stations and output station at random. Since no load or unload times were given 60 seconds was used for each.

The Avon system, see Figure 1, is linked with an automatic storage and retrieval system. This is why the inputs are centralized at one end of the AGVS and the outputs at the other end. The park and refuel areas where placed at the input end of the system. A distance matrix was not used in the Avon AGVS because of this opposite end destination setup. The refuel area placed in this model is optional since its system effects can be determined after the simulation.

There are four inputs, 10 outputs, one park area and one refuel area in the Avon AGVS. It takes 60 seconds to load or unload a job from a vehicle. Each input is preloaded with four jobs as the modeling process begins and a new job is created at each input station every three minutes (calculates to 80 jobs input to the system per hour). Destination of these jobs are randomly chosen from

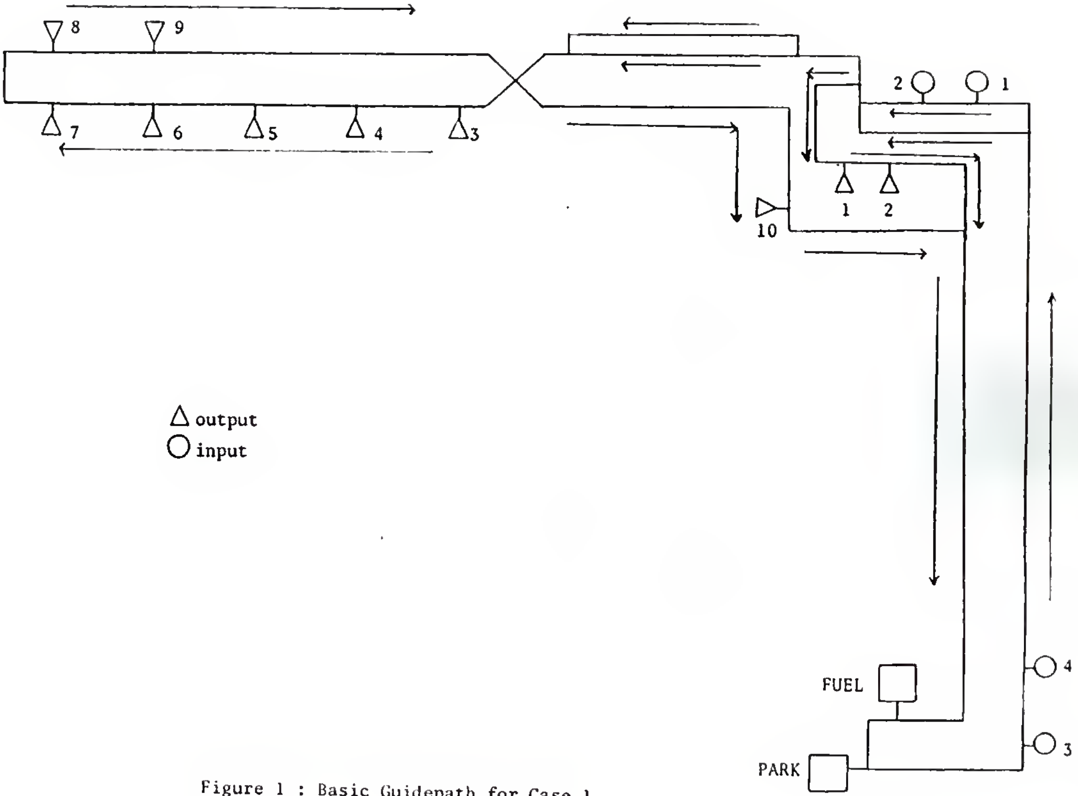


Figure 1 : Basic Guidepath for Case 1.

the 10 outputs.

Vehicles take 10 seconds to refuel (represents exchanging of battery) and each battery has a capacity of 5000 seconds travel time. When the battery level goes below 1000 seconds the next destination assignment is the refuel area. There is no limit on the park area capacity. Measurement of time spent in the park area is important for it represents possible work time that is lost because of no demand. The refuel area also has no capacity limit and as many vehicles needing refuelling are allowed in at one time.

For study of system utilization, system efficiency, and job completion rate, the number of vehicles in the system was incremented from 3 to 11. With each specified number of vehicles the system was run for five shifts of eight hours each. The shifts were run back to back with each vehicle starting a new shift at the location it was in at the end of the previous shift.

The measurements of system utilization can be seen in Figure 2. As the number of vehicles was decremented, system utilization increases by relatively equal steps between 11 vehicles and 6 vehicles. For 3, 4, and 5 vehicles system utilizations are, in essence, equal. The vehicles (at levels 3, 4 and 5 vehicles) are in constant use and are being utilized to the maximum of their capabilities.

The leveling off observed in Figure 2 is due to the pre-loading of the system. During shift one, not only did the vehicles have to complete the standard number of jobs input the system but also the 16 jobs that were queued up at the

CASE 1: SYSTEM UTILIZATION PER SHIFT

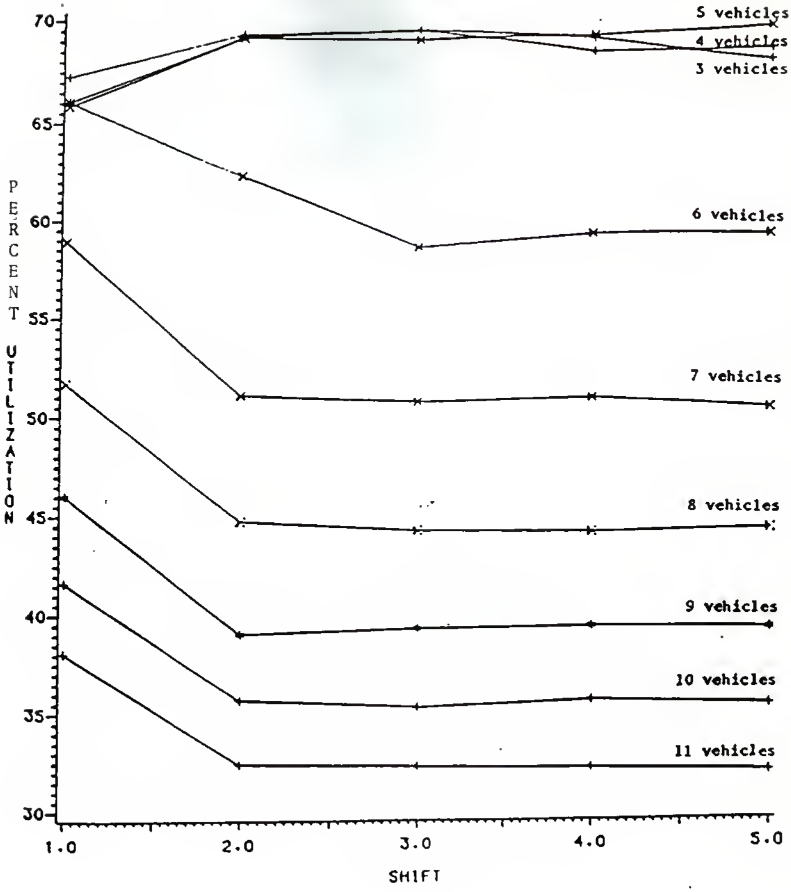


FIGURE 2.

input stations as the simulation began.

From Figure 3, system utilization is averaged over all five shifts for each level of vehicles. The difference between the averages can be explained by two factors. The first factor, which causes decreased utilization, is that if there are more vehicles in the system, jobs are handled more quickly with minimal job pickup waiting time. This provides the vehicles with "free time", which is spent in the park area. As stated before, time spent in the park area is not considered work and thus detracts from utilization. This factor is called the vehicle's "added reserve capacity" and describes that vehicles ability to handle more jobs per hour.

The second factor, which also detracts from system utilization, is increased waiting time caused by the addition of more vehicles to the system. By increasing the number of vehicles the AGV path becomes congested and blocking occurs. The waiting time is not considered work and thus not factored into system utilization. This factor is called "additional congestion".

Figure 3, shows that once you get to five vehicles there is no difference in the average utilization as vehicles are removed from the system. This indicates that there is no added reserve capacity or additional congestion when the system is run with 3, 4, or 5 vehicles.

When the number of vehicles is increased from five, there is a decrease in utilization as each vehicle is added. As more vehicles are added not only is the reserve capacity

CASE 1: AVERAGE SYSTEM UTILIZATION PER CAR

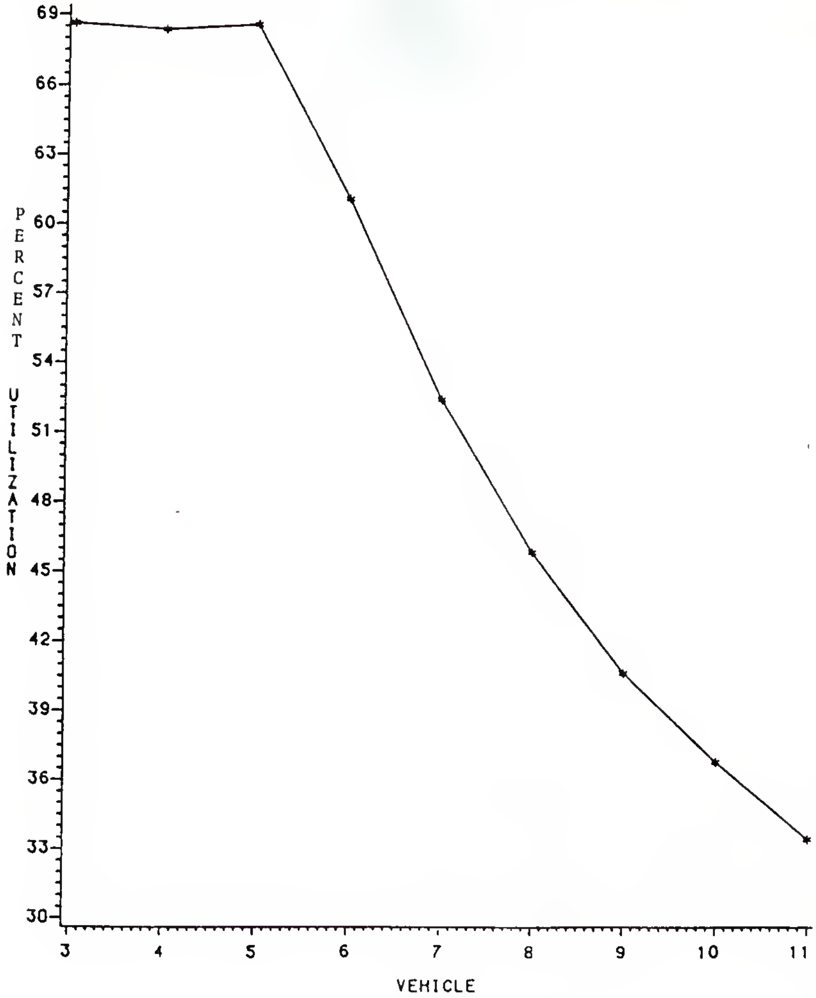


FIGURE 3.

increased (more vehicles do more jobs) but so is additional congestion (more vehicles, more blocking){see Table 1}.

The measurements of system efficiency can be seen in Figure 4. As with system utilization, system efficiency increases as the number of vehicles decreases. The values plotted in Figure 4 are cummulative efficiency. For 8, 9, 10, and 11 vehicles the system efficiency levels off at values that are banded within a range of 1.5%. This indicates that with eight or more vehicles the system runs at basically the same efficiency. All are putting the same number of vehicles into the system to process the input load rate. Whenever there is a call from an input to do a job, a vehicle is promptly dispatched with no job pickup waiting besides the travel time to the input. With this many vehicles there is always at least one in the parking area waiting for dispatch.

As the number of vehicles is decreased the efficiency increases. Because there are fewer vehicles in the system, waiting time is reduced. For 7 vehicles there is a jump of 2% from the group of 8, 9, 10, and 11 vehicles. For 6 there is an increase of over 2% from 7 vehicles.

As can be seen from Figure 5, from 6 vehicles to 3 vehicles the slope of the efficiency increase is less than from 11 to 6 vehicles. This indicates that the waiting time is not dramatically reduced by removing a vehicle from the system at this point.

# of vehicles	average wait time	average park time
3	71.4	0
4	143.2	0
5	176.0	0
6	315.2	2137
7	543.8	5424
8	738.0	8751
9	825.0	12116
10	790.0	15763
11	880.2	19107

Table 1: Average wait and park time - seconds per shift

CASE 1: SYSTEM EFFICIENCY PER SHIFT

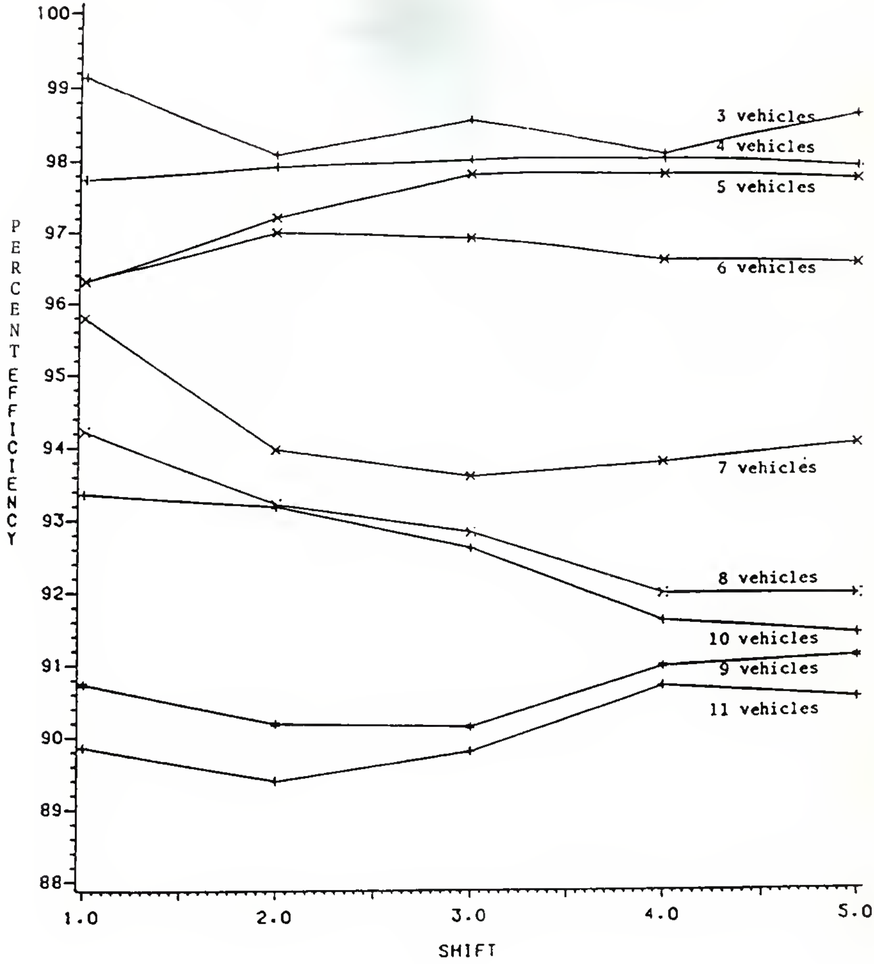


FIGURE 4.

CASE 1: AVERAGE SYSTEM EFFICIENCY PER CAR

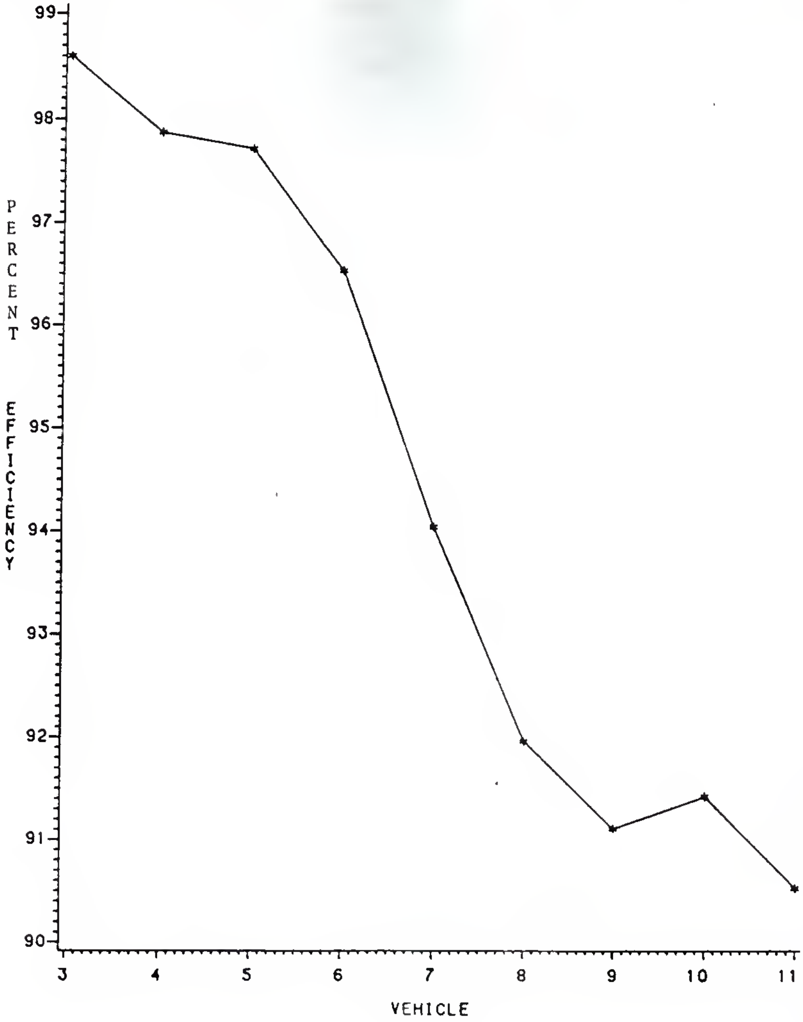


FIGURE 5.

For a system with 3, 4, or 5 vehicles, the vehicles are being utilized to their maximum, hence waiting time is kept at a minimum. The system efficiency range at this level is less then 1%. By increasing the number of vehicles to 6 the system efficiency is reduced just over 1%. Then larger drop-offs in efficiency occur until after 8 vehicles the efficiency levels off because the system will use only a certain number of vehicles at one time to process loads.

Jobs completed per shift is, of course, the ultimate goal of any system. A job completion rate must be met, in this case 80 jobs per hour. As would be expected, as the number of vehicles are increased the number of jobs completed increases. As Figure 6, shows 3 or 4 vehicles could not handle the load of 80 jobs per hour. Five vehicles are marginally enough, being able to complete 80 jobs in one of its shifts. For a system with 6, 7, 8, 9, 10, or 11 vehicles the job completion rate of 80 jobs per hour is easily met.

By pre-loading the system with sixteen jobs, the capacities of systems with a different number of vehicles can be checked. As would be expected with 3, 4, or 5 vehicles the system is running at maximum capacity and there is no drop in number of jobs done over the length of the simulation. But with six or more vehicles the capacity is much higher than 80 jobs per hour (from 92 jobs for six vehicles to at least 102 jobs for 11 vehicles).

Figure 7 shows the average number of jobs completed by each of the levels. It clearly shows the point at which

CASE 1: JOBS COMPLETED PER SHIFT

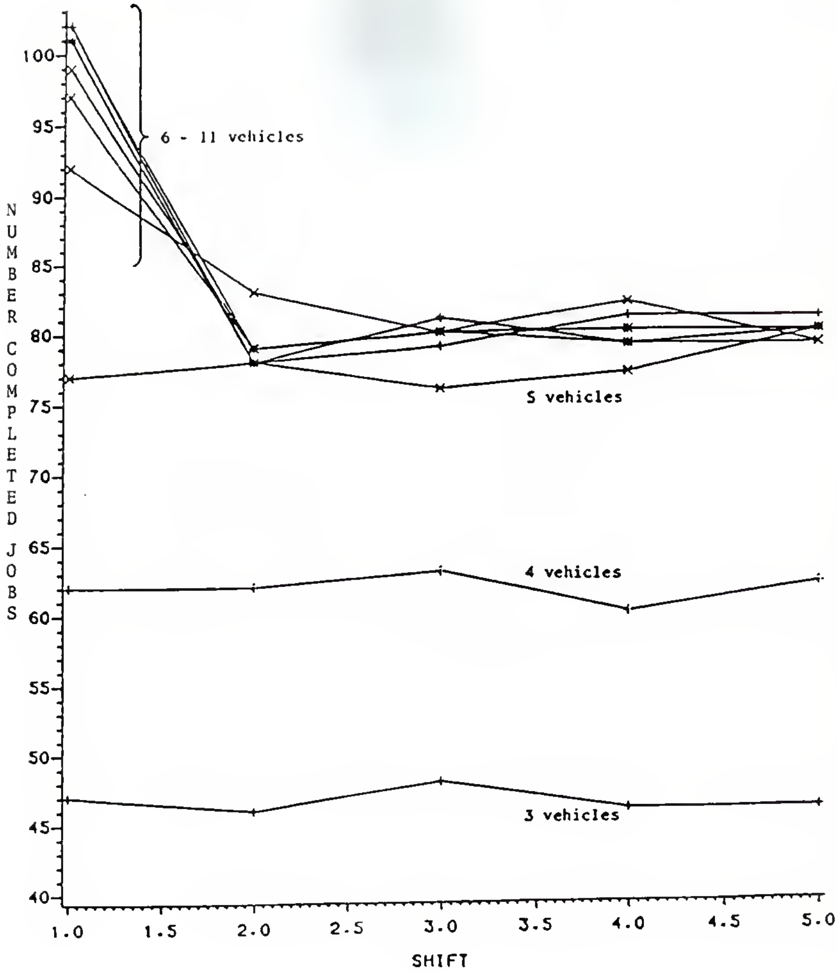


FIGURE 6.

CASE 1: AVERAGE JOBS COMPLETED PER CAR

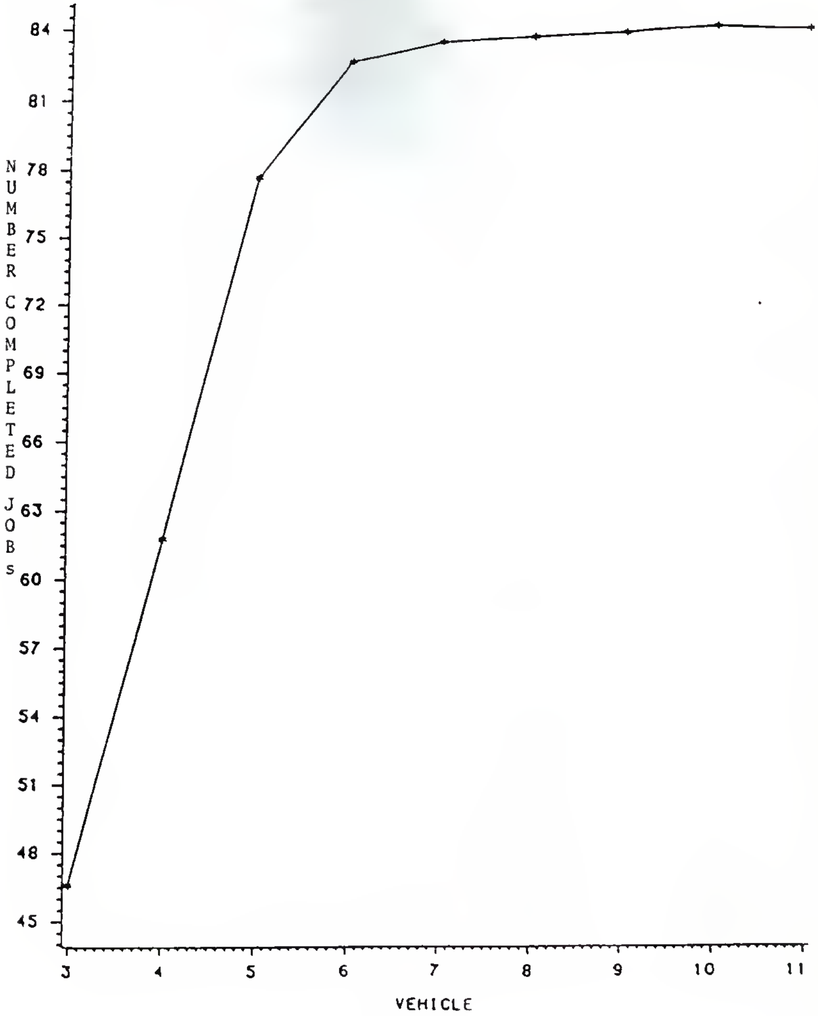


FIGURE 7.

there are enough vehicles to process the system load.

For the study of block sizing 5 and 6 vehicles were run in the simulation. Block sizing analysis consists of varying the maximum size of the travel blocks which only one vehicle can occupy at one time. There are three different block sizes used in this analysis. The first size was the maximum possible sized blocks for this system. The maximum block travel time in this case is 24 seconds and there were a total of 41 blocks. The second case set the maximum block size at 14 seconds travel time and there were a total of 50 blocks. The third case set the maximum block size at seven seconds and there were a total of 70 blocks. The basic concept is the greater the number of blocks the smaller the waiting time in the system. The simulation was run for 10 shifts and the effects of block sizing were monitored on system utilization, system efficiency, and job completion.

The effects of block sizing on system utilization can be seen in Figure 8 for 5 vehicles and Figure 9 for 6 vehicles. For 5 vehicles the largest difference in block system utilization is 2.37% at any one shift and the different block sizes follow the same general pattern over the 10 shifts. For 6 vehicles the system utilization is effectively the same for all three block sizes. A possible explanation for the variability of block system utilization for 5 vehicles, as compared to 6 vehicles, is that there was no added reserve capacity. For 6 vehicles there was added reserve capacity which could be put into use when the number of blocks was decreased and waiting time increased.

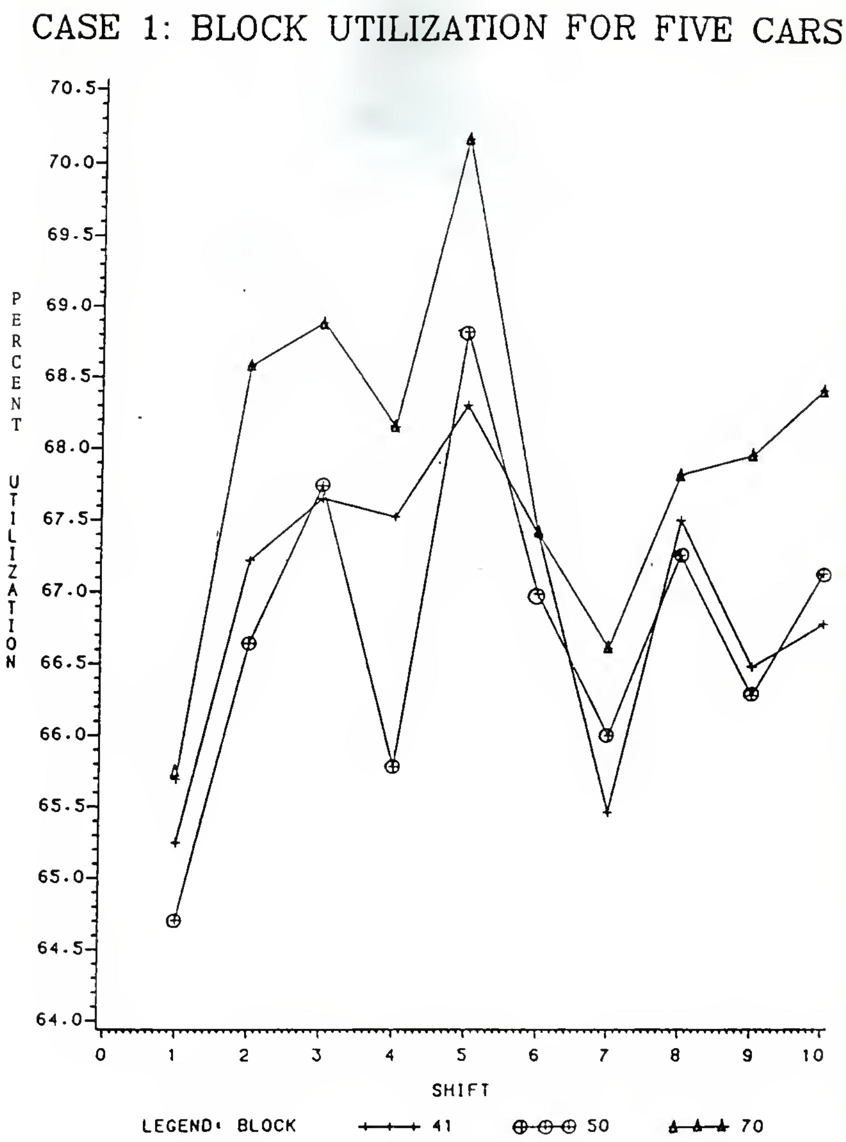

CASE 1: BLOCK UTILIZATION FOR FIVE CARS
PERCENT UTILIZATION
70.5
70.0
69.5
69.0
68.5
68.0
67.5
67.0
66.5
66.0
65.5
65.0
64.5
64.0
0
1
2
3
4
5
6
7
8
9
10
SHIFT
LEGEND: BLOCK
41
50
70

FIGURE 8.

CASE 1: BLOCK UTILIZATION FOR SIX CARS

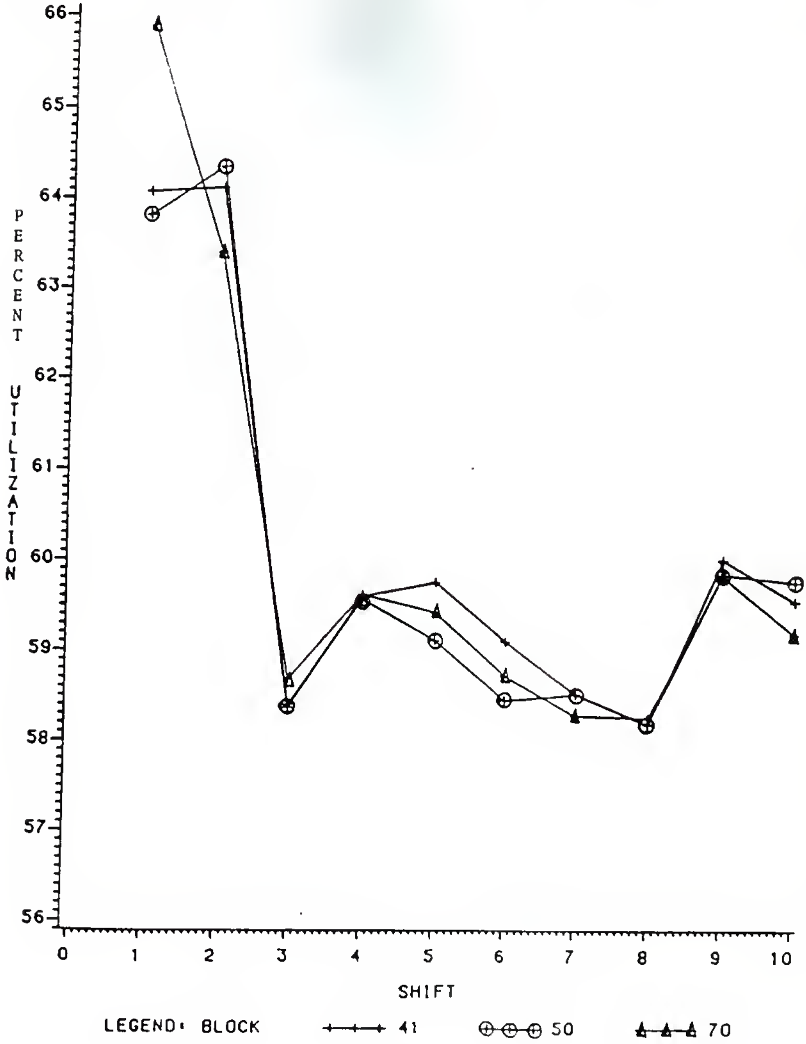


FIGURE 9.

This is further substantiated by seeing the effect block sizing has on system efficiency for 5 vehicles in Figure 10 and six vehicles in Figure 11. For both 5 and 6 vehicles there is a small difference in efficiency between the 70 and 50 block runs (70 block having the higher efficiency in both cases). But when the block number was reduced to 41 the efficiency drop was dramatic in both cases. With longer blocks, there is more waiting time and since a 5 vehicle system has no reserve capacity to make up for lost waiting time the system utilization is not constant. But a 6 vehicle system has reserve capacity to make up for this lost waiting time and hence system utilization remains constant. The waiting time for a 6 vehicle system, in larger blocks, is the time spent in the area in smaller sized blocks.

This explanation is also appropriate for the block sizing effect on job completion seen in Figure 12 for 5 vehicles and Figure 13 for 6 vehicles. For 5 vehicles fluctuation in job completion is experienced for different block sizes, while for 6 vehicles the job completion rate remains relatively constant for different block sizes. The largest variation for a system run with 5 vehicles is five jobs between block size for any one shift and for a 6 vehicle system it is two jobs. Again the explanation is that if during a shift an excessive time is spent in waiting for blocks to become empty, a 5 vehicle system has no reserve capacity to make up the difference and hence fewer jobs are processed. But a 6 vehicle system has reserve

CASE 1: BLOCK EFFICIENCY FOR FIVE CARS

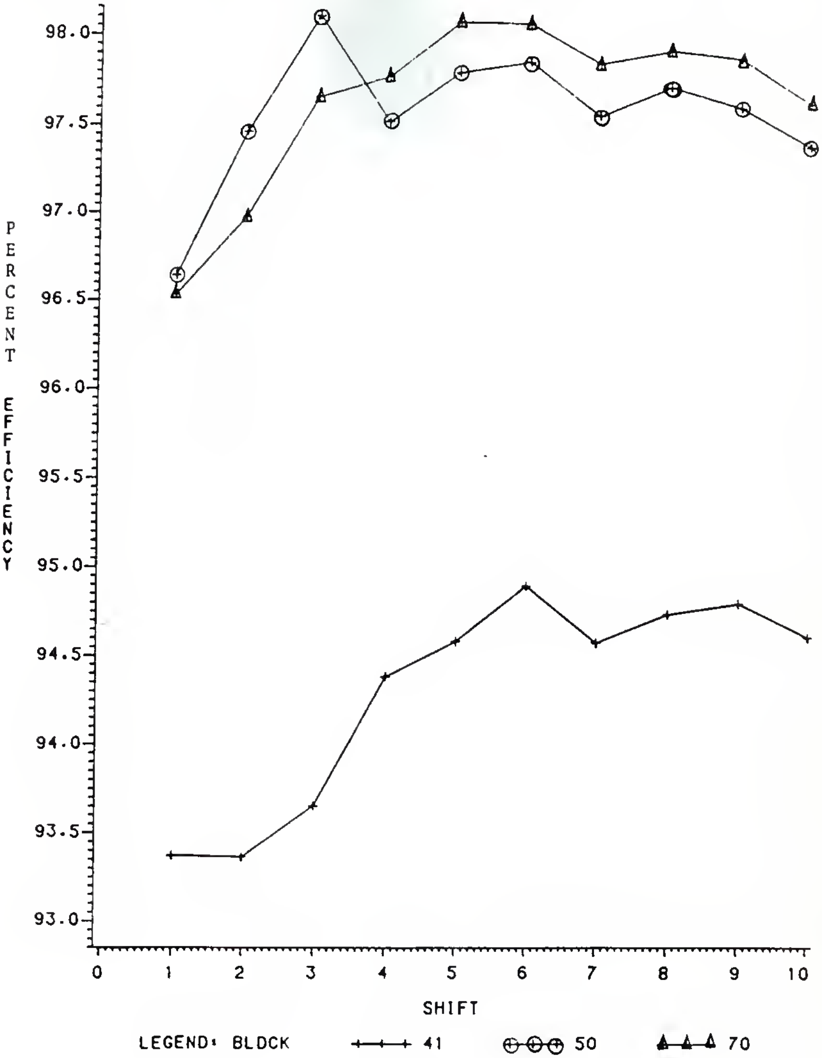


FIGURE 10.

CASE 1: BLOCK EFFICIENCY FOR SIX CARS

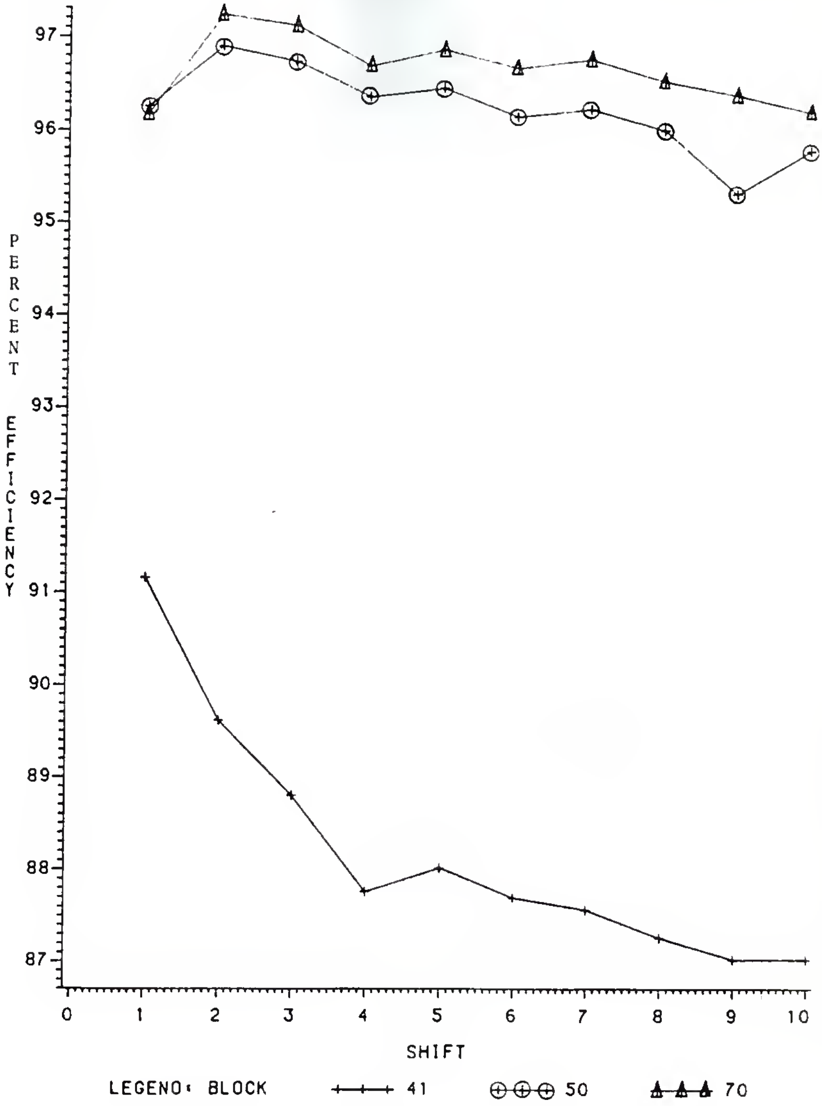


FIGURE 11.

CASE 1: BLOCK JOBS FOR FIVE CARS

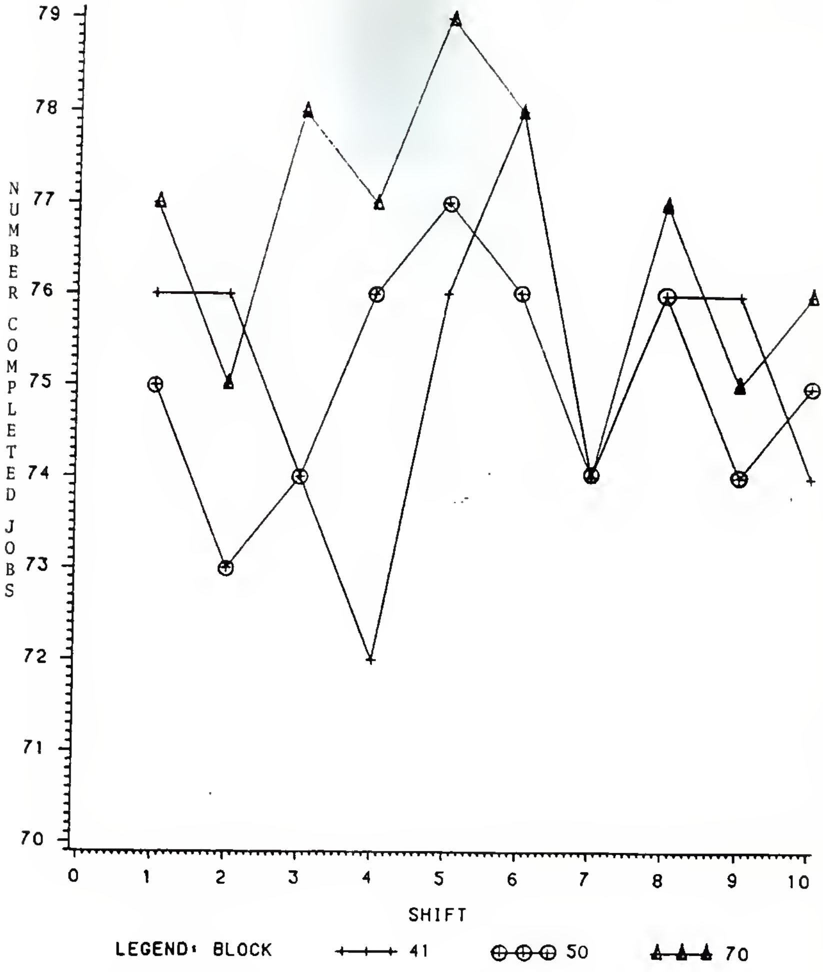


FIGURE 12.

CASE 1: BLOCK JOBS FOR SIX CARS

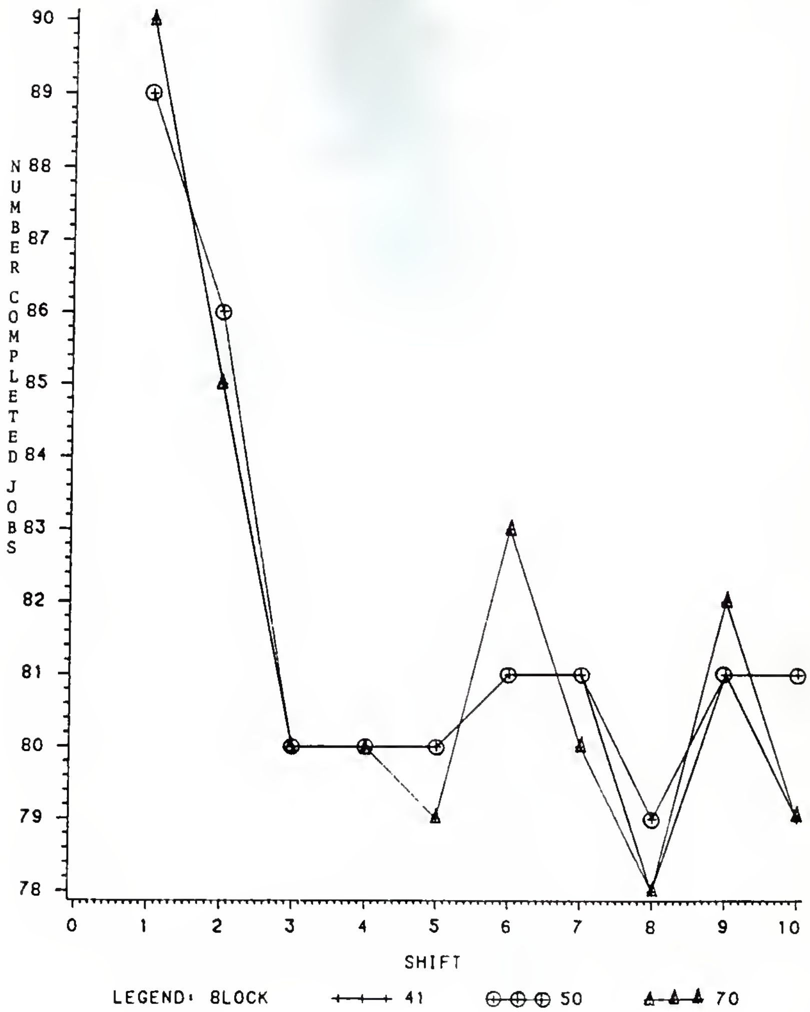


FIGURE 13.

capacity and can make up for lost waiting time and thus process the required jobs.

To investigate the reserve capacity hypothesis, waiting times per shift were plotted for 5 (Figure 14) and 6 vehicles (Figure 15) at the different block sizes. The difference in the waiting time graphs are obvious. The 6 vehicle system waiting times are clearly defined and separated while in the 5 vehicle system the different block size waiting times are intertwined. This is because there is an extra vehicle in the 6 vehicle system and more blockage occurs as the number of blocks is decreased. On the other hand the 5 vehicle system has one less vehicle and thus is less affected by the decrease in the number of blocks.

In Figure 16, system utilization is plotted versus waiting time for the 5 vehicle system and regression lines fitted to the points for each block size. There is a definite linear relationship that shows that when waiting time is increased utilization decreases. This is explained by the lack of reserve capacity for 5 vehicles. The presence of reserve capacity for 6 vehicles allows the system utilization (Figure 9) to remain constant even though the waiting time varies from 160 seconds/shift for the 70 block system to 1360 seconds/shift for the 41 block system.

In Figure 17, completed jobs are plotted versus waiting time for the 5 vehicle system and a regression line fitted to the points for each block size. There is a linear relationship that showing that as waiting time is increased

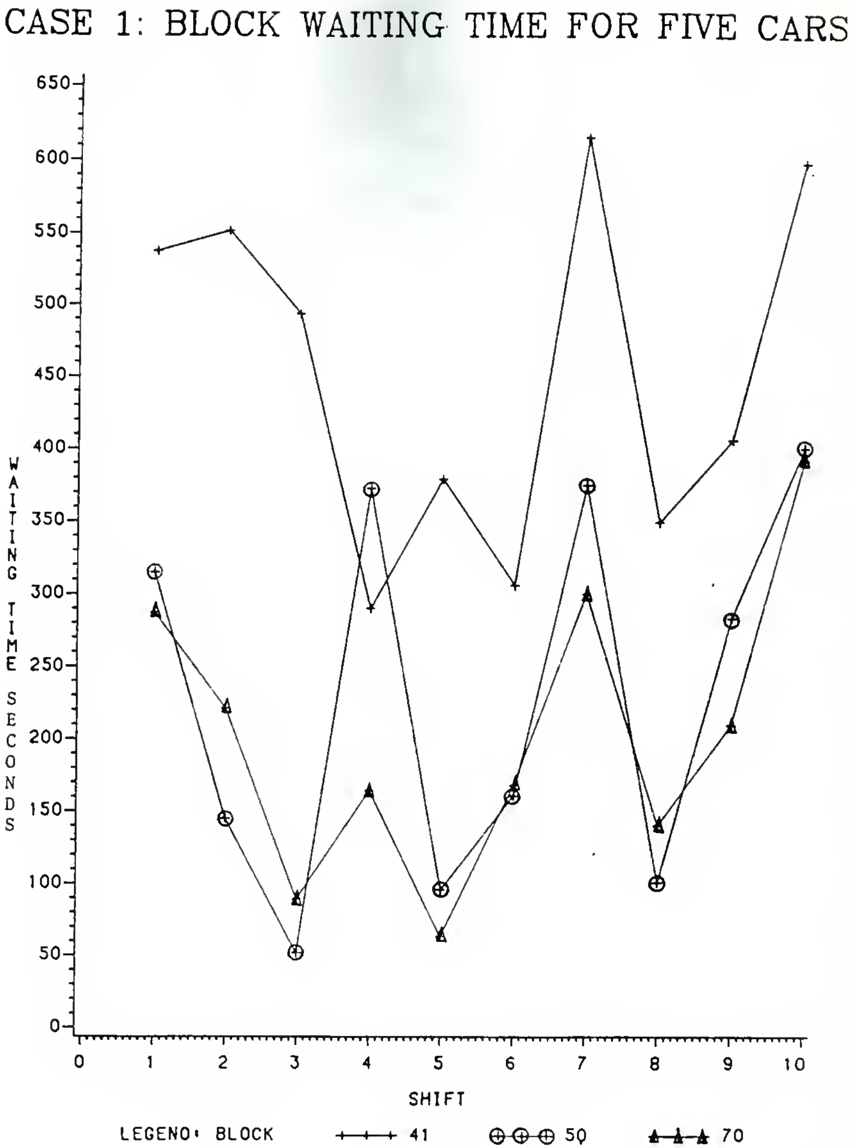

CASE 1: BLOCK WAITING TIME FOR FIVE CARS
WAITING TIME SECONDS
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
SHIFT
LEGEND: BLOCK 41 50 70

FIGURE 14.

CASE 1: BLOCK WAITING TIME FOR SIX CARS

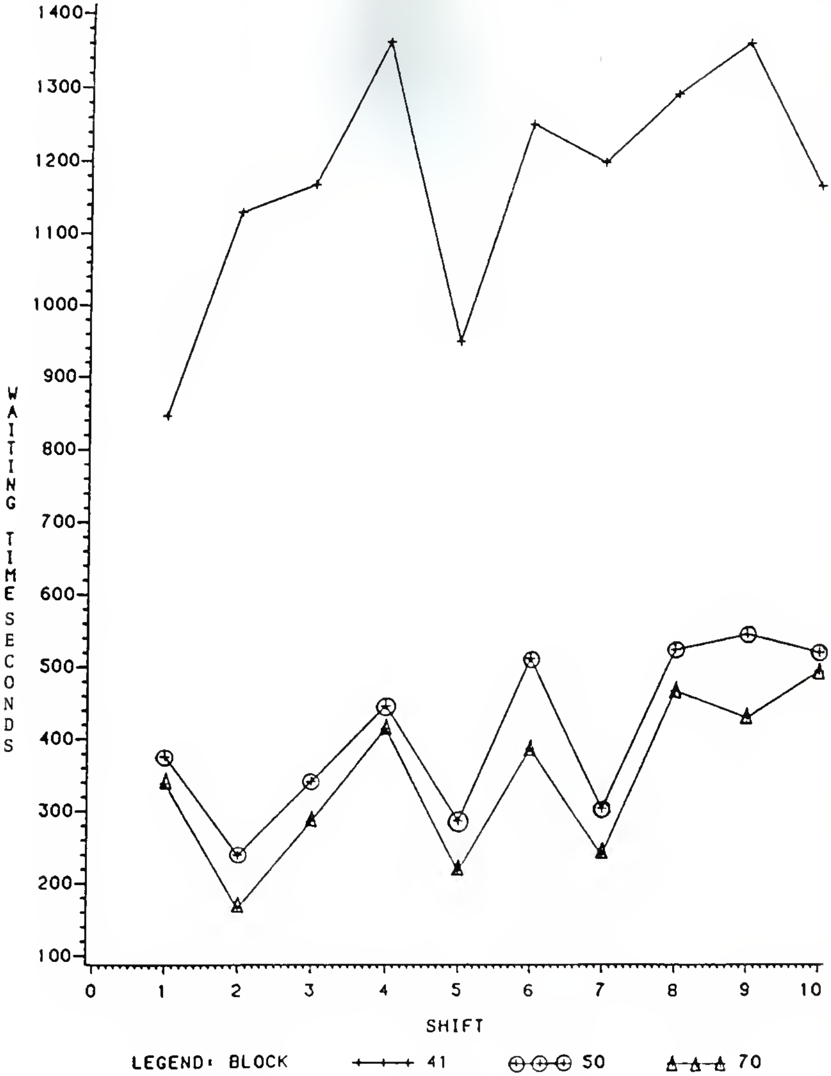


FIGURE 15.

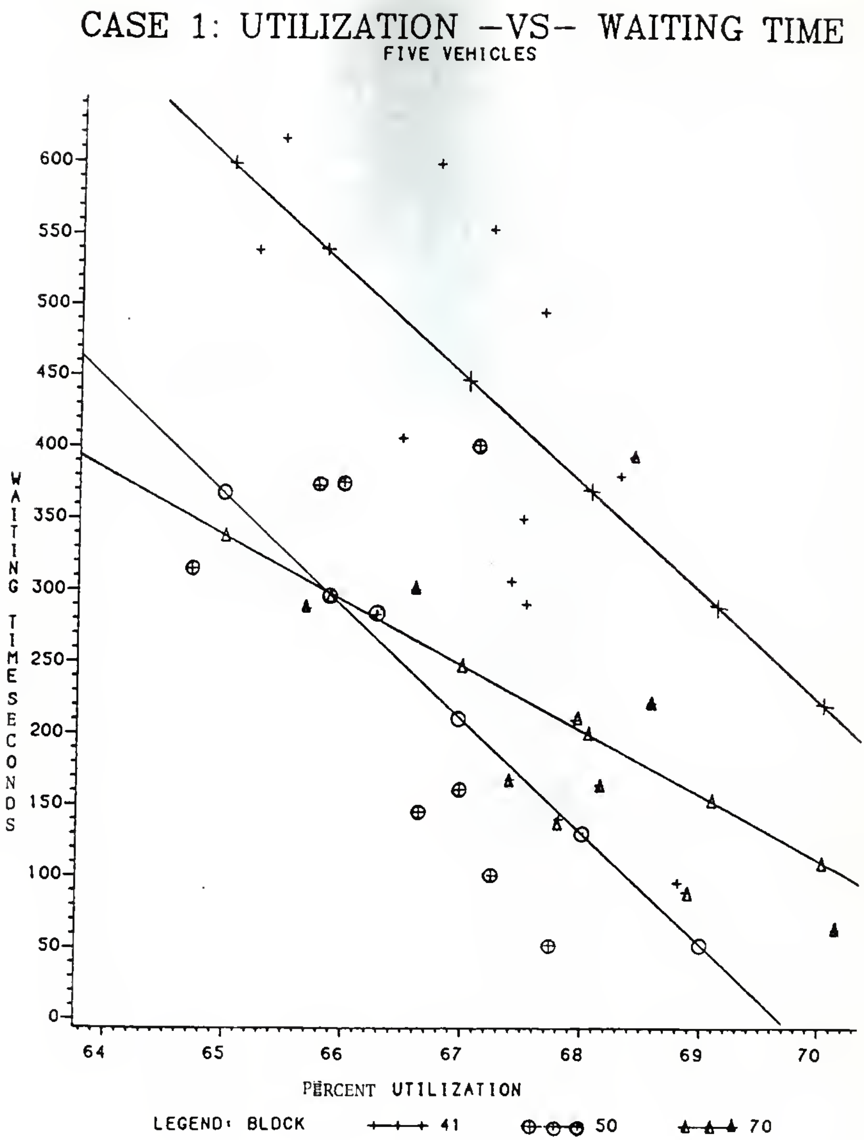

CASE 1: UTILIZATION -VS- WAITING TIME
FIVE VEHICLES
WAITING TIME SECONDS
600
550
500
450
400
350
300
250
200
150
100
50
0
64
65
66
67
68
69
70
PERCENT UTILIZATION
LEGEND: BLOCK
41
50
70

FIGURE 16.

CASE 1: JOBS -VS- WAITING TIME

FIVE VEHICLES

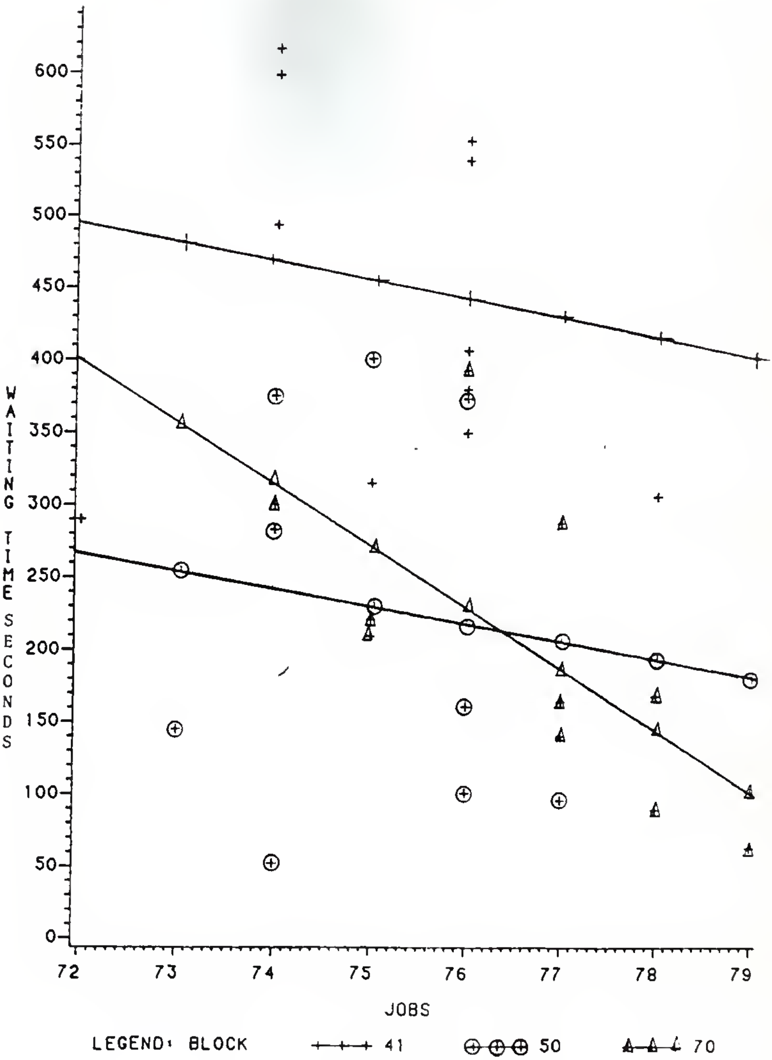


FIGURE 17.

the number of jobs completed decreases. Again the explanation is the lack of reserve capacity to compensate for the lost time to waiting. Job completion (Figure 13) remains constant for 6 vehicles for all block sizes as its reserved capacity is able to make up for the lost time to waiting and complete the shift loads.

The overall conclusion is that the reserve capacity regulates the effect that blocking has on the total performance of a system. The lack of reserve capacity combined with a reduction in the number of blocks causes a decline in system efficiency plus a loss in system utilization and jobs completed. Likewise, the availability of reserve capacity permits the reduction of the number of blocks with no adverse effect, although a drop in efficiency is experienced, on system utilization or jobs completed.

CASE 2

The second AGVS studied is one that has yet to be installed by a local manufacturer. There was no guidepath although a blueprint of the manufacturing workplace was provided. This included the position of all inputs and outputs. Also provided was a "from-to" chart which tells the number of jobs going from any particular input to any particular output per shift. Vehicle speed, input time, and output time were also provided. No park area was designated so the author placed one at his own discretion. A refuel area was not included for its effects were not desired for this study. The purpose of Case 2 is the development of a procedure to create a workable AGVS. The concepts developed to do this are:

(1) loadfeet directioning
(2) vehicle estimating
(3) cutoff implementation
(4) block division.

Through these procedures reduction in the number of vehicles will be achieved along with increased utilization and efficiency.

Loadfeet directioning, which is a pre-simulation procedure, is the decision making process on which direction the traffic should flow on a AGV circuit. After a simple guidepath has been proposed (usually by connecting all inputs and outputs with a straight line configuration), the first step is to cut up the guidepath into separate sections between decision points (input stations, output stations, turnoffs, etc.). The flow of jobs is calculated across each section for all possible traffic patterns. The flow of jobs for each section is multiplied by its section length and summed over the whole system for each particular traffic pattern. The resulting value is in units of load-feet. The sums for each of the traffic pattern are compared and the one with the smallest value is adopted as the traffic pattern.

Vehicle estimation, also a pre-simulation procedure, is the prediction of the range of the number of vehicles needed to handle the AGVS load. A "from-to" chart for the AGVS is needed to complete this procedure. The number of loads per shift moved from each input to each output is multiplied by the distance between them and summed over the entire system. The resulting sum is in feet per shift and it is divided by the vehicle speed (in feet per second) to obtain the total vehicle travel seconds needed per shift.

$$\frac{\text{vehicle travel}}{\text{seconds per shift}} = \frac{\text{section distance X section load}}{\text{vehicle speed}}$$

Add this to the total number of jobs moved per shift multiplied by the load time plus the unload time and the result is the vehicle work seconds needed per shift.

$$\text{vehicle work seconds per shift} = \text{vehicle travel seconds} + \left| \text{\# jobs per shift} \times \text{load/unload seconds} \right|$$

Convert this into minutes and divide by 8 hours per shift to obtain the number of vehicle work minutes needed per hour.

$$\frac{\text{vehicle work}}{\text{minutes per hour}} = \frac{\text{vehicle work seconds per shift}}{\text{(60 seconds/minute X 8 hours/shift)}}$$

At this point Kulweic (5) suggests dividing this value by 85 which he calls the "traffic congestion factor". The "traffic congestion factor" is merely a representation of system efficiency developed in Case 1. The writer believes this is a conservative estimate and would suggest using a system efficiency of 95 percent. The vehicle work minutes per hour should also be divided by 60 minutes per hour and the result is an estimate of the number of vehicles needed when waiting time is taken into account.

$$\frac{\text{\# vehicles needed}}{\text{(waiting time included)}} = \frac{\text{vehicle work minutes per hour}}{\text{(efficiency factor X 60 minutes/hr)}}$$

Vehicle utilization must also be taken into account and Kulweic (5) suggests dividing this vehicle number by an "idle time factor" ranging from .6 to .8. The reader recognizes this "idle time factor" as a substitute for system utilization developed in Case 1. From the evidence previously presented the author believes this to be too liberal a utilization range and suggests the use of a range between 50 and 80 percent. The resulting is a range in which the number of vehicles needed to handle the present AGVS work requirement is included.

$$\text{range of \# of vehicles needed (including utilization)} = \frac{\text{vehicles needed (waiting included)}}{\text{utilization range}}$$

Cutoff implementation is a process to determine where possible cutoffs or shortcuts are needed in the AGVS guidepaths to shorten travel distances between input stations and output stations. This is done by the analysis of area job movement. The "from-to" chart is also needed for this procedure.

The "from-to" chart is used to develop an I x J matrix where I represents the system input stations and J represents the system output stations. The number of jobs that are required to travel from a particular input (i) to a particular output (j) is placed in the matrix position represented by the values in (i,j).

The collapse of the matrix over inputs and outputs is then performed. This collapse is done by stations which are in the same general area. It is to up the user's discretion how far he or she wishes to collapse. If the matrix is not collapsed enough station job movement is represented instead of area job movement. If the matrix is collapsed too much, area job movement is eliminated by the collapsing over areas after collapsing over stations.

When the area job movement matrix is completed each value in the matrix is evaluated. First, it must be determined at what job movement value the designer wishes to have travel distance reduced. If there are only a minimal number of jobs which travel a certain route, it may not be feasible to create a cutoff to reduce travel distance. Secondly, it must be determined, if a matrix value exceeds the designer's minimal job movement value, if the distance travelled is excessive. For some movement of jobs there is no way to reduce the distance travelled. For example, if two areas are connected by a straight section of guidepath there is no cutoff that could reduce the travel distance. If the distance is deemed to be excessive and a cutoff is called for, possible solutions should be investigated to connect the two areas.

Block division is the process of determining where waiting time is occurring, and dividing these congested blocks into smaller, more efficient ones (i.e., more vehicles can occupy the same total length of the larger blocks). The macros, which were previously developed using GPSS-H, have the property of allowing only one vehicle to gain control at one time. If there is a vehicle inside a macro, other vehicles wishing entry must wait until the first vehicle departs the macro. This is representative of the blocks of track in a AGVS which allows only one vehicle to enter at one time.

In block division, the facilities, which represent these blocks of tracks within the macro, are converted to storages which have unlimited capacity. Facilities in GPSS-H have the property of allowing only one transaction (which represents a vehicle) to seize it at one time. Likewise, a storage in GPSS-H has the property of allowing a specified number of vehicles to seize it at one time (in block division the storage capicity is infinite). The simulation yields the maximum number of vehicles requesting simultaneous occupancy of each block (storage) during the the run. This is representative of the number of vehicles which wanted to seize a block of track at one time. If this maximum is 2 or greater this indicates waiting time has been incurred. The object of the storage substitution is to take the blocks with the largest number of vehicles requesting entries and to divide them into smaller blocks.

This should be done in conjunction with the facility simulation to monitor increased efficiency. With this increased efficiency comes the beneficial increase in reserve capacity. The block division process can be repeated until the increase in efficiency is deemed not significant enough to warrent continuation. Another way is to set the maximum number of vehicles allowed in any one block and use block division until all blocks have values less than that level.

Case 2 has 18 inputs and 17 outputs. There is one park area which was positioned by the author. Vehicle travel time is 2.8 feet/second and job load and unload times are 50 seconds. Job inputs are predetermined and jobs arrive at a uniform rate.

The four guidepath concepts were applied to Case 2 and their effects measured. After each step a table is updated which shows the procedure used in Case 2. The first step was to lay down a basic guidepath. This was done as simply as possible by connecting the inputs and outputs in a straight line configuration represented by Figure 18. Improvements on this by the removal of obstacles would have been possible but we were not at liberty to rearrange the work environment.

The guidepath was then separated into blocks between decision points. Using the "from-to" chart (see Table 2) job flow was measured across each section in both the clockwise and counterclockwise directions. These job flow totals were multiplied by the block lengths and the load-feet totals were summed for each direction (see Table 3). For the clockwise direction the system load-feet was 359,149 compared to 388,004 load-feet for the counterclockwise direction. The clockwise direction was adopted because of its smaller load-feet total.

PROCEDURAL SUMMARY 1.

step	description	dir	eff	util	veh range	needed veh	cngstd blocks
1	loadfeet analysis	clock wise					

Vehicle estimation was then performed. The calculations are as follows:

$$\text{total vehicle seconds/shift} = \text{vehicle travel seconds/ shift} + \text{load \& unload seconds/shift}$$

$$= 135240 + 41400$$

$$= 176640 \text{ seconds/shift}$$

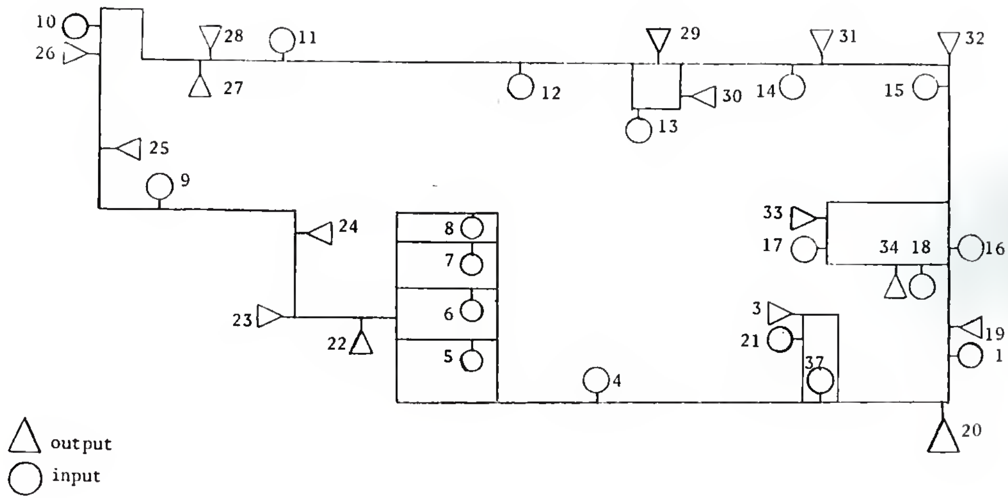


Figure 18 : Basic Guidepath for Case 2.

INPUT	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
1			.8		.2		.4	.4	.4		.7	.1					3.0
2	3.6			1.0	5.6												10.2
3	16.2	.4		.2			.2	2.8	.2								20.0
4	33.8	.2															34.0
5	10.7										.1						10.8
6	9.6																9.6
7	10.7										.1						10.8
8	5.2	.4	1.4	10.4	8.0			1.0			5.0	.6	12.4		1.4		45.8
9	4.8		2.0	.6	1.6			2.1			2.8	.4	1.2		11.1	1.0	27.6
10	.4		.2	2.2		2.4					.7	.1			4.8	.2	11.0
11				12.8	3.8						1.2	.1	3.8				21.7
12	2.8	.6		2.2	3.2			.9			1.3	.2	2.2		.2		13.6
13	4.6		.4	1.4	1.2	.2	.8	1.2		3.3			.2		.6		13.9
14	45.2		.8	.8	9.4			.2		.4							56.8
15	2.8																2.8
16		5.2	16.4	24.8	21.1	.4	4.0	5.6	1.8	1.0	12.4	1.8	1.6	2.9	5.8	.2	105.0
17	7.8			.4			4.4	.2		3.9	.7	.1	.2				17.7
18	.2						.2		.2	.2	.2						1.0
	158.4	6.8	22.0	56.8	54.1	3.0	10.0	14.4	2.6	8.8	25.2	3.4	21.6	2.9	23.9	1.4	415.3

(Column header: OUTPUT)

Table 2 : Case 2 From-To chart.

BLOCK	DISTANCE (FEET)	CLCKWS LOADS	CNTRCLCKWS LOADS	CLCKWS LOAD-FT	CNTRCLCKWS LOAD-FT
1	182	206.9	129.2	37674	23478
2	104	10.8	10.8	1123	1123
3	140	9.6	9.6	1344	1344
4	172	10.8	10.8	1858	1858
5	192	45.8	45.8	8794	8794
6	52	229.9	187.0	11955	9724
7	60	175.0	240.1	10500	14406
8	164	171.2	243.1	28077	39868
9	104	189.4	225.5	19698	23452
10	68	188.7	225.5	12832	15334
11	132	186.3	228.9	24592	30215
12	36	196.8	230.3	7085	8291
13	188	195.8	218.6	36810	41097
14	80	209.4	205.0	16752	16400
15	32	206.0	216.3	6602	6922
16	96	17.3	17.3	1661	1661
17	48	194.7	219.7	9346	10545
18	91	229.9	184.0	20921	16744
19	88	230.8	184.6	20310	16245
20	96	25.3	32.0	2429	3072
21	100	20.1	25.3	2010	2530
22	40	204.5	165.9	8180	6636
23	56	223.2	191.0	12499	10696
24	32	175.9	240.6	5629	7699
25	88	166.9	246.4	14687	21683
26	24	155.1	218.4	3722	5323
27	152	41.6	41.0	6232	6232
28	152	169.9	214.2	25825	36632
				359147	388004

Table 3 : Case 2 Loadfeet directioning.

$$\text{total vehicle minutes/hour} = \frac{\text{total vehicle seconds per shift}}{\text{60 seconds/minute X 8 hours/shift}}$$

$$= \frac{176640}{60 \text{ X } 8}$$

$$= 368 \text{ minutes/hour}$$

$$\text{vehicles needed (with waiting)} = \frac{\text{vehicle minutes per hour}}{\text{efficiency factor X 60 minutes/hour}}$$

$$= \frac{368}{.95 \text{ X } 60} = 6.456 \text{ vehicles}$$

$$\text{vehicle range needed} = \frac{\text{vehicles needed (with waiting)}}{\text{utilization factor}}$$

$$= \frac{6.456}{.5 \text{ and } .8}$$

$$= 8.07 \text{ to } 12.91 \text{ vehicles}$$

The range indicates that the simulation should be run with 8,9,10,11,12 and 13 vehicles.

PROCEDURAL SUMMARY 2.

step	description	dir	eff	util	veh range	needed veh	cngstd blocks
1	loadfeet analysis	clock wise					
2	vehicle estimation				8-13		

Simulation of the system with this proposed range of vehicles using the GPSS-H macros was the next step. Eleven vehicles was found to be the minimum number that could handle the load. The system efficiency was 91.18 indicating there were significant amounts of waiting time. The system utilization was 52.57 which is also relatively low and worth further investigation.

PROCEDURAL SUMMARY 3.

step	description	dir	eff	util	veh range	needed veh	cngstd blocks
1	loadfeet analysis	clock wise					
2	vehicle estimation				8-13		
3	simulation		91.18	52.57		11	

Cutoff analysis was then applied to the system. The inputs and outputs were grouped by their relative location around the guidepath. The inputs into 5 groups and the outputs into 4 groups as shown in Table 4 . A job flow matrix was developed for jobs going from a given group of inputs to a given group of outputs (see Table 4). Any matrix value with a job flow greater then 10 was considered to see if a cutoff could be made to reduce significantly the travel distance. The matrix values for which the travel distance was deemed not significantly effected by a possible cutoff were (4,1),(5,1),(3,4),(5,3) and (2,2). The matrix values for which a possible cutoff was deemed a significant reduction in travel distance were (1,1), (2,1), (4,2), (5,2), (5,3), (2,4), and (5,4). The cutoffs investigated

	OUTPUT GROUP				
INPUT GROUP	1	2	3	4	ROW TOTAL
1	55.0	7.0	4.4	.8	67.2
2	38.0	18.4	1.0	19.6	77.0
3	7.4	6.8	2.1	22.3	38.6
4	54.4	35.0	6.8	9.8	106.0
5	32.4	46.7	21.5	25.9	126.5
COLUMN TOTAL	187.2	113.9	35.8	78.4	415.3

INPUT GROUPING:

Group 1- input stations 1, 2, 3, and 4.
Group 2- input stations 5, 6, 7, and 8.
Group 3- input stations 9 and 10.
Group 4- input stations 11, 12, 13, and 14.
Group 5- input stations 15, 16, 17, and 18.

OUTPUT GROUPING:

Group 1- output stations 19, 20, and 21.
Group 2- output stations 22, 23, and 24.
Group 3- output stations 25, 26, 27, and 28.
Group 4- output stations 29, 30, 31, 32, 33, and 34.

Table 4 : Case 2 Job Flow Matrix

were to alleviate the travel distance for (1,1), (2,1), (2,4), and (5,4). The procedure to institute the cutoffs was to connect the groups of stations with straight lines but again with regard to immobile obstacles. The system with the proposed cutoffs is represented in Figure 19.

Vehicle estimation was then reperformed and the range computed was 6.30 to 10.15 vehicles. These results indicate that the simulation should be run with 6,7,8,9, 10, and 11 vehicles.

PROCEDURAL SUMMARY 4.

step	description	dir	eff	util	veh range	needed veh	cngstd blocks
1	loadfeet analysis	clock wise					
2	vehicle estimation				8-13		
3	simulation		91.18	52.57		11	
4	cutoff analysis						
5	vehicle estimation				6-11		

From the resulting simulation of the modified system, 8 vehicles were found to be the minimum number that could handle the load. The effectiveness of the cutoffs is noticed immediately by the reduction of 3 vehicles needed to handle the load. System efficiency and system utilization are also increased to 92.07 and 55.45, respectively. This can be explained by the reduction of

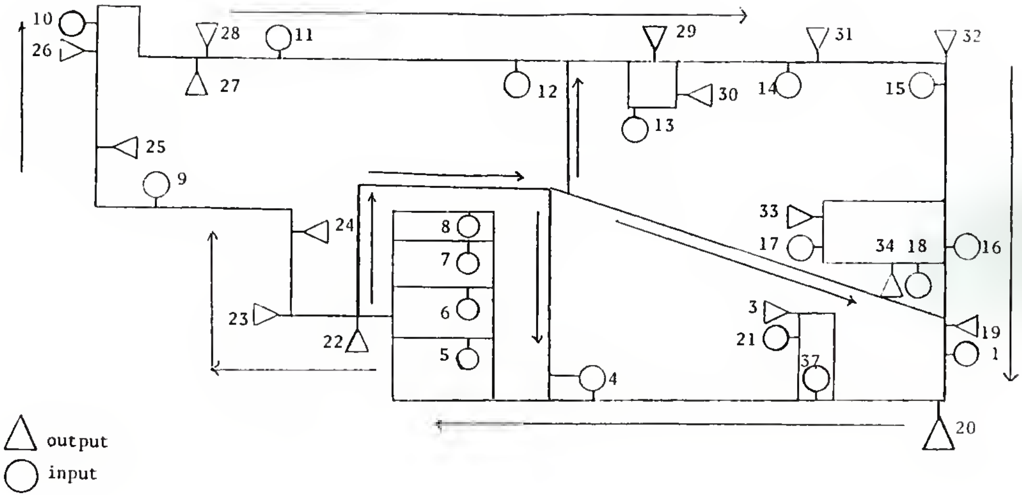


Figure 19 : Proposed Cutoffs for Case 2.

vehicles which reduces waiting time and the implementation of the cutoffs which reduces unloaded vehicle travel time.

PROCEDURAL SUMMARY 5.

step	description	dir	eff	util	veh range	needed veh	cngstd blocks
1	loadfeet analysis	clock wise					
2	vehicle estimation				8-13		
3	simulation		91.18	52.57		11	
4	cutoff analysis						
5	vehicle estimation				6-11		
6	simulation		92.07	55.45		8	

The effect of block length was then investigated by using the block division technique. By running the simulation under the storage option one of the statistics available is the maximum number of vehicles in any one block at any one time. The blocks with the highest maximum vehicle count are the blocks where most of the system waiting time will occur. By dividing congested blocks into smaller blocks more vehicles can travel the congested area and hence waiting time is reduced.

The storage simulation was run and 5 blocks were found to have a maximum of 4 vehicles in them at one time (see Figure 20). The traverse time of these blocks ranged from 25 to 56 seconds. These are comparatively long blocks but unfortunately block length is not the only criterion for

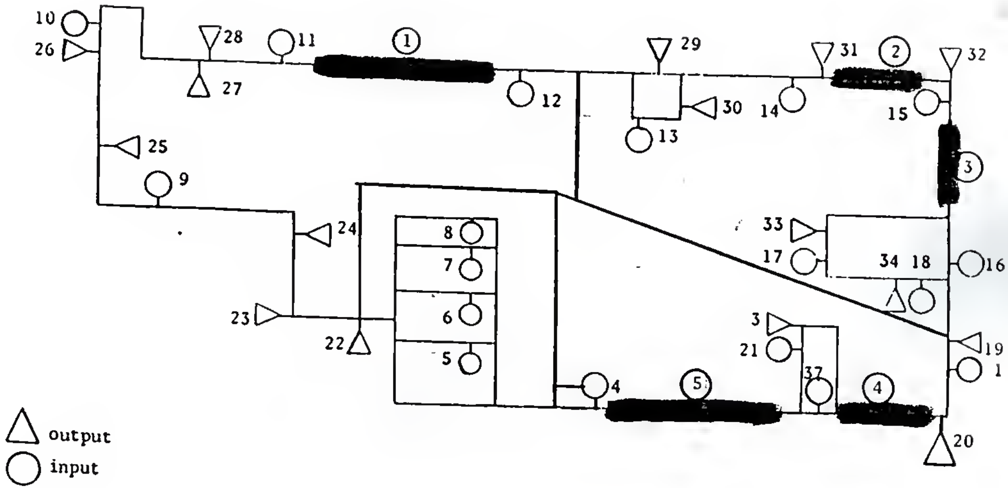


Figure 20 : Identification of Congested Blocks for 1st Storage Run.

waiting time. Load traffic is also an important factor. For this reason the division of blocks into an arbitrary uniform size is not recommended prior to an investigation of the waiting times. The 5 blocks, with a 4 vehicle maximum, were each cut in half forming 10 separate blocks. The facility simulation was run and the system efficiency and system utilization were increased to 97.03 and 55.70, respectively. This is an obvious increase in efficiency while the utilization remained relatively the same. This indicates that the waiting time in the system has been converted into reserve capacity. With added reserve capacity the system has the ability to accomodate an increase in loads moved and in some circumstances the reduction in the number of vehicles needed if reserve capacity is large enough.

PROCEDURAL SUMMARY 6.

step	description	dir	eff	util	veh range	needed veh	cngstd blocks
1	loadfeet analysis	clock wise					
2	vehicle estimation				8-13		
3	simulation		91.18	52.57		11	
4	cutoff analysis						
5	vehicle estimation				6-11		
6	simulation		92.07	55.45		8	
7	storage simulation						5
8	facility simulation		93.03	55.61		8	

The storage simulation was run again and 6 blocks were found to have a maximum of 4 vehicles in them at one time (see Figure 21). All the blocks were either blocks previously mentioned or one of their divisions. The traverse time for these blocks ranged from 12 to 25 seconds. It is important to notice the reduction in traverse time because although there is probably waiting time at these blocks it is shorter in length than waiting time prior to division. The tradeoff is the point were the waiting times experienced are short enough that further block divisions have no effect on the system. The congested blocks were cut in half to form two separate blocks. The facility simulation was run and system efficiency and system utilization showed a slight drop to 96.76 and 55.61, respectively. In this case the waiting times were short enough prior to the block division so that the split of the blocks had no significant effect.

PROCEDURAL SUMMARY 7.

step	description	dir	eff	util	veh range	needed veh	cngstd blocks
1	loadfeet analysis	clock wise					
2	vehicle estimation				8-13		
3	simulation		91.18	52.57		11	
4	cutoff analysis						

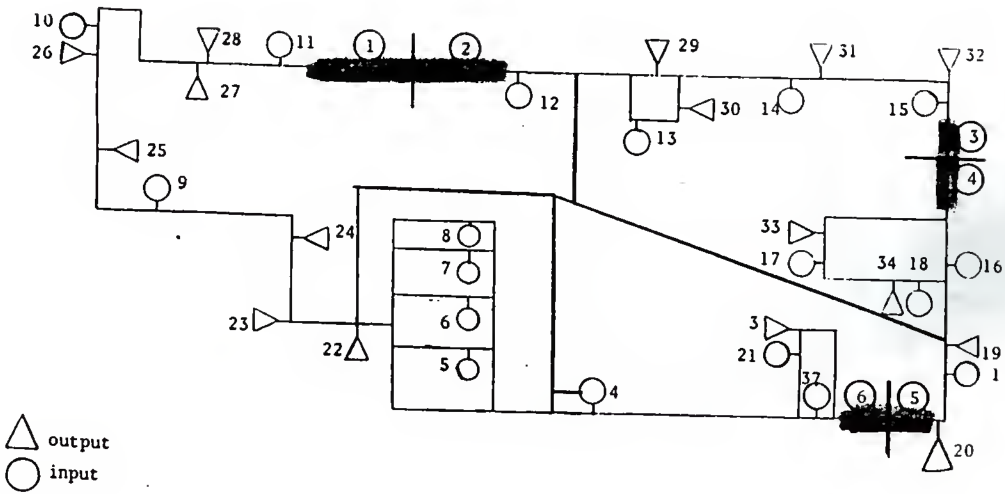


Figure 21 : Identification of Congested Blocks for 2nd Storage Run

5	vehicle estimation				6-11		
6	simulation		92.07	55.45		8	
7	storage simulation						5
8	facility simulation		97.03	55.70		8	
9	storage simulation						6
10	facility simulation		96.76	55.61		8	

To prove further the point of levelling off of system indicators the storage simulation was run again and 5 blocks were found to have a maximum of 4 vehicles in them at one time. All the blocks were either previously mentioned or created by a block division. The blocks were split and the facility simulation was run. The resulting system efficiency and system utilization was 97.43 and 56.04, respectively. Again there was no significant change in the system indicators. Although there was waiting time at the blocks divided, it was short enough that it had no effect on the system.

PROCEDURAL SUMMARY 8.

step	description	dir	eff	util	veh range	needed veh	cngstd blocks
1	loadfeet analysis	clock wise					
2	vehicle estimation				8-13		
3	simulation		91.18	52.57		11	
4	cutoff analysis						

5	vehicle estimation			6-11		
6	simulation	92.07	55.45		8	
7	storage simulation					5
8	facility simulation	97.03	55.70		8	
9	storage simulation					6
10	facility simulation	96.76	55.61		8	
11	storage simulation					5
12	facility simulation	97.43	56.04		8	

From the block division process it can be seen that the only cut which had a significant effect on the system was the first. After that the blocks were short enough that additional divisions had no effect on the system. The general levelling off effect (see Figure 22) is a definite argument against arbitrary cutting up of large blocks into uniform small ones.

EFFICIENCY LEVELING FOR CASE 2

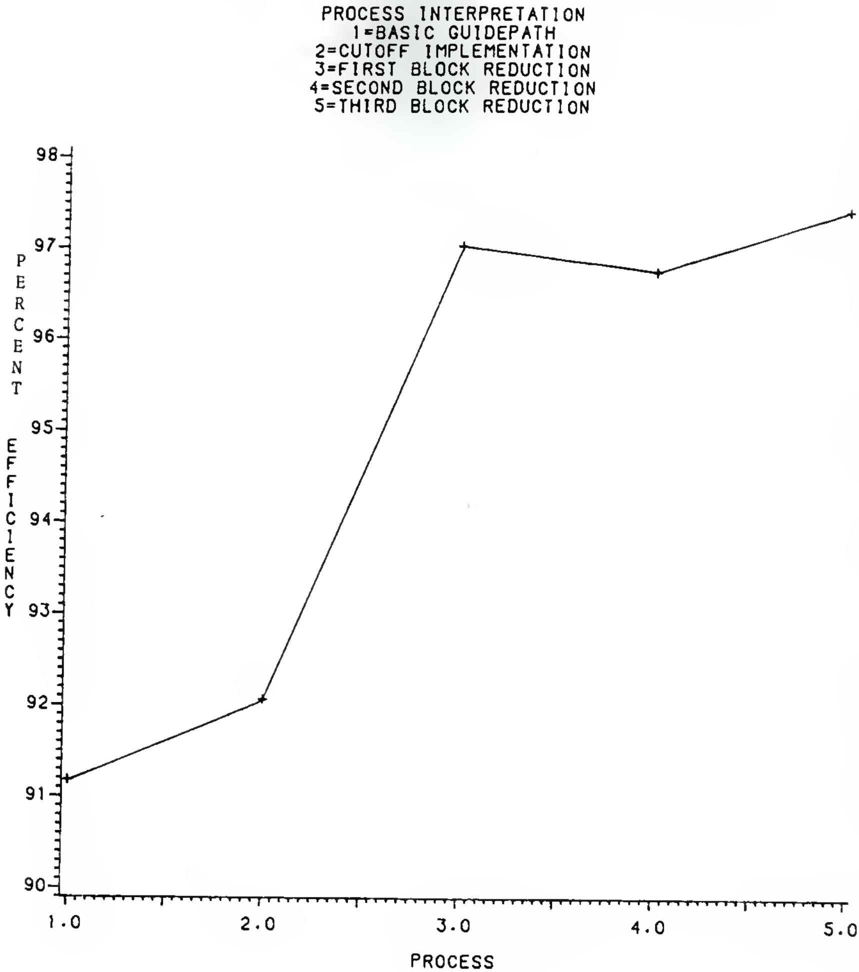


FIGURE 22.

CASE 3

The third AGVS studied is another that has yet to be installed by a local manufacturer. Again no guidepath was given but a blueprint of the manufacturing workplace (which included locations of inputs and outputs) and a 'from-to' chart was provided (see Table 5). Vehicle speed, load and unload times were the same as in Case 2 and again a park area was placed at the author's discretion.

The purpose of Case 3 is to use the concepts developed in Case 1 and the procedural techniques developed in Case 2 and apply them to a more complex manufacturing workplace in the hopes of creating a workable AGVS.

The concepts developed in Case 1 on a simple circuit were:

(1) system utilization
(2) system efficiency
(3) GPSS-H simulation macros.

The procedural techniques developed in Case 2 on a simple circuit were:

(1) loadfeet directioning
(2) vehicle estimating
(3) cutoff implementation
(4) block division.

In the original layout that was provided there were 24 inputs and 26 outputs. Only one park area was placed in the system. Vehicle travel speed was 2.8 feet/second and job load and unload times were 50 seconds. Job inputs were predetermined and jobs arrived at a uniform rate.

The basic guidepath was laid with a straight line

OUTPUT

INPUT	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	
1				1.8	61.8															9.5	9.5	7.8	9.5	9.5	9.5	9.5	128.4
2			15.8																	9.1	9.1	2.7	9.1	9.1	9.1	9.1	73.1
3																			14.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	22.8
4														6.0	6.0												12.0
5						.6														1.1	1.1	1.0	1.1	1.1	1.1	1.1	8.2
6					13.7														.2	2.3	2.3	2.1	2.3	2.3	2.3	2.3	29.8
7																				.2	.2	.2	.2	.2	.2	.2	1.4
8																				.3	.3	.3	.3	.3	.3	.3	2.1
9																				.3	.3	.3	.3	.3	.3	.3	2.1
10		5.0																		.4	.4	.4	.4	.4	.4	.4	7.8
11																			20.0	.6	.6	.8	.6	.6	.6	.6	24.4
12																			73.0	2.3	2.3	2.1	2.3	2.3	2.3	2.3	88.9
13			3.0				39.4													.8	.8		.8	.8	.8	.8	47.2
14																			15.0	.9	.9	.8	.9	.9	.9	.9	21.2
15																			16.0								16.0
16																			25.0								25.0
17																			25.0								25.0
18	5.8	4.7		.8	.3	1.9	8.6	.9	.9	.5	5.2	1.0	2.1	11.8	11.8	2.8	1.9	2.1				3.1					66.2
19	5.8	4.7		.8	.3	1.9	8.6	.9	.9	.5	5.2	1.0	2.1	11.8	11.8	2.8	1.9	2.1				3.1					66.2
20	1.7	2.1			.1	2.0	13.0	.4	.4	.2	2.3	.4	.9	2.5	2.5	1.3	.9	.9		11.4	11.4		11.4	11.4	11.4	11.4	100.0
21	5.8	4.7		.8	.3	1.9	8.6	.9	.9	.5	5.2	1.0	2.1	11.8	11.8	2.8	1.9	2.1				3.1					66.2
22	5.8	4.7		.8	.3	1.9	8.6	.9	.9	.5	5.2	1.0	2.1	11.8	11.8	2.8	1.9	2.1				3.1					66.2
23	5.8	4.7		.8	.3	1.9	8.6	.9	.9	.5	5.2	1.0	2.1	11.8	11.8	2.8	1.9	2.1				3.1					66.2
24	5.8	4.7		.8	.3	1.9	8.6	.9	.9	.5	5.2	1.0	2.1	11.8	11.8	2.8	1.9	2.1				3.1					66.2
	36.5	35.3	18.8	6.6	77.4	14.0	104.0	5.8	5.8	3.2	33.5	6.4	13.5	79.3	79.3	18.1	12.3	13.5	188.6	40.4	40.4	38.3	40.4	40.4	40.4	40.4	1032.6

Table 5 : Case 3 From-To chart.

configuration connecting the inputs and outputs (see Figure 23). This guidepath is more complex than the previous simple circuits studied but should follow the same principles developed earlier.

Two directional flow alternatives were considered using loadfeet directioning. Alternative 1 (see Figure 24) had a loadfeet total of 1,085,249 while Alternative 2 (see Figure 25) had a loadfeet total of 952,209 (see Table 6 for calculations). Needless to say Alternative 2 was the directional flow adopted.

PROCEDURAL SUMMARY 1.

step	description	dir	eff	util	range	needed veh	cngstd blocks
1	general layout			(see Figure 23)			
2	loadfeet analysis	Alt. 2		(see Figure 25)			

Cutoff analysis was then applied to the system and the inputs and outputs were grouped by their relative location around the guidepath, the inputs into 6 groups and the outputs into 7 groups (see Table 7 for groupings). It should be again noted that re-design of floor obstacles was not undertaken in this study so that in some instances cutoffs that would have been otherwise advisable were deemed impossible.

A job flow matrix was developed for jobs going from any one input group to any output group (see Table 7). All the matrix values were considered for possible reduction in load

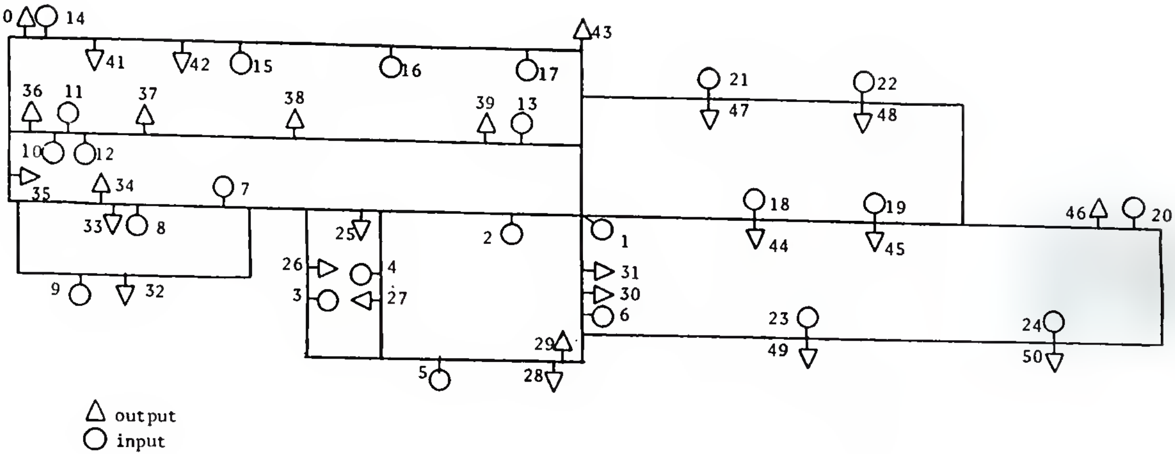


Figure 23 : Basic Guidepath for Case 3.

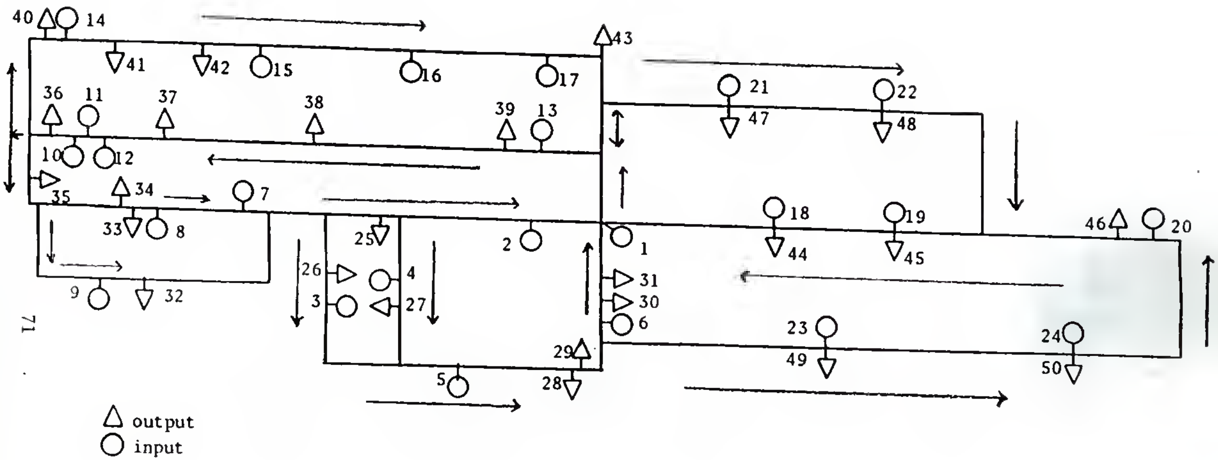


Figure 24 : Alternative 1 for Case 3 Loadfeet Directioning.

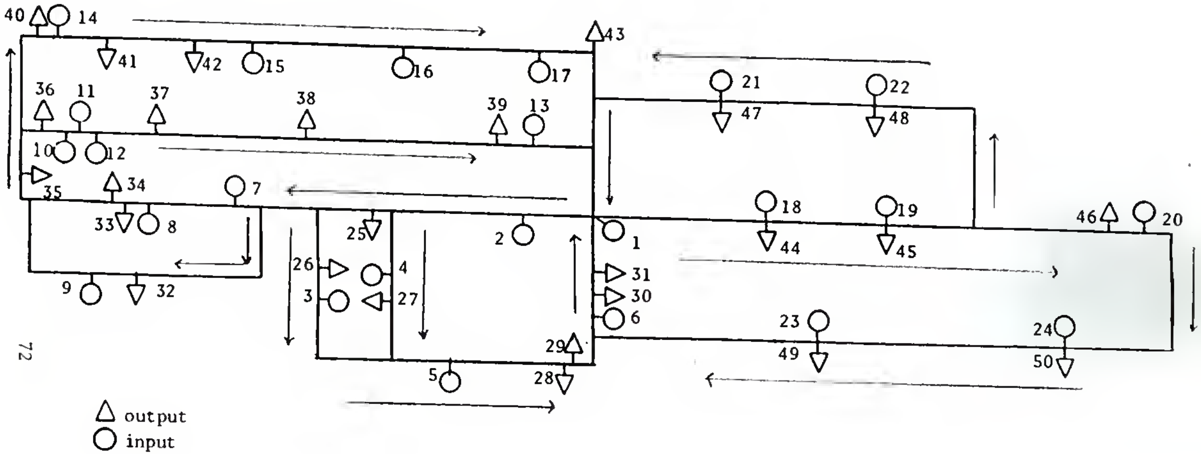


Figure 25 : Alternative-2 for Case 3 Loadfeet Directioning.

Table 6 : Case 3 Loadfeet Directioning.

BLOCK	DISTANCE (FEET)	ALT 1 LOADS	ALT 2 LOADS	ALT 1 LOAD-FT	ALT 2 LOAD-FT
0	42	128.6	190.8	5401	8014
X	18	778.2	857.7	14008	15439
5	62	133.1	556.3	8252	34491
6	116	60.0	629.4	6960	73010
7	56	18.8	179.3	1053	10041
8	18	18.8	191.3	338	3443
9	50	12.0	172.5	600	8625
10	66	288.6	22.8	19048	1505
11	50	288.6	22.8	14430	1140
12	26	265.8	-	6911	-
13	52	282.3	35.3	14680	1836
14	52	300.6	196.1	15631	10197
15	102	308.8	203.5	31498	20757
16	10	304.0	198.7	3040	1987
17	38	226.7	121.3	8615	4607
18	10	109.6	398.6	1096	3986
19	10	128.1	428.4	1281	4284
20	12	107.4	414.4	12888	4973
21	58	49.5	349.8	2871	20288
22	16	78.8	423.7	1261	6779
23	50	115.3	387.2	5765	19360
24	52	396.2	378.3	20602	19672
25	34	395.5	372.5	13447	12665
26	80	393.1	374.9	31448	29992
27	12	391.0	374.9	4692	4499
28	4	396.4	369.1	1586	1476
29	74	399.6	368.0	29570	27232
30	178	2.1	5.8	374	1032
31	40	8.3	-	332	-
32	116	6.2	2.1	719	244
33	42	405.8	370.1	17044	15544
34	32	440.3	335.6	14090	10739
35	16	603.2	184.1	9651	2946
36	12	609.6	177.7	7315	2132
37	16	601.8	185.5	9629	2968
38	15	577.4	185.5	8661	2782
39	60	488.5	274.4	29310	16464
40	128	502.0	285.3	64256	36518
41	178	581.3	206.0	103471	36668
42	18	662.6	132.7	11927	2389
43	54	613.4	173.9	33124	9391
44	102	162.9	151.5	16616	15453
45	10	144.8	133.4	1448	1334
46	46	166.0	154.6	7636	7112
47	58	153.7	142.3	8915	8253

(Table 6 continued on the next page)

Table 6 : Case 3 Loadfeet Directioning (cont.).

BLOCK	DISTANCE (FEET)	ALT 1 LOADS	ALT 2 LOADS	ALT 1 LOAD-FT	ALT 2 LOAD-FT
48	54	140.2	128.8	7571	6955
49	138	156.2	144.8	21556	19982
50	120	181.2	159.8	21744	19176
51	52	206.3	194.8	10722	10130
52	40	6.2	6.2	248	248
53	64	736.8	291.8	47155	18675
54	148	467.0	245.5	69116	36334
55	136	441.2	271.3	60003	36897
56	60	415.3	297.1	24918	17826
57	200	171.8	133.1	34360	26620
58	136	150.7	158.9	20495	21610
59	112	129.6	183.7	14515	20574
60	120	246.7	164.0	29604	19680
61	26	285.4	131.9	7420	3429
62	204	174.0	231.9	35496	47308
63	236	147.9	254.6	34904	60086
64	196	122.1	328.6	23932	64406
				1085249	952209

OUTPUT GROUP

INPUT GROUP	1	2	3	4	5	6	7	ROW TOTAL
1	-	66.0	-	-	-	-	-	66.0
2	-	15.0	-	-	-	-	6.2	21.2
3	-	93.0	-	-	-	5.0	23.1	121.1
4	-	-	-	-	-	3.0	44.2	47.2
5	-	-	-	-	1.0	-	5.6	6.6
6	43.9	14.6	19.9	158.6	48.8	166.6	318.1	770.0
COLUMN TOTAL	43.9	188.6	19.9	158.6	49.8	174.6	397.2	1032.6

INPUT GROUPING:

Group 1- input stations 15, 16, and 17.
Group 2- input station 14.
Group 3- input stations 10, 11, and 12.
Group 4- input station 13.
Group 5- input stations 7, 8, and 9.
Group 6- input stations 1,2,3,4,5,6,18,19,20,21,22,23, and 24.

OUTPUT GROUPING:

Group 1- output stations 40, 41, and 42.
Group 2- output station 43.
Group 3- output stations 36 and 37.
Group 4- output stations 38 and 39
Group 5- output stations 32, 33, 34, and 35.
Group 6- output stations 25, 26, 27, 28, and 29.
Group 7- output stations 30, 31, 44, 45, 46, 47, 48, 49, and 50

Table 7 : Case 3 Job Flow Matrix

travel distance with special attention given to the jobs going to output groups 2 and 7 and jobs going from input group 6. Cutoffs were suggested and the result can be seen in Figure 26.

PROCEDURAL SUMMARY 2.

step	description	dir	eff	util	range	needed veh	cngstd blocks
1	general layout	(see Figure 23)					
2	loadfeet analysis	Alt. 2	(see Figure 25)				
3	cutoff analysis		(see Figure 26)				

Vehicle estimation was then performed and the range computed was 15.91 to 25.46 vehicles. This indicates that the simualtion should be run with between 15 and 26 vehicles.

PROCEDURAL SUMMARY 3.

step	description	dir	eff	util	range	needed veh	cngstd blocks
1	general layout	(see Figure 23)					
2	loadfeet analysis	Alt. 2	(see Figure 25)				
3	cutoff analysis		(see Figure 26)				
4	vehicle estimation				15-26		

A simulation was then run with the result that 20 vehicles was found to be able to handle the system load.

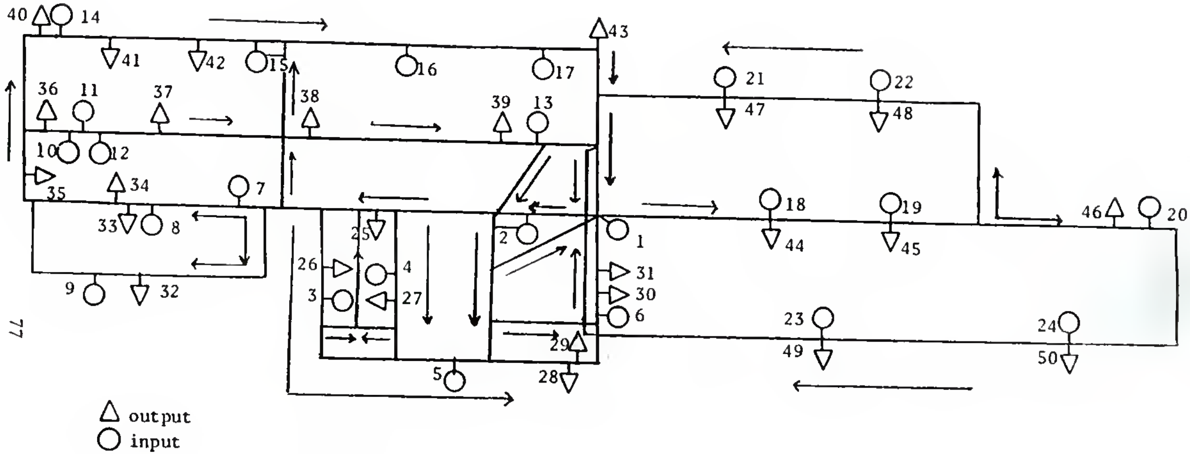


Figure 26 : Proposed Cutoffs for Case 3.

The system efficiency was 81.80 and the system utilization was 60.49. From previous indications the system efficiency is low and will increase with the use of block division.

PROCEDURAL SUMMARY 4.

step	description	dir	eff	util	range	needed veh	cngstd blocks
1	general layout			(see Figure 23)			
2	loadfeet analysis	Alt. 2		(see Figure 25)			
3	cutoff analysis			(see Figure 26)			
4	vehicle estimation				15-26		
5	simulation		81.80	60.49		20	

Four successive block divisions were done and the final number of vehicles required was 17. The system efficiency was increased to 97.30 and the system utilization was increased to 70.96. The summary of these cuts is shown below.

PROCEDURAL SUMMARY 5.

step	description	dir	eff	util	range	needed veh	cngstd blocks
1	general layout			(see Figure 23)			
2	loadfeet analysis	Alt. 2		(see Figure 25)			
3	cutoff analysis			(see Figure 26)			

PROCEDURAL SUMMARY 5 (cont.).

step	description	dir	eff	util	range	needed veh	cngstd blocks
4	vehicle estimation				15-26		
5	simulation		81.80	60.49		20	
6	storage simulation						16
7	facility simulation		91.00	66.80		18	
8	storage simulation						17
9	facility simulation		94.99	70.34		17	
10	storage simulation						13
11	facility simulation		96.99	71.41		17	
12	storage simulation						9
13	facility simulation		97.37	70.96		17	

The reduction in the rate of increase of system efficiency and system utilization was the reason the block division process was abandoned.

Figure 27 shows the approach to steady state in system utilization after the second cut. The peak in the utilization curves indicates at what vehicle level within each cut that the system load can be handled. More vehicles than are needed produces an almost linear drop in system utilization due to overcrowding.

Figure 28 shows the attainment of steady state after a

CASE 3: UTILIZATION -VS- VEHICLE

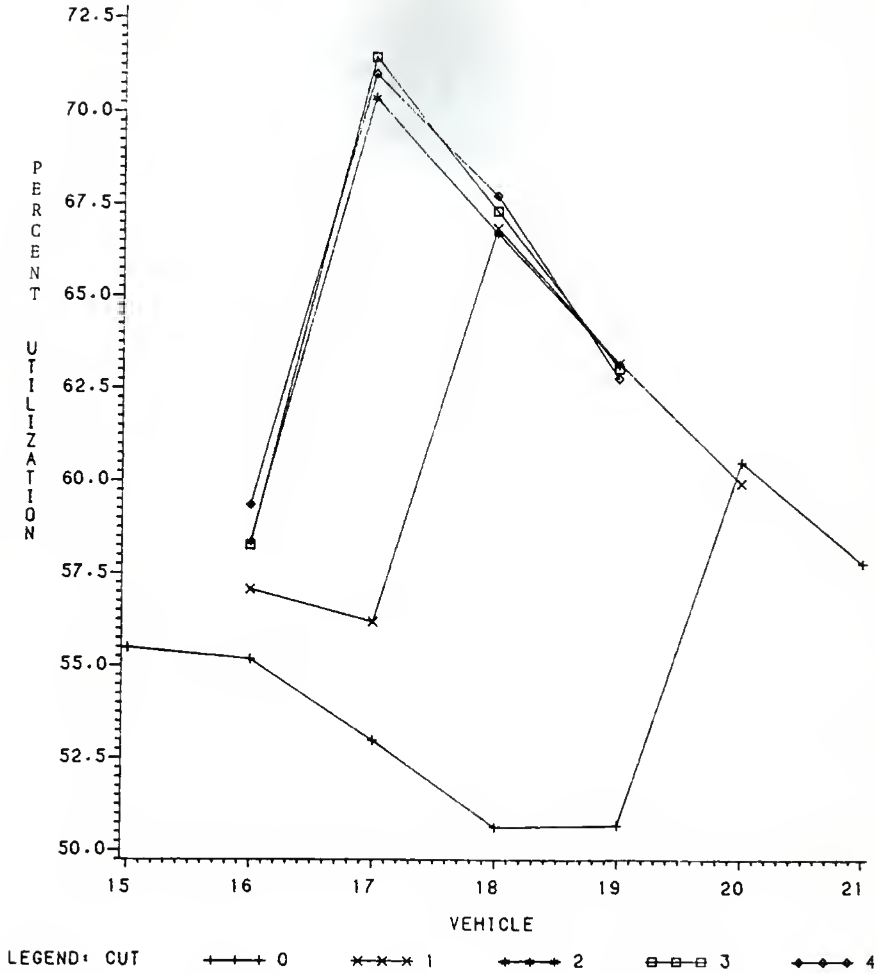


FIGURE 27.

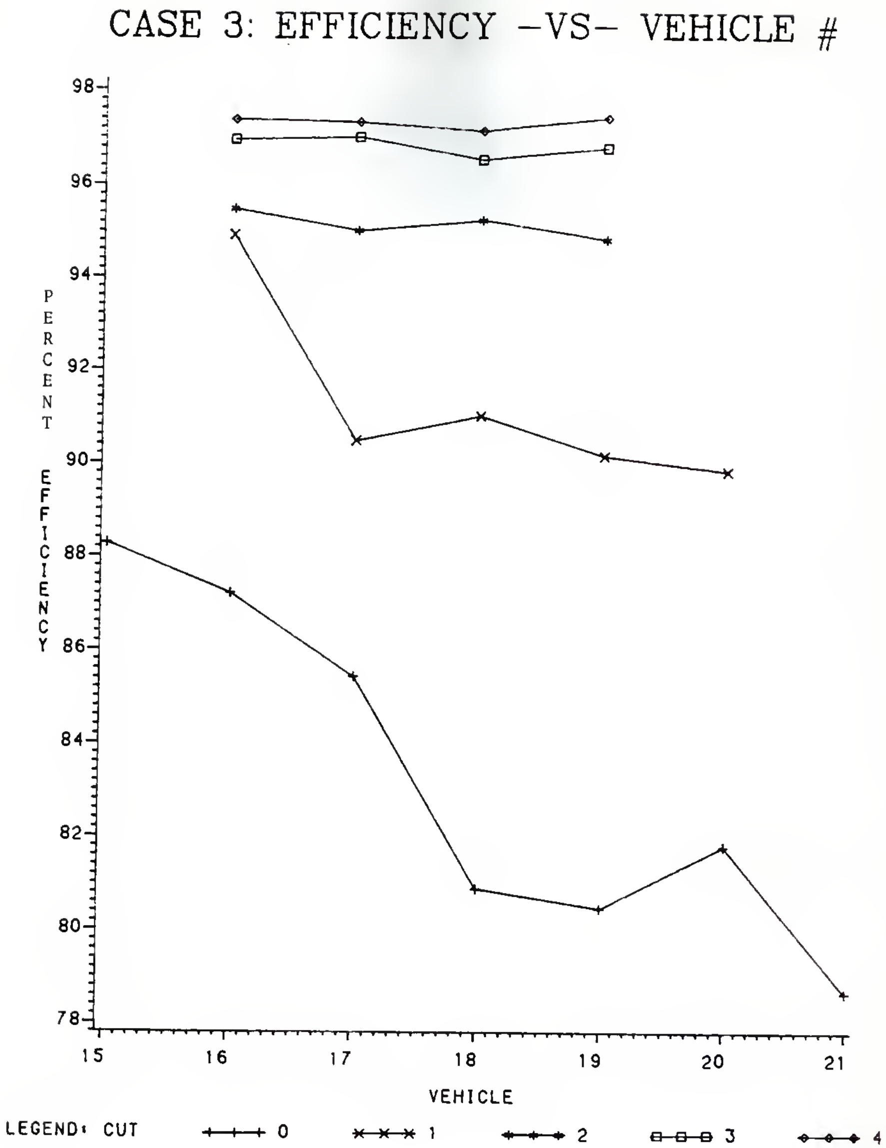

CASE 3: EFFICIENCY -VS- VEHICLE #
PERCENT EFFICIENCY
98
96
94
92
90
88
86
84
82
80
78
15
16
17
18
19
20
21
VEHICLE
LEGEND: CUT
0
1
2
3
4

FIGURE 28.

vehicle has reached the point where it can handle the system load. Note that 16 vehicles was never able to handle the load and its system utilization is lower than 17-19's. This is because there is job backup at the input stations and the vehicles do not follow a dispatch schedule that reduces distance travelled unloaded but rather a schedule which reduces the backup loads at a given input. Hence the vehicles travel longer distances and the system utilization is lower. But if the vehicle count can process the load (17-19) there is a stepped effect with the smallest vehicle number yielding the highest utilization.

In Figure 29 the reduction in the rate of increase in system efficiency can be seen as each progressive cut is performed. Note the general levelling effect of the system efficiency curves over the progression of the cuts. Each cut makes the system more efficient and hence the number of vehicles in the system has less effect on system efficiency. This can be seen by the difference of 7 percent system efficiency between 16 and 19 vehicles in the uncut system compared to virtually no difference in system efficiency between 16 and 19 vehicles in the system cut 4 times.

This is further demonstrated in Figure 30 where as the cuts progress the system efficiency for each vehicle conut converges.

CONCLUSION

In the course of this study the objectives stated at the beginning of this thesis were met.

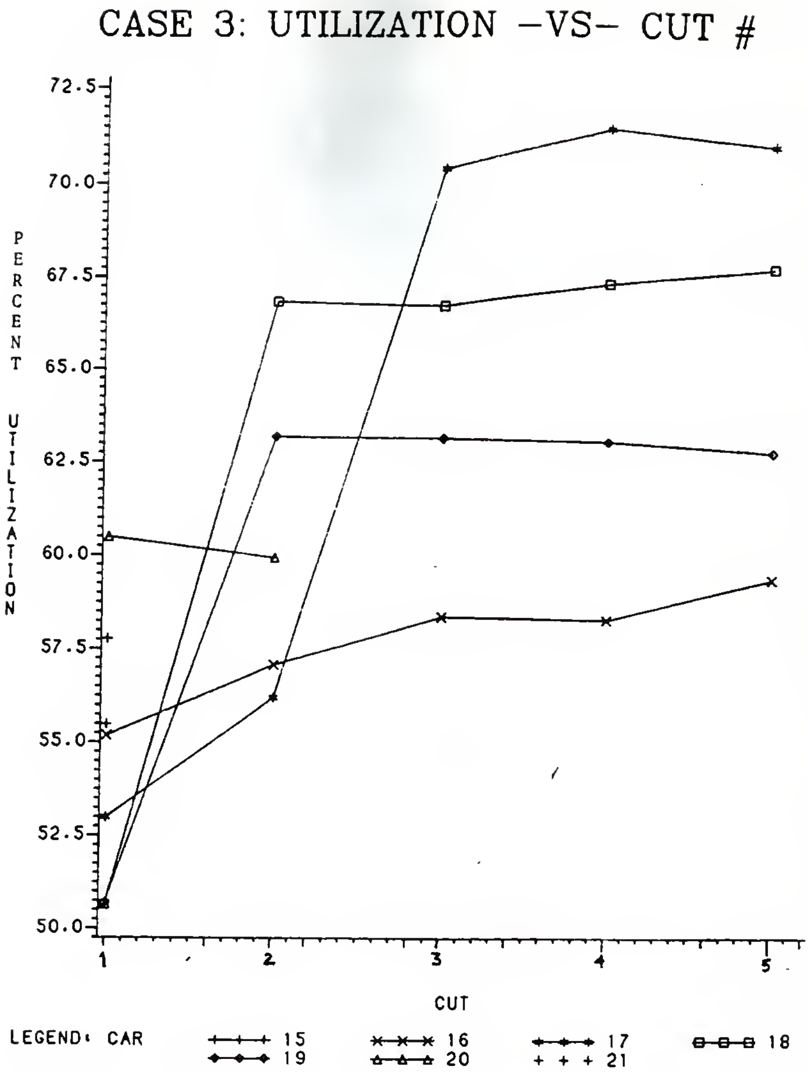
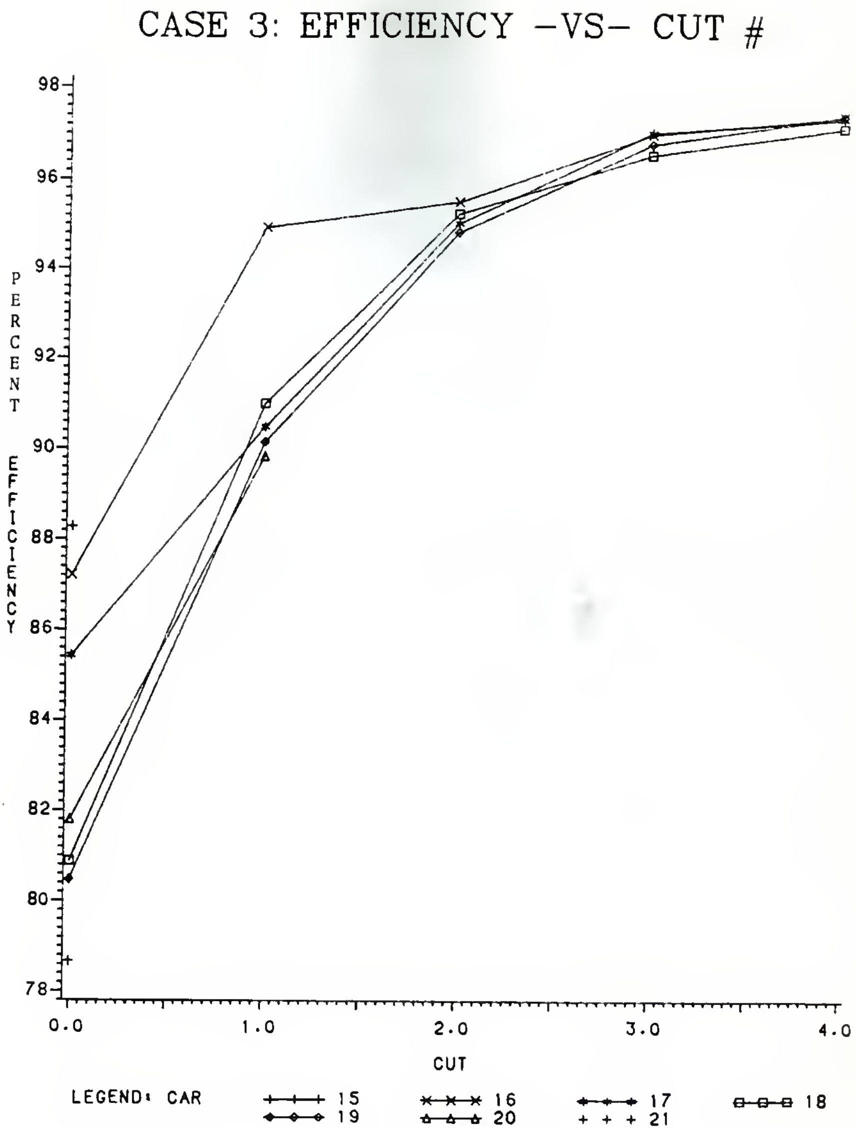

CASE 3: UTILIZATION -VS- CUT #
PERCENT UTILIZATION
72.5
70.0
67.5
65.0
62.5
60.0
57.5
55.0
52.5
50.0
1
2
3
4
5
CUT
LEGEND: CAR
15
16
17
18
19
20
21

FIGURE 29



CASE 3: EFFICIENCY -VS- CUT #
PERCENT EFFICIENCY
98
96
94
92
90
88
86
84
82
80
78
0.0
1.0
2.0
3.0
4.0
CUT
LEGEND: CAR
15
16
17
18
19
20
21

FIGURE 30.

The first section presented a viable method of emulating a AGVS. The overall simplicity of the macros was what was strived for.

In Case 1 the redefinition of system utilization and system efficiency brought added significance to their purpose. The further investigation with blocking introduced the concept of reserve capacity.

In Case 2 steps were developed for the implementation of a AGVS. The step-by-step procedure proved to produce a viable guidepath and vehicle count.

In Case 3 the previous evaluation and implementation techniques were applied and their viability further demonstrated.

FUTURE STUDY

The techniques developed in this thesis are, of course, only a simplistic approach to the problem of the implementation of AGV systems. There are many improvements that can be made on the existing proposal and viable alternatives that can be investigated.

Improvements on the existing proposal include a more sophisticated approach to the dispatch and scheduling algorithm. In the D/S algorithm developed in this thesis, when there was an overload (i.e. any input station with 3 or more jobs in queue) in 2 or more input stations, the input chosen is the one with the lowest identification number. Because the input station chosen might be the furthest of any of the overloaded input stations, extra distance would be incurred and efficiency lost. The obvious solution is to scan the overloaded stations and choose the closest one.

Another possible D/S improvement would be if a destination were chosen and its distance exceeded a specified unloaded travel limit, the vehicle could wait a specified amount of time to see if another closer job would become available. If a closer job materialized the vehicle would switch the destination to the closer job. If not, the vehicle would proceed to the further destination. This would help eliminate needlessly long travelling periods when the vehicle was not loaded, which would cause an increase in efficiency and utilization.

A third improvement in the D/S algorithm would be, in essence, to create "smart" vehicles. This would entail vehicles making decisions while they were enroute to a predetermined destination. The advantage of this would be that if a job materialized along the route of a vehicle, a decision could be made whether or not to switch the destination. Also if a vehicle were going to the park area, it would not have to complete the trip to the park area but could divert and pick up a load. Travel distance of unloaded vehicles would be reduced and efficiency and utilization would be increased.

These former concepts could definitely be incorporated into the D/S algorithm, the overload destination and waiting principal very easily while the "smart" vehicle concept would be more difficult.

Another area of improvement would be in the cutoff analysis technique. Presently, the cutoffs instituted are to eliminate excessive travel distances from input stations to output stations. The other aspect of the problem is: What about the travel distances from output stations to input stations? Wholesale installation of cutoffs is, of course, a viable solution, but the cost of unneeded cutoffs would be incurred. Another solution would be to run a simulation that records all vehicle path movements. This would provide a "from-to" chart for output stations to input stations. Possible cutoffs could then be considered for this traffic flow as well as the previously considered input-to-output traffic flow.

A viable alternative which became apparent in the course of this study, is to create an on-screen grid that would represent the manufacturing workplace where the AGVS was to be installed. Input and output stations are placed on the screen to represent their position on the workfloor. With the use of a "mouse" or a light pen, possible guidepaths could be drawn directly onto the screen. With proper supporting software the attributes of any proposed guidepath could be evaluted. The simplest of these would be a calculation of the load-feet used to handle the system load. With more complicated software, simulations could be run of the suggested guidepaths and the number of vehicles, system efficiency, and system utilization could be calculated. From that point cutoffs could be "drawn" on the screen and their effectiveness measured versus their proposed implementation costs.

An important consideration in the accuracy of the pre-installation evalution process is to get the production planning department more involved. Presently, the system created uses a random dispatch method of jobs from the inputs and a uniform rate of jobs materializing at the input stations. These methods do not take into consideration any trends or fluctuations that occur in the workplace. If a better picture can be presented of the work order schedule by production planning then more accurate information will be created by the pre-installation evalution.

In conclusion, it is imperative that any pre-installation system created must be kept as simple as possible. The increased application of AGVSs to solve today's material flow problems makes the need for such pre-installation systems crucial. Although the savings produced by a AGVS can be large, so are the installation costs. A simple system will allow for in-house evalution by a company's own engineers.

BIBLIOGRAPHY

1 Adams, Walter P. Automated Guided Rehicle System Capibilities and Design Considerations. USA: Auerbach Publishers Inc., 1985.

2 Automated Guided Vehicle Systems. Proceedings of 1st International Conference. Stratford-upon-Avon, United Kingdom, 1981.

3 Gartland, J.P. "Computer Simulati/n as a Tool in Making Design and Purc(asing Decisions for an Automated Guided Vehicle System" Unpublished Master's Report, North Carolina State University, 1984.

4 Hitchens, Max W. "Simulation: The Key to Automation Without Risk." CAD/CAM Technology, Fall, 1984, pp.15-17.

5 Kulwiec, Ray "Trends in Automated Guided Vehicle Systems." Plant Engineering, October 11, 1984, pp. 66-73.

6 Muller, Thomas. Automated Guided Vehicles. United Kingdom: IFS Publications Limited, 1983.

7 Newton, Dave "Simulation Model Calculates How Many Automated Guided Vehicles Are Needed." Industrial Engineering, February, 1985, pp. 68-78.

8 Nof, Shimon Y. "A Methodology for Computer-aided Facility Planning." International Journal of Production Research, Vol. 18 No. 6 (1980), 699-722.

9 "'Our order-filling system handles any surge demands.'" Modern Materials Handling, June 6, 1983, pp. 48-51.

10 Quinn,Ed "Factors Influencing Simulation Accuracy of AGV Networks." 1984 National Material Handling Forum (Guided Vehicle Systems Session), (March 28, 1984).

11 Stauffer, Robert N. "Graphic Simulation Answers Preproduction Questions." CAD/CAM Technology, Fall, 1984, pp. 11-13.

APPENDIX A

GPSS-H Macros

TRVL MACRO

Used to travel a section of track. Will perform no other functions. Will only allow one vehicle to travel a particular section at one time. Used in main program and called from OUTPT, INPT, GAS, PLACE, and LOOP macros.

Inputs:

(1) vehicle number
(2) section travel time
(3) section to travel
(4) section leaving

Outputs:

(1) completion of travel of section
(2) tabulation of time travelling with or without a load
(3) depletion of fuel
(4) waiting time for loaded and non-loaded vehicles for given section to become unoccupied
(5) entrance in queue for either loaded or non-loaded vehicle to mark time for waiting to enter next section

Procedure:

(1) Vehicle attempts to seize section of track, if it is occupied the vehicle will wait until it is free and then will take control of it.
(2) Vehicle will leave queue and tabulate waiting time for section to become availible.
(3) Vehicle will release previous section so it can be used by other vehicles.
(4) Tabulation of travel time in either loaded or non-loaded travel time.
(5) Vehicle travels section.
(6) Fuel level decremented.
(7) Enter queue which will mark the time at which waiting to enter the next section will begin
(8) Vehicle exits macro.

```
 TRVL MACRO

 OPERAND DESCRIPTIONS
 #A - VEHICLE NUMBER STORED IN PARAMETER 1
 #B - TRAVEL TIME
 #C - SECTION ENTERING
 #D - SECTION LEAVING


 TRVL  STARTMACRO #A,#B,#C,#D
*
*  TAKE CONTROL OF NEXT BLOCK OF TRACK AND RELEASE WAITING*
*  QUEUE AND BLOCK PRESENTLY OCCUPIED
*
       SEIZE        #C
       TEST E       XF*(PF1+50),0,*+4
       DEPART       (#D+1)
       DEPART       350
       TRANSFER     ,*+3
       DEPART       #D
       DEPART       351
       RELEASE      #D
*
* ASSIGN PARAMETER VEHICLE STATUS VALUE                        *
*
       ASSIGN      4,XF*(#A+50),PF
*
* ADD SECTION LENGTH TRAVELLED TO LOADED OR UNLOADED           *
* SAVEVALUE                                                    *
*
       SAVEVALUE  (FN25)+,#B,XF
*
* INCREMENT VEHICLE CLOCK                                      *
*
       ADVANCE     #B
*
* OPTIONAL DECREMENT OF VEHICLE'S FUEL LEVEL                   *
*
       SAVEVALUE  (#A+36)-,#B,XF
*
* ENTER LOAD OR UNLOAD QUEUE AND WAIT TO ENTER NEXT BLOCK *
*
       TEST E      XF*(PF1+50),0,*+4
       QUEUE       (#C+1)
       QUEUE       350
       TRANSFER    ,*+3
       QUEUE       #C
       QUEUE       351
       ENDMACRO
```

INPUT MACRO

Used to load a vehicle. Will allow one vehicle in the input station at one time. Vehicle leaves track to perform loading procedure so that other vehicles can proceed unobstructed if not to be loaded. Called from the INPT macro.

Inputs:

(1) vehicle number
(2) load time
(3) loading area
(4) section leaving

Outputs:

(1) completion of vehicle loading
(2) tabulation of loading time
(3) depletion of jobs from loading area queue
(4) assignment of output station
(5) depletion of fuel
(6) waiting time for non-loaded vehicles for given section to become unoccupied
(7) entrance in queue for loaded vehicles to mark time for waiting to enter next section

Procedure:

(1) Vehicle attempts to seize loading area. If it is occupied the vehicle will wait until it is free and then will take control of it.
(2) Vehicle will leave queue and tabulate waiting time for loading area to become free.
(3) Vehicle releases previous section so it can be used by other vehicles.
(4) Load vehicle and tabulate loading time.
(5) Subtract job from loading area queue.
(6) Check individual load destination distribution and assign output destination.
(7) Decrement fuel.
(8) Place flag on vehicle that it is carrying a load.
(9) Enter queue which will mark time at which waiting to enter the next section will begin.
(10) Vehicle exits macro.

INPUT MACRO

OPERAND DESCRIPTIONS
#A - VEHICLE NUMBER STORED IN PARAMETER 1
#B - LOADING TIME
#C - INPUT STATION ENTERING
#D - SECTION LEAVING

```
 INPUT STARTMACRO #A,#B,#C,#D
*
*  TAKE CONTROL OF INPUT STATION AND RELEASE WAITING  QUEUE*
*  AND BLOCK OF TRACK PRESENTLY OCCUPIED                   *
*
      SEIZE       #C
      TEST E      XF*(PF1+50),0,*+4
      DEPART      (#D+1)
      DEPART      350
      TRANSFER    ,*+3
      DEPART      #D
      DEPART      351
      RELEASE     #D
*
* INCREMENT VEHICLE CLOCK                                 *
*
      ADVANCE     #B
*
* DECREMENT JOB ASSIGNED QUEUE                            *
*
      SAVEVALUE  (PF2+24)-,1,XF
*
* ASSIGN OUTPUT STATION DESTINATION  FROM FROM-TO         *
* FUNCTIONS                                               *
*
      ASSIGN      2,FN*(PF2),PF
*
* OPTIONAL DECREMENT OF VEHICLE'S FUEL LEVEL              *
*
      SAVEVALUE  (#A+36)-,#B,XF
*
* ASSIGN VEHICLE STATUS TO LOAD                           *
*
      SAVEVALUE  (PF1+50),1,XF
*
* ENTER LOAD OR UNLOAD QUEUE AND WAIT TO ENTER NEXT BLOCK *
*
      TEST E      XF*(PF1+50),0,*+4
      QUEUE       (#C+1)
      QUEUE       350
      TRANSFER    ,*+3
      QUEUE       #C
      QUEUE       351
      ENDMACRO
```

OUT MACRO

Used to unload a vehicle. Will allow one vehicle in the output station at one time. Vehicle leaves track to perform unloading procedure so other vehicles can proceed unobstructed if not to be unloaded. Called from the OUTPT macro.

Inputs:

(1) vehicle number
(2) unload time
(3) unloading area
(4) section leaving

Outputs:

(1) completion of vehicle unloading
(2) tabulation of unloading time
(3) depletion of fuel
(4) assignment of destination; input,fuel,park
(5) if destination input station depletion of input station buffer and addition to input station assigned job by one job
(6) entrance in queue for non-loaded vehicles to mark time for waiting to enter next section

Procedure:

(1) Vehicle attempts to seize unloading area. If it is occupied the vehicle will wait until it is free and then take control of it.
(2) Vehicle will leave queue and tabulate time for unloading area to come free.
(3) Will release previous section so it can be used by other vehicles.
(4) Unload vehicle and tabulate time of unloading.
(5) Decrement of fuel.
(6) Check if fuel is below refuel level. If so assign destination refuel area.
(7) Check if any input station has over a specified number of jobs to process. If so destination is assigned to the overloaded station.
(8) If job assigned destination of a input station subtract one job from the input buffer and add one job to input job assigned for that station.
(9) If no job has been assigned, destination is park area
(10) Place flag on vehicle that it is not carrying a load.

(11) Enter queue which will mark the time at which waiting to enter next section will begin.
(12) Vehicle exits macro.

OUT MACRO

OPERAND DESCRIPTIONS
#A - VEHICLE NUMBER STORED IN PARAMETER 1
#B - UNLOADING TIME
#C - OUTPUT STATION ENTERING
#D - SECTION LEAVING

```
OUT   STARTMACRO #A,#B,#C,#D
*
*  TAKE CONTROL OF INPUT STATION AND RELEASE WAITING  QUEUE*
*  AND BLOCK OF TRACK PRESENTLY OCCUPIED                   *
*
      SEIZE       #C
      TEST E      XF*(PF1+50),0,*+4
      DEPART      (#D+1)
      DEPART      350
      TRANSFER    ,*+3
      DEPART      #D
      DEPART      351
      RELEASE     #D
*
* INCREMENT VEHICLE CLOCK                                  *
*
      ADVANCE     #B
*
* OPTIONAL DECREMENT OF VEHICLE'S FUEL LEVEL               *
*
      SAVEVALUE  (#A+36)-,#B,XF
*
* ASSIGNMENT OF VEHICLE DESTINATION PARAMETERS             *
*
      ASSIGN      3,24,PF
      ASSIGN      5,25,PF
      ASSIGN      6,25,PF
*
* OPTIONAL CHECK IF REFUEL NEEDED; IF SO DESTINATION       *
* REFUEL AREA AND BYPASS OTHER DESTINATION OPERATIONS      *
*
      TEST LE     XF*(#A+36),1000,*+3
      ASSIGN      6,35,PF
      TRANSFER    ,*+16
*
* CHECK FOR OVERLOADED JOB QUEUES; ASSIGN DESTINATION      *
* TO INPUT STATION WITH OVERLOADED JOB QUEUE AND BYPASS    *
* OTHER DESTINATION OPERATIONS                             *
*
      TEST G      XF*(PF3),3,*+2
      ASSIGN      6,PF3,PF
      LOOP        3PF,*-2
      TEST E      PF6,25,*+10
*
* CHECK IF ANY JOBS TO BE DONE; ASSIGN VEHICLE DESTINATION*
* TO CLOSEST INPUT STATION AND BYPASS OTHER DESTINATION    *
* OPERATIONS                                               *
```

```
*
        ASSIGN      3,24,PF
        TEST GE     XF*(PF3),1,*+4
        TEST L      MX1(PF2,PF3),PF5,*+3
        ASSIGN      5,MX1(PF2,PF3),PF
        ASSIGN      6,PF3,PF
        LOOP        3PF,*-4
*
* IF THERE IS NO DESTINATION ASSIGNMENT; ASSIGN             *
* DESTINATION TO THE PARK AREA                              *
*
        TEST E      PF6,25,*+3
        ASSIGN      2,51,PF
        TRANSFER    ,*+4
*
* IF VEHICLE ASSIGNED DESTINATION OF AN INPUT STATION:      *
* DECREMENT JOB QUEUE AND INCREMENT JOB ASSIGNED QUEUE      *
*
        SAVEVALUE   (PF6)-,1,XF
        SAVEVALUE   (PF6+24)+,1,XF
*
* ATTACH DESTINATION TO VEHICLE                             *
*
        ASSIGN      2,PF6,PF
*
* ASSIGN VEHICLE STATUS TO UNLOAD                           *
*
        SAVEVALUE   (PF1+50),0,XF
*
* ENTER LOAD OR UNLOAD QUEUE AND WAIT TO ENTER NEXT BLOCK *
*
        TEST E      XF*(PF1+50),0,*+4
        QUEUE       (#C+1)
        QUEUE       350
        TRANSFER    ,*+3
        QUEUE       #C
        QUEUE       351
        ENDMACRO
```

FUEL MACRO

Used to refuel vehicle. Will allow multiple vehicles in refuel station at one time (prespecified by user). Vehicle leaves track to perform refueling so that other vehicles can proceed if refueling is not necessary. Called from the GAS macro.

Inputs:
(1) vehicle number
(2) refueling time
(3) refueling area
(4) section leaving

Outputs:

(1) completion of refueling
(2) tabulation of refueling time
(3) depletion of fuel
(4) waiting time for unloaded vehicle to enter refuel area
(5) entrance into queue for unloaded vehicle to mark time for waiting to enter next section

Procedure:

(1) Vehicle enters refueling area.
(2) Vehicle leaves queue and tabulates waiting time to enter refueling area (=0).
(3) Releases previous section so it can be used by other vehicles.
(4) Vehicle is refueled and refuel time tabulated.
(5) Fuel depletion.
(6) Enter queue which will mark time at which waiting to enter next section will begin.
(7) Vehicle exits macro.

```
FUEL MACRO

OPERAND DESCRIPTIONS
#A - VEHICLE NUMBER STORED IN PARAMETER 1
#B - REFUELLING TIME
#C - REFUELLING STATION ENTERING
#D - SECTION LEAVING


FUEL  STARTMACRO #A,#B,#C,#D
*
*  ENTER FUEL AREA AND RELEASE WAITING  QUEUE AND BLOCK OF *
*  TRACK PRESENTLY OCCUPIED                                *
*
      ENTER      #C
      TEST E     XF*(PF1+50),0,*+4
      DEPART     (#D+1)
      DEPART     350
      TRANSFER   ,*+3
      DEPART     #D
      DEPART     351
      RELEASE    #D
*
* INCREMENT VEHICLE CLOCK                                 *
*
      ADVANCE    #B
*
* OPTIONAL REFUEL AND DECREMENT OF FUEL LEVEL              *
*
      SAVEVALUE  (#A+36),30000,XF
      SAVEVALUE  (#A+36)-,#B,XF
*
* ENTER LOAD OR UNLOAD QUEUE AND WAIT TO ENTER NEXT BLOCK *
*
      TEST E     XF*(PF1+50),0,*+4
      QUEUE      (#C+1)
      QUEUE      350
      TRANSFER   ,*+3
      QUEUE      #C
      QUEUE      351
      ENDMACRO
```

PARK MACRO

Used as an area to place vehicles when there are no jobs for that need to be done. Will allow multiple vehicles in park station at one time(prespecified by user). Vehicle leaves track so that other vehicle can proceed if undertaking transportation of a job. Called from the PLACE macro.

Inputs:

(1) vehicle number
(2) parking area
(3) section leaving

Outputs:

(1) vehicle released; recieves new destination
(2) waiting time for unloaded vehicle to enter park (=0)
(3) entrance into queue for unloaded vehicles to mark time for waiting to enter next section
(4) tabulation of parking time

Procedure:

(1) Vehicle enters parking area.
(2) Vehicle leaves queue and tabulates time waiting to enter parking area (=0).
(3) Release previous section so it can be used by other vehicles.
(4) Stop at gate until logic switch is in set position and then proceeds to receive new destination and exit.
(5) Reset logic switch so not to let all vehicles through at once.
(6) Stop until one of the buffers has a job for the vehicle to do, then proceed.
(7) Enter queue which will mark the time at which waiting to enter next section will begin.
(8) Vehicle exits macro.

PARK MACRO

OPERAND DESCRIPTIONS
#A - VEHICLE NUMBER STORED IN PARAMETER 1
#B - PARKING STATION ENTERING
#C - SECTION LEAVING

```
 PARK  STARTMACRO #A,#B,#C
*
*  ENTER PARK AREA AND RELEASE WAITING  QUEUE AND BLOCK OF *
*  TRACK PRESENTLY OCCUPIED                                 *
*
       ENTER      #B
       TEST E     XF*(PF1+50),0,*+4
       DEPART     (#C+1)
       DEPART     350
       TRANSFER   ,*+3
       DEPART     #C
       DEPART     351
       RELEASE    #C
*
*  GATE THAT WILL ALLOW ONLY ONE VEHICLE TO LEAVE FOR EVERY*
*  ONE JOB THAT NEEDS TO BE DONE                            *
*
       GATE LS    2
       LOGIC R    2
       TEST E     BV22,1
*
* ENTER LOAD OR UNLOAD QUEUE AND WAIT TO ENTER NEXT BLOCK *
*
       TEST E     XF*(PF1+50),0,*+4
       QUEUE      (#B+1)
       QUEUE      350
       TRANSFER   ,*+3
       QUEUE      #B
       QUEUE      35I
       ENDMACRO
```

ENTER MACRO

Used to reenter track from either parking or refuel area. Only one vehicle can enter at one time. Travels retreat section of park or refuel section with the TRAVEL macro. Called from the GAS and PLACE macros.

Inputs:

(1) vehicle number
(2) section travel time
(3) section to enter
(4) section to leave
(5) logic switch number to allow only one vehicle out at a time

Outputs:

(1) completion of travel of section
(2) tabulation of time spent travelling with or without load
(3) tabulation of time spent in park or refuel area
(4) assignment of destination; park, refuel, or input
(5) if destination input station, depletion of input station buffer and addition to input station loading area queue
(6) logic switch placed on set position
(7) depletion of fuel
(8) waiting time for non-loaded vehicles for given section to become unoccupied
(9) entrance in queue for non-loaded vehicles to mark time for waiting to enter next section

Procedure:

(1) Vehicle attempts to seize section of track. If it is occupied the vehicle will wait until it is free and then take control of it.
(2) Vehicle will leave queue and tabulate waiting time for the section to come open.
(3) Vehicle will leave refuel or park area.
(4) Check if fuel is below refuel level. If so, assign destination refuel area.
(5) Check if any input station has over a specified number of jobs to process. If so destination is assigned to the overloaded station.
(6) If vehicle is assigned the destination of an input station, subtract one job from the input buffer and

one job to input job assigned for that input station.

(7) If no job has been assigned, destination is park area

(8) Set logic switch to set position.

(9) Travel section (see TRAVEL macro).

(10) Tabulation of travel time in non-loaded vehicle travel time.

(11) Enter queue which will mark the time at which waiting to enter next section will begin.

(12) Vehicle exits macro.

ENTER MACRO

OPERAND DESCRIPTIONS
#A - VEHICLE NUMBER STORED IN PARAMETER 1
#B - TRAVEL TIME
#C - SECTION ENTERING
#D - PARK OR REFUEL AREA VEHICLE IS LEAVING
#E - GATE NUMBER FOR PARK OR FUEL

ENTER STARTMACRO #A,#B,#C,#D,#E

```
*
*  TAKE CONTROL OF REENTRANCE BLOCK AND RELEASE WAITING     *
*  QUEUE AND PARK OR REFUEL AREA PRESENTLY OCCUPIED          *
*
      SEIZE       #C
      TEST E      XF*(PF1+50),0,*+4
      DEPART      (#D+1)
      DEPART      350
      TRANSFER    ,*+3
      DEPART      #D
      DEPART      351
      LEAVE       #D
*
* ASSIGNMENT OF VEHICLE DESTINATION PARAMETERS               *
*
      ASSIGN      3,24,PF
      ASSIGN      5,25,PF
      ASSIGN      6,25,PF
*
* OPTIONAL CHECK IF REFUEL NEEDED; IF SO DESTINATION        *
* REFUEL AREA AND BYPASS OTHER DESTINATION OPERATIONS       *
*
      TEST LE     XF*(#A+36),1000,*+3
      ASSIGN      6,35,PF
      TRANSFER    ,*+16
*
* CHECK FOR OVERLOADED JOB QUEUES; ASSIGN DESTINATION       *
* TO INPUT STATION WITH OVERLOADED JOB QUEUE AND BYPASS     *
* OTHER DESTINATION OPERATIONS                              *
*
      TEST G      XF*(PF3),3,*+2
      ASSIGN      6,PF3,PF
      LOOP        3PF,*-2
      TEST E      PF6,25,*+10
*
* CHECK IF ANY JOBS TO BE DONE; ASSIGN VEHICLE DESTINATION*
* TO CLOSEST INPUT STATION AND BYPASS OTHER DESTINATION     *
* OPERATIONS                                                *
*
      ASSIGN      3,24,PF
      TEST GE     XF*(PF3),1,*+4
      TEST L      MX1(PF2,PF3),PF5,*+3
      ASSIGN      5,MX1(PF2,PF3),PF
      ASSIGN      6,PF3,PF
      LOOP        3PF,*-4
```

```
*
* IF THERE IS NO DESTINATION ASSIGNMENT; ASSIGN          *
* DESTINATION TO THE PARK AREA                           *
*
      TEST E      PF6,25,*+3
      ASSIGN      2,51,PF
      TRANSFER    ,*+4
*
* IF VEHICLE ASSIGNED DESTINATION OF AN INPUT STATION;   *
* DECREMENT JOB QUEUE AND INCREMENT JOB ASSIGNED QUEUE   *
*
      SAVEVALUE   (PF6)-,1,XF
      SAVEVALUE   (PF6+24)+,1,XF
*
* ATTACH DESTINATION TO VEHICLE                          *
*
      ASSIGN      2,PF6,PF
*
* ASSIGN VEHICLE STATUS TO UNLOAD                        *
*
      SAVEVALUE   (PF1+50),0,XF
*
* RESET PARK GATE TO ALLOWOTHER VEHICLES TO PASS         *
*
      LOGIC S     #E
*
* OPTIONAL DECREMENT OF VEHICLE'S FUEL LEVEL             *
*
      SAVEVALUE   (#A+36)-,#B,XF
*
* ADD SECTION LENGTH TRAVELLED TO LOADED OR UNLOADED     *
* SAVEVALUE                                              *
*
      SAVEVALUE   (FN25)+,#B,XF
*
* INCREMENT VEHICLE CLOCK                                *
*
      ADVANCE     #B
*
* ENTER LOAD OR UNLOAD QUEUE AND WAIT TO ENTER NEXT BLOCK *
*
      TEST E      XF*(PF1+50),0,*+4
      QUEUE       (#C+1)
      QUEUE       350
      TRANSFER    ,*+3
      QUEUE       #C
      QUEUE       351
      ENDMACRO
```

OUTPT MACRO

Used to travel section which has an output station in its boundaries. Divided into three sections : (1) an approach section, (2) an output station, and (3) a retreat section. Only one vehicle can be in each of the parts at one time. The approach and retreat sections are traversed within the TRAVEL macro, the output station by the OUT macro. The car leaves the track to output job so if a vehicle does not need to unload it can proceed unobstructed.

Inputs:

(1) section leaving
(2) output station number
(3) approach section
(4) retreat section
(5) unloading area
(6) five transfer locations

Outputs:

(1) completion of approach section
(2) completion of retreat section
(3) if load to be dropped, completion of unloading

Procedure:

(1) Vehicle completes approach within travel block (see TRAVEL macro).
(2) If unloading to be performed:
    (a) vehicle completes unloading within output block (see OUT macro).
    (b) vehicle completes retreat within travel block (see TRAVEL macro).
    (c) vehicle exits macro.
(3) If unloading not to be performed:
    (a) vehicle completes retreat within travel block (see TRAVEL macro).
    (b) vehicle exits macro.

OUTPT MACRO

OPERAND DESCRIPTIONS
#A - SECTION LEAVING
#B - OUTPUT STATION ID NUMBER
#C - APPROACH SECTION
#D - RETREAT SECTION
#E - OUTPUT NAME
#F - APPROACH SECTION TRAVEL TIME
#G - RETREAT SECTION TRAVEL TIME
#H - UNLOAD TIME
#I - PROGRAM TRANSFER LOCATION
#J - PROGRAM TRANSFER LOCATION

```
 OUTPT STARTMACRO #A,#B,#C,#D,#E,#F,#G,#H,#I,#J
*
* TRAVEL OUTPUT STATION APPROACH BLOCK                        *
*
 TRVL   MACRO       PF1,#F,#C,#A
*
* IF UNLOADING REQUIRED; UNLOAD AND TRAVEL OUTPUT RETREAT *
* BLOCK                                                       *
*
        TEST E      PF2,#B,#I
 OUT    MACRO       PF1,#H,#E,#C
 TRVL   MACRO       PF1,#G,#D,#E
        TRANSFER    ,#J
*
* IF NO UNLOADING REQUIRED; TRAVEL OUTPUT RETREAT SECTION *
*
 #I     ADVANCE     0
 TRVL   MACRO       PF1,#G,#D,#C
 #J     ADVANCE     0
        ENDMACRO
```

INPT MACRO

Used to travel section which has an input station within its boundaries. Divided into three sections : (1) an approach section, (2) an output station, and (3) a retreat section. Only one vehicle can be in each of these sections at one time. The approach and retreat sections are traversed by the TRAVEL macro, the input station by the INPUT macro. The vehicle leaves the track to input a job. If a vehicle does not need to load a job it can proceed unobstructed.

Inputs:

(1) vehicle number
(2) section travel times (approach and retreat)
(3) section leaving
(4) input station number
(5) approach section
(6) retreat section
(7) input area
(8) two transfer locations

Outputs:

(1) completion of approach section
(2) completion of retreat section
(3) if load to be picked up, completion of loading

Procedure:

(1) Vehicle completes approach within travel block(see TRAVEL macro).
(2) If loading to be performed:
    (a) vehicle completes loading within input block(see INPUT macro).
    (b) vehicle completes retreat within travel block (see TRAVEL macro).
    (c) vehicle exits macro.
(3) If loading not to be performed:
    (a) vehicle completes retreat within travel block (see TRAVEL macro).
    (b) vehicle exits macro.

INPT MACRO

OPERAND DESCRIPTIONS
#A - LOAD TIME
#B - PROGRAM TRANSFER LOCATION
#C - SECTION LEAVING
#D - INPUT STATION ID NUMBER
#E - APPROACH SECTION
#F - RETREAT SECTION
#G - INPUT NAME
#H - APPROACH SECTION TRAVEL TIME
#I - RETREAT SECTION TRAVEL TIME
#J - PROGRAM TRANSFER LOCATION

```
 INPT  STARTMACRO #A,#B,#C,#D,#E,#F,#G,#H,#I,#J
*
* TRAVEL INPUT  STATION APPROACH BLOCK                          *
*
 TRVL  MACRO      PF1,#H,#E,#C
*
* IF LOADING REQUIRED; LOAD AND TRAVEL INPUT RETREAT            *
* BLOCK                                                         *
*
       TEST E     PF2,#D,#J
 INPUT MACRO      PF1,#A,#G,#E
 TRVL  MACRO      PF1,#I,#F,#G
       TRANSFER   ,#B
*
* IF NO   LOADING REQUIRED; TRAVEL INPUT  RETREAT SECTION *
*
 #J    ADVANCE    0
 TRVL  MACRO      PF1,#I,#F,#E
 #B    ADVANCE    0
       ENDMACRO
```

GAS MACRO

Used in travel section which has refueling station within its boundaries. Divided into three sections : (1) an approach section, (2) a refuel station, and (3) a retreat section. Only one vehicle can be in the approach or retreat section at one time while the refuel section can hold a prespecified number of vehicles. The approach and retreat sections are traversed by the TRAVEL macro, and the refuel station by the FUEL macro. The vehicle leaves the track to refuel so that vehicles not needing to refuel can proceed unobstructed.

Inputs:

(1) section leaving
(2) refuel station number
(3) approach section
(4) retreat section
(5) refueling section
(6) travel time for the approach and retreat sections
(7) two transfer locations for the GAS macro
(8) refuel time

Outputs:

(1) completion of approach section
(2) completion of retreat section
(3) if refueling takes place, completion of refueling
(4) if refueling takes place, completion of reentrance of the system

Procedure:

(1) Vehicle completes approach within travel block (see TRAVEL macro).
(2) If refuel to be performed:
    (a) vehicle completes refueling within fuel block (see FUEL macro).
    (b) vehicle completes reentrance to the system and travels retreat within enter block (see ENTER macro).
    (c) vehicle exits macro.
(3) If refuel not to be performed;
    (a) vehicle completes retreat within travel block(see TRAVEL macro).
    (b) vehicle exits macro.

GAS MACRO

OPERAND OESCRIPTIONS
#A - SECTION LEAVING
#B - REFUEL AREA IO NUMBER
#C - APPROACH SECTION
#D - RETREAT SECTION FOR LEAVING GAS MACRO
#E - APPROACH SECTION FOR ENTER MACRO
#F - APPROACH TRAVEL TIME
#G - RETREAT TRAVEL TIME
#H - PROGRAM TRANSFER LOCATION
#I - PROGRAM TRANSFER LOCATION
#J - REFUEL TIME

```
 GAS   STARTMACRO #A,#B,#C,#O,#E,#F,#G,#H,#I,#J
*
* TRAVEL REFUEL STATION APPROACH BLOCK                          *
*
 TRVL  MACRO      PF1,#F,#C,#A
*
* IF REFUEL REQUIREO; REFUEL ANO TRAVEL REFUEL RETREAT          *
* BLOCK                                                         *
*
       TEST E     PF2,#B,#H
 FUEL  MACRO      PF1,#J,#E,#C
 ENTER MACRO      PF1,#G,#O,#E,1
       TRANSFER   ,#I
*
* IF NO REFUEL REQUIREO; TRAVEL REFUEL RETREAT SECTION          *
*
 #H    AOVANCE    0
 TRVL  MACRO      PF1,#G,#O,#C
 #I    AOVANCE    0
       ENOMACRO
```

PLACE MACRO

Used to travel section which has a parking station within its boundaries. Divided into three sections: (1) an approach section, (2) a parking area, and (3) a retreat area. Only one vehicle can be in both the approach and retreat sections at one time while the park section can hold a prespecified number of vehicles. The approach and retreat sections are traversed by the TRAVEL macro and the parking section by the PARK macro. The vehicle leaves the track to park so that other vehicles which do not need to park can proceed unobstructed.

Inputs:

(1) section leaving
(2) parking station number
(3) approach section
(4) retreat section
(5) parking area
(6) two transfer locations for PLACE macro

Outputs:

(1) completion of approach section
(2) completion of retreat section
(3) if parking takes place, entrance and exit of parking area
(4) if parking takes place, completion of reentrance to the system

Procedure:

(1) Vehicle completes approach within travel block (see TRAVEL macro).
(2) If parking takes place:
  (a) vehicle enters park until it is summonned to do a job within the park block (see PARK macro).
  (b) vehicle completes reentrance to the system and travels retreat section within the travel block (see TRAVEL macro).
  (c) vehicle exits macro.
(3) If vehicle bypasses parking area:
  (a) vehicle completes retreat section within the travel block (see TRAVEL macro).
  (b) vehicle exits macro.

PLACE MACRO

OPERAND DESCRIPTIONS
#A - SECTION LEAVING
#B - PARK AREA ID NUMBER
#C - APPROACH SECTION
#D - RETREAT SECTION FOR LEAVING PLACE MACRO
#E - APPROACH SECTION FOR ENTER MACRO
#F - APPROACH TRAVEL TIME
#G - RETREAT TRAVEL TIME
#H - PROGRAM TRANSFER LOCATION
#I - PROGRAM TRANSFER LOCATION

```
 PLACE STARTMACRO #A,#B,#C,#D,#E,#F,#G,#H,#I
*
* TRAVEL PARK STATION APPROACH BLOCK                                *
*
 TRVL  MACRO       PF1,#F,#C,#A
*
* IF PARK REQUIRED; PARK AND WHEN SUMMONED REENTER THE              *
* GUIDEPATH                                                         *
*
       TEST E      PF2,#B,#H
 PARK  MACRO       PF1,#E,#C
 ENTER MACRO       PF1,#G,#D,#E,2
       TRANSFER    ,#I
*
* IF NO PARK REQUIRED; TRAVEL PARK RETREAT SECTION                  *
*
 #H    ADVANCE     0
 TRVL  MACRO       PF1,#G,#D,#C
 #I    ADVANCE     0
       ENDMACRO
```

LOOP MACRO

Used to travel section which has more then one route from point A to point B. If the beginning of the main route is being used an alternative route will be immediately attempted. If the first section of the alternate route is also in use the vehicle will wait for the first available path. Each route consists of two sections which are each traversed by the TRAVEL macro. The succeeding section is also contained in the LOOP macro and is traversed normally in the TRAVEL macro. Vehicles will always try the main route first. Purpose is to prevent back up of vehicles if jam occurs at one block.

Inputs:

(1) first half of loop to be traveled if main route taken
(2) second half of loop to be traveled if main route taken
(3) first half of loop to be traveled if alternate route taken
(4) second half of loop to be traveled if alternate route taken

Outputs:

(1) completion of loop by either main or alternate route
(2) completion of succeeding section of track

Procedure:

(1) Vehicle attempts to enter main path portion of track. If it is occupied will attempt to enter alternate path of track. If it is also occupied the vehicle will wait until main or alternate becomes available and will then proceed.
(2) Vehicle completes travel of loop, by either main or alternate path (both are divided into two sections), within travel block (see TRAVEL macro).
(3) Vehicle exits macro.

LOOP MACRO

OPERAND DESCRIPTIONS

#A - MAIN PATH SECTION 1
#B - MAIN PATH SECTION 2
#C - ALTERNATIVE PATH SECTION 1
#D - ALTERNATIVE PATH SECTION 2
#E - EXIT FROM GUIDEPATH TO LOOP SECTION
#F - REENTRY ON GUIDEPATH SECTION
#G - REENTRY ON GUIDEPATH TRAVEL TIME
#H - PROGRAM TRANSFER LOCATION
#I - PROGRAM TRANSFER LOCATION
#J - PROGRAM TRANSFER LOCATION

```
 LOOP   STARTMACRO #A,#B,#C,#D,#E,#F,#G,#H,#I,#J
        TRANSFER    ,*+2
 RET    ADVANCE     1
*
* CHECK IF MAIN PATH OCCUPIED                                    *
*
        GATE NU     #A,#H
*
* IF MAIN PATH UNOCCUPIED; TRAVEL ITS LENGTH                     *
*
 TRVL   MACRO       PF1,4,#A,#E
 TRVL   MACRO       PF1,3,#B,#A
        TRANSFER    ,#I
*
* CHECK IF ALTERNATIVE PATH OCCUPIED                             *
*
 #H     GATE NU     #C,RET
*
* IF ALTERNATIVE PATH UNOCCUPIED; TRAVEL ITS LENGTH              *
* AND REENTER MAIN GUIDEPATH                                     *
*
 TRVL   MACRO       PF1,5,#C,#E
 TRVL   MACRO       PF1,4,#D,#C
 TRVL   MACRO       PF1,#G,#F,#D
        TRANSFER    ,#J
*
* RETURN TO REGULAR GUIDEPATH FROM MAIN ROUTE                    *
*
 #I     ADVANCE     0
 TRVL   MACRO       PF1,#G,#F,#B
 #J     ADVANCE     0
        ENDMACRO
```

APPENDIX B

Example Program for Case 1

```
*  THIS EXAMPLE IS OF CASE 1. NOTE THAT IT WAS RUN WITHOUT
*  A DISTANCE MATRIX BECAUSE A FROM-TO CHART OF THIS SYSTEM
*  WAS UNAVAILABLE.
*
*
       SIMULATE
*
*
*  GIVES EACH BLOCK OF TRACK,INPUT STATION, AND OUTPUT STATION
*  AN EQUIVALENT NUMERICAL VALUE. IN THIS WAY THE VEHICLE'S
*  WAITING TIME CAN BE MEASURED WHEN TRAVELLING LOADED (X)
*  OR TRAVELLING UNLOADED (X+1).
*
 SEC46 SYN        1
 AP1   SYN        3
 UNLD3 SYN        5
 RP1   SYN        7
 SEC2  SYN        9
 AP3   SYN        11
 UNLD4 SYN        13
 RP3   SYN        15
 SEC4  SYN        17
 AP5   SYN        19
 UNLD5 SYN        21
 RP5   SYN        23
 SEC6  SYN        25
 AP7   SYN        27
 UNLD6 SYN        29
 RP7   SYN        31
 SEC8  SYN        33
 AP9   SYN        35
 UNLD7 SYN        37
 RP9   SYN        39
 SEC10 SYN        41
 AP11  SYN        43
 UNLD8 SYN        45
 RP11  SYN        47
 SEC12 SYN        49
 AP13  SYN        51
 UNLD9 SYN        53
 RP13  SYN        55
 SEC14 SYN        57
 SEC15 SYN        59
 SEC16 SYN        61
 SEC17 SYN        63
 CROSS SYN        65
 SEC19 SYN        67
 SEC20 SYN        69
 SEC21 SYN        71
 AP22  SYN        73
 UND10 SYN        75
 RP22  SYN        77
 SEC23 SYN        79
 SEC24 SYN        81
 SEC25 SYN        83
```

```
 SEC26 SYN        85
 SEC27 SYN        87
 SEC28 SYN        89
 SEC29 SYN        91
 AP30  SYN        93
 REFIL SYN        95
 RP30  SYN        97
 AP31  SYN        99
 PARK  SYN        101
 RP31  SYN        103
 SEC32 SYN        105
 AP33  SYN        107
 INPT3 SYN        109
 RP33  SYN        111
 SEC34 SYN        113
 AP35  SYN        115
 INPT4 SYN        117
 RP35  SYN        119
 SEC36 SYN        121
 SEC37 SYN        123
 SEC38 SYN        125
 SEC39 SYN        127
 SEC40 SYN        129
 CLOG1 SYN        131
 CLOG2 SYN        133
 INPT1 SYN        135
 CLOG3 SYN        137
 CLOG4 SYN        139
 INPT2 SYN        141
 CLOG5 SYN        143
 CLOG6 SYN        145
 CLOG7 SYN        147
 CLOG8 SYN        149
 UNLD1 SYN        151
 CLOG9 SYN        153
 CLG10 SYN        155
 UNLD2 SYN        157
 CLG11 SYN        159
 CLG12 SYN        161
 CLG13 SYN        163
 SEC41 SYN        165
 SEC42 SYN        167
 LOP1A SYN        169
 LOP1B SYN        171
 LOP2A SYN        173
 LOP2B SYN        175
 SEC43 SYN        177
 SEC44 SYN        179
*
*
*  REALLOCATION OF COMPUTER SPACE NEEDED TO PERFORM RUN.
*
*
       REALLOCATE COM,50000
*
```

```
*  DISPATCH OF VEHICLES FROM INPUT STATIONS TO THE OUTPUT
*  STATIONS. SINCE NO PREVIOUS INFORMATION OF DISTRIBUTION
*  OF THE DELIVERY OF JOBS, EACH OUTPUT STATION HAD AN EQUAL
*  PROBABILITY.
*
 1      FUNCTION   RN1,D10
.1,1/.2,2/.3,3/.4,4/.5,5/.6,6/.7,7/.8,8/.9,9/1.0,10
*
*  CONVERSION OF THE VALUES STORED IN PARAMETER 3 TO THE
*  VEHICLE DESTINATION.
*
 2      FUNCTION   PF3,D5O
1,16/2,14/3,13/4,12/5,11
*
*  GROUPING OF DESTINATIONS INTO ONE LOCALE REPRESENTITIVE
*  GROUP
*
 3      FUNCTION   PF2,L16
1,3/2,3/4,4/5,4/6,4/7,4/8,4/9,4/10,4/11,1/12,1/13,2/14,2/15,5
16,6
*
*  CONVERSION OF VEHICLE STATUS (EITHER LOADED=1 OR UNLOADED=0)
*  TO A SAVEVALUE WHICH STORES TOTAL TRAVELLING FOR BOTH
*
 4      FUNCTION   PF4,D2
0,37/1,38
*
*
*
*
*  BOOLEAN VARIABLES WHICH ARE USED WHEN DECISIONS ARE MADE
*  ON THE VEHICLES DESTINATION.
*
 1      BVARIABLE  XF1'G'0+XF2'G'0+XF3'G'0+XF4'G'0
 2      BVARIABLE  XF4'GE'XF1*XF4'GE'XF2*XF4'GE'XF3
 3      BVARIABLE  XF3'GE'XF1*XF3'GE'XF2*XF3'GE'XF4
 4      BVARIABLE  XF2'GE'XF1*XF2'GE'XF3*XF2'GE'XF4
 5      BVARIABLE  XF1'GE'XF2*XF1'GE'XF3*XF1'GE'XF4
 6      BVARIABLE  XF1'G'0+XF2'G'+XF3'G'0+XF4'G'0
*
*
*  MACROS SHOULD BE INSERTED HERE
*
*
*  GENERATOR OF THE VEHICLES
*
*
        GENERATE  20,5,,6,,4PF
        SAVEVALUE 25+,1,XF
        ASSIGN    1,XF25,PF
        ASSIGN    2,FN1,PF
        SEIZE     SEC46
        QUEUE     201
        QUEUE     (SEC46+1)
*
```

```
*  MAIN PROGRAM REPRESENTING THE GUIDEPATH THE VEHICLES WILL
*  FOLLOW.
*
 STRT    ADVANCE    0
 OUTPT   MACRO      SEC46,3,AP1,RP1,UNLD3,1,1,60,03A,03B
 TRVL    MACRO      PF1,1,SEC2,RP1
 OUTPT   MACRO      SEC2,4,AP3,RP3,UNLD4,1,1,60,04A,04B
 TRVL    MACRO      PF1,1,SEC4,RP3
 OUTPT   MACRO      SEC4,5,AP5,RP5,UNLD5,1,1,60,05A,05B
 TRVL    MACRO      PF1,1,SEC6,RP5
 OUTPT   MACRO      SEC6,6,AP7,RP7,UNLD6,1,1,60,06A,06B
 TRVL    MACRO      PF1,1,SEC8,RP7
 OUTPT   MACRO      SEC8,7,AP9,RP9,UNLD7,1,1,60,07A,07B
 TRVL    MACRO      PF1,1,SEC10,RP9
 OUTPT   MACRO      SEC10,8,AP11,RP11,UNLD8,1,1,60,08A,08B
 TRVL    MACRO      PF1,1,SEC12,RP11
 OUTPT   MACRO      SEC12,9,AP13,RP13,UNLD9,1,1,60,09A,09B
 TRVL    MACRO      PF1,4,SEC14,RP13
 TRVL    MACRO      PF1,4,SEC15,SEC14
 TRVL    MACRO      PF1,4,SEC16,SEC15
 TRVL    MACRO      PF1,1,SEC17,SEC16
 TRVL    MACRO      PF1,1,CROSS,SEC17
 TRVL    MACRO      PF1,4,SEC19,CROSS
 TRVL    MACRO      PF1,4,SEC20,SEC19
 TRVL    MACRO      PF1,5,SEC21,SEC20
 OUTPT   MACRO      SEC21,10,AP22,RP22,UND10,1,1,60,010A,010B
 TRVL    MACRO      PF1,4,SEC23,RP22
 TRVL    MACRO      PF1,2,SEC24,SEC23
 TRVL    MACRO      PF1,4,SEC25,SEC24
 CLOG    ADVANCE    0
 TRVL    MACRO      PF1,4,SEC26,SEC25
 TRVL    MACRO      PF1,4,SEC27,SEC26
 TRVL    MACRO      PF1,4,SEC28,SEC27
 TRVL    MACRO      PF1,4,SEC29,SEC28
 GAS     MACRO      SEC29,15,AP30,RP30,REFIL,1,1,GAS1,GAS2
 PLACE   MACRO      RP30,16,AP31,RP31,PARK,1.1,PLC1,PLC2
 TRVL    MACRO      PF1,1,SEC32,RP31
 INPT    MACRO      50,IN3B,SEC32,13,AP33,RP33,INPT3,1,1,IN3A
 TRVL    MACRO      PF1,1,SEC34,RP33
 INPT    MACRO      50,IN4B,SEC34,14,AP35,RP35,INPT4,1,1.IN4A
 TRVL    MACRO      PF1,1,SEC36,RP35
 TRVL    MACRO      PF1,4,SEC37,SEC36
 TRVL    MACRO      PF1,4,SEC38,SEC37
 TRVL    MACRO      PF1,4,SEC39,SEC38
 TRVL    MACRO      PF1,3,SEC40,SEC39
         TEST E     FN3,1,AAA
 TRVL    MACRO      PF1,1,CLOG1,SEC40
 INPT    MACRO      50,IN1B,CLOG1,11,CLOG2,CLOG3,INPT1,1,1,IN1A
 INPT    MACRO      50,IN2B,CLOG3,12,CLOG4,CLOG5,INPT2,1,1,IN2A
 TRVL    MACRO      PF1,1,CLOG6,CLOG5
         TEST E     FN3,3,BBB
 CCC     ADVANCE    0
 OUTPT   MACRO      CLOG7,1,CLOG8,CLOG9,UNLD1,1,1,60,01A,01B
 OUTPT   MACRO      CLOG9,2,CLG10,CLG11,UNLD2,1,1,60,02A,02B
 TRVL    MACRO      PF1,3,CLG12,CLG11
```

```
 TRVL    MACRD      PF1,4,SEC25,CLG12
         TRANSFER   ,CLDG
 AAA     ADVANCE    0
 TRVL    MACRD      PF1,6,CLG13,SEC40
 TRVL    MACRD      PF1,1,CLDG6,CLG13
         TEST E     8V7,4,CCC
 TRVL    MACRD      PF1,1,SEC41,CLDG6
 TRVL    MACRD      PF1,1,SEC42,SEC41
 LODP    MACRD      LDP1A,LDP1B,LDP2A,LDP2B,SEC42,SEC43,1,LDP1,LOF2,LDP3
 TRVL    MACRD      PF1,1,SEC44,SEC43
 TRVL    MACRD      PF1,1,CROSS,SEC44
 TRVL    MACRD      PF1,1,SEC46,CRDSS1
         TRANSFER   ,STRT

*
*  GENERATIDN DF JDBS FDR EACH INPUT. GENERATED AT A UNIFDRM
*  RATE 8ECAUSE ND DISTRIBUTIDN KNDWN. DNE JD8 CREATED AT EACH
*  INPUT EVERY 180 SECDNDS.
*
        GENERATE    ,,,1
 TDP    ADVANCE     180
        SAVEVALUE   1+,1,XF
        SAVEVALUE   2+,1,XF
        SAVEVALUE   3+,1,XF
        SAVEVALUE   4+,1,XF
        TRANSFER    ,TDP
*
*  CLDCK TD REGULATE DNE SHIFT DR 28800 SECDNDS DF SIMULATIDN
*  TIME.
*
        GENERATE    ,,,1
        ADVANCE     28800
        TERMINATE   1
        START       1
        END
```

APPENDIX C

Example Program for Case 2

```
*  THIS EXAMPLE IS AFTER THE CUTOFFS HAD BEEN PUT IN.
*  BLOCK CUTTING HAD NOT YET BEEN PERFORMED.
*
*
*
      SIMULATE
*
*
*  GIVES EACH BLOCK OF TRACK,INPUT STATION, AND OUTPUT STATION
*  AN EQUIVALENT NUMERICAL VALUE. IN THIS WAY THE VEHICLE'S
*  WAITING TIME CAN BE MEASURED WHEN TRAVELLING LOADED (X)
*  OR TRAVELLING UNLOADED (X+1).
*
AP1    SYN        1
INP1   SYN        3
RP1    SYN        5
SEC16  SYN        7
AP20   SYN        9
UNL20  SYN        11
RP20   SYN        13
SEC17  SYN        15
AP3    SYN        17
INP3   SYN        19
RP3    SYN        21
AP21   SYN        23
UNL21  SYN        25
RP21   SYN        27
AP2    SYN        29
INP2   SYN        31
RP2    SYN        33
SEC20  SYN        35
AP4    SYN        37
INP4   SYN        39
RP4    SYN        41
AP5    SYN        43
INP5   SYN        45
RP5    SYN        47
AP6    SYN        49
INP6   SYN        51
RP6    SYN        53
AP7    SYN        55
INP7   SYN        57
RP7    SYN        59
AP8    SYN        61
INP8   SYN        63
RP8    SYN        65
SEC21  SYN        67
AP22   SYN        69
UNL22  SYN        71
RP22   SYN        73
SEC26  SYN        75
AP23   SYN        77
UNL23  SYN        79
RP23   SYN        81
SEC27  SYN        83
```

```
AP24   SYN        85
UNL24  SYN        87
RP24   SYN        89
SEC28  SYN        91
AP9    SYN        93
INP9   SYN        95
RP9    SYN        97
SEC1   SYN        99
AP25   SYN        101
UNL25  SYN        103
RP25   SYN        105
SEC2   SYN        107
AP26   SYN        109
UNL26  SYN        111
RP26   SYN        113
AP10   SYN        115
INP10  SYN        117
RP10   SYN        119
SEC3   SYN        121
AP27   SYN        123
UNL27  SYN        125
RP27   SYN        127
AP28   SYN        129
UNL28  SYN        131
RP28   SYN        133
SEC4   SYN        135
AP11   SYN        137
INP11  SYN        139
RP11   SYN        141
SEC5   SYN        143
AP12   SYN        145
INP12  SYN        147
RP12   SYN        149
SEC6   SYN        151
AP13   SYN        153
INP13  SYN        155
RP13   SYN        157
AP30   SYN        159
UNL30  SYN        161
RP30   SYN        163
AP29   SYN        165
UNL29  SYN        167
RP29   SYN        169
SEC9   SYN        171
AP14   SYN        173
INP14  SYN        175
RP14   SYN        177
AP31   SYN        179
UNL31  SYN        181
RP31   SYN        183
SEC10  SYN        185
AP32   SYN        187
UNL32  SYN        189
RP32   SYN        191
AP15   SYN        193
```

```
 INP15 SYN        195
 RP15  SYN        197
 SEC11 SYN        199
 SEC13 SYN        201
 AP33  SYN        203
 UNL33 SYN        205
 RP33  SYN        207
 AP17  SYN        209
 INP17 SYN        211
 RP17  SYN        213
 SEC14 SYN        215
 AP34  SYN        217
 UNL34 SYN        219
 RP34  SYN        221
 AP18  SYN        223
 INP18 SYN        225
 RP18  SYN        227
 AP16  SYN        229
 INP16 SYN        231
 RP16  SYN        233
 SEC15 SYN        235
 AP19  SYN        237
 UNL19 SYN        239
 RP19  SYN        241
 APG   SYN        243
 RPG   SYN        245
 APP   SYN        247
 RPP   SYN        249
 TSQU1 SYN        253
 TSQUH SYN        255
 TSQUV SYN        257
 LINK  SYN        259
 TSQU2 SYN        261
 TSQU3 SYN        263
 TSQU4 SYN        265
 TSQH1 SYN        267
 TSQH2 SYN        269
 TSQV2 SYN        271
 TSQV3 SYN        273
 TSQV4 SYN        275
 UP1   SYN        277
 UP2   SYN        279
*
*
*  REALLOCATION OF COMPUTER SPACE NEEDED TO PERFORM RUN.
*
*
       REALLOCATE COM,50000
*
*
*  DECLARATION OF MATRIX TO CONTAIN OUTPUT-TO-INPUT DISTANCES.
*
*
 1     MATRIX     MX,36,18
*
```

```
*  INITIALIZATION OF OUTPUT-TO-INPUT DISTANCE MATRIX. THE ROW
*  VALUE INDICATES THE OUTPUT STATION AND THE COLUMN VALUE THE
*  INPUT STATION. THE VALUE IN THAT MATRIX POSITION IS THE RANK
*  OF DISTANCES FROM THAT PARTICULAR OUTPUT (1=CLOSEST
*  18=FURTHEST). THE ROW VALUE 36 REPRESENTS THE DISTANCE FROM
*  THE PARK AREA.
*
      INITIAL    MX1(19,1),1/MX1(19,2),2/MX1(19,3),3/MX1(19,4),4
      INITIAL    MX1(19,5),5/MX1(19,6),6/MX1(19,7),7/MX1(19,8),8
      INITIAL    MX1(19,9),9/MX1(19,10),12/MX1(19,11),15
      INITIAL    MX1(19,12),10/MX1(19,13),11/MX1(19,14),13
      INITIAL    MX1(19,15),14/MX1(19,16),16/MX1(19,17),17
      INITIAL    MX1(19,18),18

      INITIAL    MX1(20,1),13/MX1(20,2),1/MX1(20,3),2/MX1(20,4),3
      INITIAL    MX1(20,5),4/MX1(20,6),5/MX1(20,7),6/MX1(20,8),7
      INITIAL    MX1(20,9),8/MX1(20,10),10/MX1(20,11),15
      INITIAL    MX1(20,12),9/MX1(20,13),11/MX1(20,14),12
      INITIAL    MX1(20,15),14/MX1(20,16),16/MX1(20,17),17
      INITIAL    MX1(20,18),18

      INITIAL    MX1(21,1),11/MX1(21,2),13/MX1(21,3),20/MX1(21,4),1
      INITIAL    MX1(21,5),2/MX1(21,6),3/MX1(21,7),4/MX1(21,8),5
      INITIAL    MX1(21,9),6/MX1(21,10),9/MX1(21,11),14
      INITIAL    MX1(21,12),7/MX1(21,13),8/MX1(21,14),10
      INITIAL    MX1(21,15),12/MX1(21,16),15/MX1(21,17),16
      INITIAL    MX1(21,18),17

      INITIAL    MX1(22,1),10/MX1(22,2),12/MX1(22,3),13/MX1(22,4),14
      INITIAL    MX1(22,5),15/MX1(22,6),16/MX1(22,7),17/MX1(22,8),18
      INITIAL    MX1(22,9),1/MX1(22,10),2/MX1(22,11),3
      INITIAL    MX1(22,12),4/MX1(22,13),5/MX1(22,14),6
      INITIAL    MX1(22,15),7/MX1(22,16),8/MX1(22,17),9
      INITIAL    MX1(22,18),11

      INITIAL    MX1(23,1),10/MX1(23,2),12/MX1(23,3),13/MX1(23,4),14
      INITIAL    MX1(23,5),15/MX1(23,6),16/MX1(23,7),17/MX1(23,8),18
      INITIAL    MX1(23,9),1/MX1(23,10),2/MX1(23,11),3
      INITIAL    MX1(23,12),4/MX1(23,13),5/MX1(23,14),6
      INITIAL    MX1(23,15),7/MX1(23,16),8/MX1(23,17),9
      INITIAL    MX1(23,18),11

      INITIAL    MX1(24,1),10/MX1(24,2),12/MX1(24,3),13/MX1(24,4),14
      INITIAL    MX1(24,5),15/MX1(24,6),16/MX1(24,7),17/MX1(24,8),18
      INITIAL    MX1(24,9),1/MX1(24,10),2/MX1(24,11),3
      INITIAL    MX1(24,12),4/MX1(24,13),5/MX1(24,14),6
      INITIAL    MX1(24,15),7/MX1(24,16),8/MX1(24,17),9
      INITIAL    MX1(24,18),11

      INITIAL    MX1(25,1),9/MX1(25,2),11/MX1(25,3),12/MX1(25,4),13
      INITIAL    MX1(25,5),14/MX1(25,6),15/MX1(25,7),16/MX1(25,8),17
      INITIAL    MX1(25,9),18/MX1(25,10),1/MX1(25,11),2
      INITIAL    MX1(25,12),3/MX1(25,13),4/MX1(25,14),5
      INITIAL    MX1(25,15),6/MX1(25,16),7/MX1(25,17),8
      INITIAL    MX1(25,18),10
```

```
INITIAL    MX1(26,1),8/MX1(26,2),10/MX1(26,3),11/MX1(26,4),12
INITIAL    MX1(26,5),13/MX1(26,6),14/MX1(26,7),15/MX1(26,8),16
INITIAL    MX1(26,9),17/MX1(26,10),20/MX1(26,11),1
INITIAL    MX1(26,12),2/MX1(26,13),3/MX1(26,14),4
INITIAL    MX1(26,15),5/MX1(26,16),6/MX1(26,17),7
INITIAL    MX1(26,18),9

INITIAL    MX1(27,1),8/MX1(27,2),10/MX1(27,3),11/MX1(27,4),12
INITIAL    MX1(27,5),13/MX1(27,6),14/MX1(27,7),15/MX1(27,8),16
INITIAL    MX1(27,9),17/MX1(27,10),18/MX1(27,11),1
INITIAL    MX1(27,12),2/MX1(27,13),3/MX1(27,14),4
INITIAL    MX1(27,15),5/MX1(27,16),6/MX1(27,17),7
INITIAL    MX1(27,18),9

INITIAL    MX1(28,1),8/MX1(28,2),10/MX1(28,3),11/MX1(28,4),12
INITIAL    MX1(28,5),13/MX1(28,6),14/MX1(28,7),15/MX1(28,8),16
INITIAL    MX1(28,9),17/MX1(28,10),18/MX1(28,11),1
INITIAL    MX1(28,12),2/MX1(28,13),3/MX1(28,14),4
INITIAL    MX1(28,15),5/MX1(28,16),6/MX1(28,17),7
INITIAL    MX1(28,18),9

INITIAL    MX1(29,1),5/MX1(29,2),7/MX1(29,3),8/MX1(29,4),9
INITIAL    MX1(29,5),16/MX1(29,6),11/MX1(29,7),12/MX1(29,8),13
INITIAL    MX1(29,9),14/MX1(29,10),17/MX1(29,11),18
INITIAL    MX1(29,12),15/MX1(29,13),16/MX1(29,14),I
INITIAL    MX1(29,15),2/MX1(29,16),3/MX1(29,17),4
INITIAL    MX1(29,18),6

INITIAL    MX1(30,1),5/MX1(30,2),7/MX1(30,3),8/MX1(30,4),9
INITIAL    MX1(30,5),10/MX1(30,6),11/MX1(30,7),12/MX1(30,8),13
INITIAL    MX1(30,9),14/MX1(30,10),17/MX1(30,11),18
INITIAL    MX1(30,12),15/MX1(30,13),16/MX1(30,14),1
INITIAL    MX1(30,15),2/MX1(30,16),3/MX1(30,17),4
INITIAL    MX1(30,18),6

INITIAL    MX1(31,1),4/MX1(31,2),6/MX1(31,3),7/MX1(31,4),8
INITIAL    MX1(31,5),9/MX1(31,6),10/MX1(31,7),11/MX1(31,8),12
INITIAL    MX1(31,9),13/MX1(31,10),16/MX1(31,11),18
INITIAL    MX1(31,12),14/MX1(31,13),15/MX1(31,14),17
INITIAL    MX1(31,15),1/MX1(31,16),2/MX1(31,17),3
INITIAL    MX1(31,18),5

INITIAL    MX1(32,1),3/MX1(32,2),5/MX1(32,3),6/MX1(32,4),7
INITIAL    MX1(32,5),8/MX1(32,6),9/MX1(32,7),10/MX1(32,8),11
INITIAL    MX1(32,9),12/MX1(32,10),15/MX1(32,11),17
INITIAL    MX1(32,12),13/MX1(32,13),14/MX1(32,14),18
INITIAL    MX1(32,15),18/MX1(32,16),1/MX1(32,17),2
INITIAL    MX1(32,18),4

INITIAL    MX1(33,1),2/MX1(33,2),3/MX1(33,3),4/MX1(33,4),5
INITIAL    MX1(33,5),6/MX1(33,6),7/MX1(33,7),8/MX1(33,8),9
INITIAL    MX1(33,9),10/MX1(33,10),13/MX1(33,11),15
INITIAL    MX1(33,12),11/MX1(33,13),12/MX1(33,14),14
INITIAL    MX1(33,15),16/MX1(33,16),17/MX1(33,17),20
```

```
       INITIAL    MX1(33,18),1

       INITIAL    MX1(34,1),2/MX1(34,2),3/MX1(34,3),4/MX1(34,4),5
       INITIAL    MX1(34,5),6/MX1(34,6),7/MX1(34,7),8/MX1(34,8),9
       INITIAL    MX1(34,9),10/MX1(34,10),13/MX1(34,11),15
       INITIAL    MX1(34,12),11/MX1(34,13),12/MX1(34,14),14
       INITIAL    MX1(34,15),16/MX1(34,16),17/MX1(34,17),18
       INITIAL    MX1(34,18),1

       INITIAL    MX1(35,1),13/MX1(35,2),1/MX1(35,3),2/MX1(35,4),3
       INITIAL    MX1(35,5),4/MX1(35,6),5/MX1(35,7),6/MX1(35,8),7
       INITIAL    MX1(35,9),8/MX1(35,10),10/MX1(35,11),15
       INITIAL    MX1(35,12),9/MX1(35,13),11/MX1(35,14),12
       INITIAL    MX1(35,15),14/MX1(35,16),16/MX1(35,17),17
       INITIAL    MX1(35,18),18

       INITIAL    MX1(36,1),13/MX1(36,2),1/MX1(36,3),2/MX1(36,4),3
       INITIAL    MX1(36,5),4/MX1(36,6),5/MX1(36,7),6/MX1(36,8),7
       INITIAL    MX1(36,9),8/MX1(36,10),10/MX1(36,11),15
       INITIAL    MX1(36,12),9/MX1(36,13),11/MX1(36,14),12
       INITIAL    MX1(36,15),14/MX1(36,16),16/MX1(36,17),17
       INITIAL    MX1(36,18),18
*
*  OPTIDNAL INITIALIZATIDN OF FUEL LEVEL.
*
       INITIAL    XF37-XF47,30000
*
*  DISPATCH FUNCTIONS FOR THE INPUTS. FUNCTIDN NUMBER REPRESENTS
*  INPUT STATIDNS AND THE FUNCTIDN CUMMULATIVE PRDBABILITY
*  CDRRESPDNDS TD THE DUTPUT STATIDN. A RANDDM NUMBER GENERATDR
*  PRDDUCES VALUE TD BE USED IN THE FUNCTIDN.
*
 9     FUNCTIDN   RN1,D10
.1015,29/.1160,30/.5182,33/.5617,31/.6342,21/.6922,23/.7139,22/.7401,34
.9140,19/1.0,26

 13    FUNCTIDN   RN1,D10
.0575,25/.2949,28/.3092,24/.3524,33/.3667,31/.3955,21/.4818,23/.5825,22
.9496,19/1.0,26

 12    FUNCTIDN   RN1,D9
.0956,29/.1103,30/.1250,33/.2868,31/.5221,23/.6838,22/.7279,20/.9338,19
1.0,26

 11    FUNCTIDN   RN1,D5
.0553,29/.0599,30/.2350,31/.4101,23/1.0,22

 8     FUNCTIDN   RN1,D10
.1092,29/.1223,30/.1529,33/.4236,31/.4542,21/.6289,23/.8560,22/.8647,20
.9782,19/1.0,26

 17    FUNCTIDN   RN1,D8
.2486,25/.2881,29/.2947,30/.5150,28/.5263,31/.5489,22/.9898,19/1.0,26
```

```
 14     FUNCTION   RN1,D6
.0070,28/.0211,21/.1866,23/.2007,22/.9964,19/1.0,26

 3      FUNCTION   RN1,D6
.0100,25/.0200,22/.0400,20/.8500,19/.9900,26/1.0,27

 4      FUNCTION   RN1,D2
.0059,20/1.0,19

 5      FUNCTION   RN1,D2
.0093,29/1.0,19


 6      FUNCTION   RN1,D1
1.0,19

 7      FUNCTION   RN1,D2
.0093,29/1.0,19

 2      FUNCTION   RN1,D3
.5490,23/.6470,22/1.0,19

 18     FUNCTION   RN1,D5
.2000,25/.4000,29/.6000,28/.8000,19/1.0,27

 15     FUNCTION   RN1,D1
1.0,19

 16     FUNCTION   RN1,D15
.0382,25/.1567,29/.1739,30/.1835,28/.1873,24/.2427,33/.2580,31/.4148,21
.6165,23/.8531,22/.9028,20/.9047,34/.9324,32/.9859,26/1.0,27

 10     FUNCTION   RN1,D8
.0636,29/.0727,30/.2909,24/.7273,33/.7455,21/.9455,22/.9637,34/1.0,19

 1      FUNCTION   RN1,D7
.1333,25/.3666,29/.3999,30/.6666,21/.7333,23/.8666,26/1.0,27
*
*  CONVERSION OF VEHICLE STATUS (EITHER LOADED=1 OR UNLOADED=0)
*  TO A SAVEVALUE WHICH STORES TOTAL TRAVELLING TIME FOR BOTH.
*
 19     FUNCTION   PF4,D2
0,59/1,60
*
*  BOOLEAN VARIABLES WHICH ARE USED AT DECISION POINTS TO
*  DETERMINE A VEHICLES ROUTE.
*
 1      BVARIABLE  PF2'E'3+PF2'E'21
 2      BVARIABLE  PF2'E'5+PF2'E'6+PF2'E'7+PF2'E'8
 3      BVARIABLE  PF2'E'5
 4      BVARIABLE  PF2'E'6
 5      BVARIABLE  PF2'E'7
 6      BVARIABLE  PF2'E'8
 7      BVARIABLE  PF2'E'13+PF2'E'30
 8      BVARIABLE  PF2'E'33+PF2'E'17+PF2'E'34+PF2'E'18
```

```
 9      BVARIABLE  BV10'E'1+BV11'E'1+BV12'E'1+BV13'E'1
 10     BVARIABLE  XF7'G'0+XF8'G'0+XF9'G'0+XF10'G'0+XF11'G'0+XF12'G'0
 11     BVARIABLE  XF13'G'0+XF14'G'0+XF15'G'0+XF16'G'0+XF17'G'0
 12     BVARIABLE  XF18'G'0
 13     BVARIABLE  XF1'G'0+XF2'G'0+XF3'G'0+XF4'G'0+XF5'G'0+XF6'G'0
 14     BVARIABLE  PF2'E'22+PF2'E'23+PF2'E'24+PF2'E'9+PF2'E'25
 15     BVARIABLE  PF2'E'26+PF2'E'10+PF2'E'27+PF2'E'28+PF2'E'11
 16     BVARIABLE  BV14'E'1+BV15'E'1
 17     BVARIABLE  PF2'E'19+PF2'E'1+PF2'E'20+PF2'E'2+PF2'E'3
 18     BVARIABLE  PF2'E'21+PF2'E'4+PF2'E'5+PF2'E'6+PF2'E'7+PF2'E'8
 19     BVARIABLE  BV17'E'1+BV18'E'1+BV20'E'1
 20     BVARIABLE  PF2'E'35+PF2'E'36
 21     BVARIABLE  PF2'E'5+PF2'D'6+PF2'E'7+PF2'E'8
 22     BVARIABLE  BV21'E'1+BV16'E'1
*
*
*
*  MACROS SHOULD BE INSERTED HERE
*
*
*
*
*
*
*  GENERATOR OF THE VEHICLES
*
*
        GENERATE  20,5,,8,,6PF
        SAVEVALUE 61+,1,XF
        ASSIGN    1,XF61,PF
        ASSIGN    2,36,PF
        SEIZE     RP1
        QUEUE     250
        QUEUE     (RP1+1)
        SAVEVALUE (PF1+47),0,XF
*
*  MAIN PROGRAM REPRESENTING THE GUIDEPATH THE VEHICLES WILL
*  FOLLOW
*
 TOP    ADVANCE   0
 TRVL   MACRO     PF1,6,SEC16,RP1
 OUTPT  MACRO     SEC16,20,AP20,RP20,UNL20,3,3,50,O20A,O20B
 GAS    MACRO     RP20,35,APG,RPG,REFILL,1,1,GAS1,GAS2,600
 PLACE  MACRO     RPG,36,APP,RPP,PARK,1,1,PLC1,PLC2
 TRVL   MACRO     PF1,28,SEC17,RPP

        TEST E    BV1,1,J1

 INPT   MACRO     50,IN3B,SEC17,3,AP3,RP3,INP3,31,2,IN3A
 OUTPT  MACRO     RP3,21,AP21,RP21,UNL21,2,18,50,O21A,O21B
 TRVL   MACRO     PF1,49,SEC20,RP21
 INPT   MACRO     50,IN4D,SEC20,4,AP4,RP4,INP4,4,24,IN4C
        TRANSFER  ,L2

 J1     ADVANCE   0
```

```
INPT     MACRO       50,IN2B,SEC17,2,AP2,RP2,INP2,4,4,IN2A
TRVL     MACRO       PF1,49,SEC20,RP2
INPT     MACRO       50,IN4B,SEC20,4,AP4,RP4,INP4,4,24,IN4A

L2       TEST E      BV22,0,J2
TRVL     MACRO       PF1,23,UP1,RP4
TRVL     MACRO       PF1,23,UP2,UP1
TRVL     MACRO       PF1,14,TSQU4,UP2
         TRANSFER    ,L3

J2       TEST E      BV2,1,J3

         TEST E      BV3,1,J4

INPT     MACRO       50,IN5B,RP4,5,AP5,RP5,INP5,18,16,IN5A
TRVL     MACRO       PF1,2,LINK,RP5
         TEST E      BV16,1,TSQU
OUTPT    MACRO       LINK,22,AP22,RP22,UNL22,7,2,50,022A,022B
         TRANSFER    ,J5

J4       TEST E      BV4,1,J6

INPT     MACRO       50,IN6B,RP4,6,AP6,RP6,INP6,31,16,IN6A
TRVL     MACRO       PF1,2,LINK,RP6
         TEST E      BV16,1,TSQU
OUTPT    MACRO       LINK,22,AP22,RP22,UNL22,7,2,50,022C,022D
         TRANSFER    ,J5

J6       TEST E      BV5,1,J7

INPT     MACRO       50,IN7B,RP4,7,AP7,RP7,INP7,42,16,IN7A
TRVL     MACRO       PF1,2,LINK,RP7
         TEST E      BV16,1,TSQU
OUTPT    MACRO       LINK,22,AP22,RP22,UNL22,7,2,50,022E,022F
         TRANSFER    ,J5

J7       ADVANCE     0

INPT     MACRO       50,INBB,RP4,B,APB,RPB,INPB,49,16,INBA
TRVL     MACRO       PF1,2,LINK,RPB
         TEST E      BV16,1,TSQU
OUTPT    MACRO       LINK,22,AP22,RP22,UNL22,7,2,50,022G,022H
         TRANSFER    ,J5

J3       ADVANCE     0
TRVL     MACRO       PF1,38,SEC21,RP4
TRVL     MACRO       PF1,2,LINK,SEC21
         TEST E      BV16,1,TSQU
OUTPT    MACRO       LINK,22,AP22,RP22,UNL22,7,2,50,022I,022J

J5       ADVANCE     0
TRVL     MACRO       PF1,14,SEC26,RP22
OUTPT    MACRO       SEC26,23,AP23,RP23,UNL23,2,4,50,023A,023B
TRVL     MACRO       PF1,14,SEC27,RP23
OUTPT    MACRO       SEC27,24,AP24,RP24,UNL24,4,4,50,024A,024B
```

```
TRVL     MACRO      PF1,28,SEC28,RP24
INPT     MACRO      50,IN9B,SEC2B,9,AP9,RP9,INP9,4,4,IN9A
PLACE    MACRO      RP9,36,APP2,RPP2,PARK,1,1,PLC3,PLC4
TRVL     MACRO      PF1,29,SEC1,RPP2
OUTPT    MACRO      SEC1,25,AP25,RP25,UNL25,3,3,50,025A,025B
TRVL     MACRO      PF1,12,SEC2,RP25
OUTPT    MACRO      SEC2,26,AP26,RP26,UNL26,3,4,50,026A,026B
INPT     MACRO      50,IN10B,RP26,10,AP10,RP10,INP10,4,6,IN10A
TRVL     MACRO      PF1,35,SEC3,RP10
OUTPT    MACRO      SEC3,27,AP27,RP27,UNL27,6,1,50,027A,027B
OUTPT    MACRO      RP27,28,AP28,RP28,UNL28,1,3,50,028A,028B
TRVL     MACRO      PF1,7,SEC4,RP28
INPT     MACRO      50,IN11B,SEC4,11,AP11,RP11,INP11,3,5,IN11A
TRVL     MACRO      PF1,56,SEC5,RP11
INPT     MACRO      50,IN12B,SEC5,12,AP12,RP12,INP12,5,7,IN12A
RET2     ADVANCE    0
TRVL     MACRO      PF1,21,SEC6,RP12

         TEST E     BV7,1,J8

INPT     MACRO      50,IN13B,SEC6,13,AP13,RP13,INP13,11,7,IN13A
OUTPT    MACRO      RP13,30,AP30,RP30,UNL30,7,8,50,030A,030B
TRVL     MACRO      PF1,14,SEC9,RP30
         TRANSFER   ,J9

J8       ADVANCE    0
OUTPT    MACRO      SEC6,29,AP29,RP29,UNL29,8,3,50,029A,029B
TRVL     MACRO      PF1,14,SEC9,RP29

J9       ADVANCE    0
INPT     MACRO      50,IN14B,SEC9,14,AP14,RP14,INP14,3,7,IN14A
OUTPT    MACRO      RP14,31,AP31,RP31,UNL31,7,3,50,031A,031B
TRVL     MACRO      PF1,28,SEC10,RP31
OUTPT    MACRO      SEC10S32,AP32,RP32,UNL32,3,2,50,032A.032B
INPT     MACRO      50,IS15B,RP32,15,AP15,RP15,INP15,2,6,IN15A
TRVL     MACRO      PF1,25,SEC11,RP15

         TEST E     BV8,1,J10

TRVL     MACRO      PF1,28,SEC13,SEC11
OUTPT    MACRO      SEC13,33,AP33,RP33,UNL33,6,4,50,033A,033B
INPT     MACRO      50,IN17B,RP33,17,AP17,RP17,INP17,4,2,IN17A
TRVL     MACRO      PF1,14,SEC14,RP17
OUTPT    MACRO      SEC14,34,AP34,RP34,UNL34,2,6,50,034A,034B
INPT     MACRO      50,IN18B,RP34,18,AP18,RP18,INP18,6,4,IN18A
TRVL     MACRO      PF1,18,SEC15,RP18
         TRANSFER   ,J11

J10      ADVANCE    0
INPT     MACRO      50,IN16B,SEC11,16,AP16,RP16,INP16,10,4,IN16A
TRVL     MACRO      PF1,18,SEC15,RP16

J11      ADVANCE    0
OUTPT    MACRO      SEC15,19,AP19,RP19,UNL19,2,1,50,019A,019B
RET1     ADVANCE    0
```

```
INPT    MACRO       50,IN1B,RP19,1,AP1,RP1,INP1,1,3,IN1A
        TRANSFER    ,TOP

TSOU    ADVANCE     0
TRVL    MACRO       PF1,14,TSOU1,LINK
TRVL    MACRO       PF1,14,TSOU2,TSOU1
TRVL    MACRO       PF1,14,TSOU3,TSOU2
TRVL    MACRO       PF1,14,TSOU4,TSOU3
L3      TEST E      BV19,0,HOR
TRVL    MACRO       PF1,12,TSOUH,TSOU4
TRVL    MACRO       PF1,13,TSOH1,TSOUH
TRVL    MACRO       PF1,53,TSOH2,TSOH1
INPT    MACRO       50,IN12D,TSOH2,12,AP12,RP12,INP12,5,6,IN12C
        TRANSFER    ,RET2

HOR     ADVANCE     0
TRVL    MACRO       PF1,25,TSOUV,TSOU4
TRVL    MACRO       PF1,25,TSOV2,TSOUV
TRVL    MACRO       PF1,25,TSOV3,TSOV2
TRVL    MACRO       PF1,29,TSOV4,TSOV3
TRVL    MACRO       PF1,25,TSOV5,TSOV4
OUTPT   MACRO       TSOV5,19,AP19,RP19,UNL19,2,1,50,O19C,O19D
        TRANSFER    ,RET2

*
*  GENERATION OF JOBS FOR EACH INPUT. FROM GIVEN DATA THE
*  NUMBER OF JOBS INPUTTED AT EACH INPUT STATION WAS KNOWN
*  AND THE GENERATE BLOCKS BELOW CREATED JOBS AT A UNIFORM
*  RATE TO SIMULATE A SHIFT'S WORTH.
*
        GENERATE    9600,960
        SAVEVALUE   1+,1,XF
        TERMINATE

        GENERATE    2824,282
        SAVEVALUE   2+,1,XF
        TERMINATE

        GENERATE    1440,144
        SAVEVALUE   3+,1,XF
        TERMINATE

        GENERATE    847,85
        SAVEVALUE   4+,1,XF
        TERMINATE

        GENERATE    2667,267
        SAVEVALUE   5+,1,XF
        TERMINATE

        GENERATE    3000,300
        SAVEVALUE   6+,1,XF
        TERMINATE

        GENERATE    2667,267
```

```
        SAVEVALUE  7+,1,XF
        TERMINATE

        GENERATE   629,63
        SAVEVALUE  8+,1,XF
        TERMINATE

        GENERATE   1043,104
        SAVEVALUE  9+,1,XF
        TERMINATE

        GENERATE   2618,262
        SAVEVALUE  10+,1,XF
        TERMINATE

        GENERATE   1327,133
        SAVEVALUE  11+,1,XF
        TERMINATE

        GENERATE   2118,212
        SAVEVALUE  12+,1,XF
        TERMINATE

        GENERATE   2072,207
        SAVEVALUE  13+,1,XF
        TERMINATE

        GENERATE   507,51
        SAVEVALUE  14+,1,XF
        TERMINATE

        GENERATE   10286,1029
        SAVEVALUE  15+,1,XF
        TERMINATE

        GENERATE   275,28
        SAVEVALUE  16+,1,XF
        TERMINATE

        GENERATE   1627,163
        SAVEVALUE  17+,1,XF
        TERMINATE

        GENERATE   28800,2880
        SAVEVALUE  18+,1,XF
        TERMINATE
*
*  CLOCK TO REGULATE ONE SHIFT OR 28800 SECONDS OF SIMULATION
*  TIME.
*
        GENERATE   ,,,1
        LOGIC S    2
        SEIZE      CLCK
        ADVANCE    28800
        RELEASE    CLCK
```

```
TERMINATE  1
START      1
END
```

APPENDIX D

Example Program for Case 3

```
*
*  THIS EXAMPLE IS AFTER THE CUTOFFS HAD BEEN PUT IN.
*  BLOCK DIVISION HAD NOT YET BEEN PERFORMED.
*
      SIMULATE
*
*
*  GIVES EACH BLOCK OF TRACK, INPUT STATION, AND OUTPUT STATION
*  AN EQUIVALENT NUMERICAL VALUE. IN THIS WAY THE VEHICLE'S
*  WAITING TIME CAN BE MEASURED WHEN TRAVELLING LOADED (X)
*  OR TRAVELLING UNLOADED (X+1)
*
 Z24A  SYN        1
 Z24B  SYN        3
 AP7   SYN        5
 INP7  SYN        7
 RP7   SYN        9
 AP8   SYN        11
 INP8  SYN        13
 RP8   SYN        15
 AP33  SYN        17
 UNL33 SYN        19
 RP33  SYN        21
 AP34  SYN        23
 UNL34 SYN        25
 RP34  SYN        27
 AP35  SYN        29
 UNL35 SYN        31
 RP35  SYN        33
 AP32  SYN        35
 UNL32 SYN        37
 RP32  SYN        39
 AP9   SYN        41
 INP9  SYN        43
 RP9   SYN        45
 AP40  SYN        53
 UNL40 SYN        55
 RP40  SYN        57
 AP14  SYN        59
 INP14 SYN        61
 RP14  SYN        63
 AP41  SYN        65
 UNL41 SYN        67
 RP41  SYN        69
 AP42  SYN        71
 UNL42 SYN        73
 RP42  SYN        75
 AP15  SYN        77
 AP15A SYN        79
 INP15 SYN        81
 RP15  SYN        83
 AP16  SYN        85
 INP16 SYN        87
 RP16  SYN        89
 AP17  SYN        91
```

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INP17 SYN        93
RP17  SYN        95
AP43  SYN        97
UNL43 SYN        99
RP43  SYN        101
OT    SYN        103
Z11   SYN        105
SEC53 SYN        107
AP36  SYN        109
UNL36 SYN        111
RP36  SYN        113
AP10  SYN        115
INP10 SYN        117
RP10  SYN        119
AP11  SYN        121
INP11 SYN        123
RP11  SYN        125
AP12  SYN        127
INP12 SYN        129
RP12  SYN        131
AP37  SYN        133
UNL37 SYN        135
RP37  SYN        137
AP38  SYN        139
UNL38 SYN        141
RP38  SYN        143
AP39  SYN        145
UNL39 SYN        147
RP39  SYN        149
AP13  SYN        151
INP13 SYN        153
RP13  SYN        155
SEC43 SYN        157
AP1   SYN        159
AP1A  SYN        161
INP1  SYN        163
RP1   SYN        165
TO    SYN        167
AP44  SYN        169
UNL44 SYN        171
RP44  SYN        173
AP18  SYN        175
INP18 SYN        177
RP18  SYN        179
AP45  SYN        181
UNL45 SYN        183
RP45  SYN        185
AP19  SYN        187
INP19 SYN        189
RP19  SYN        191
AP46  SYN        193
UNL46 SYN        195
RP46  SYN        197
AP20  SYN        199
INP20 SYN        201
```

RP20	SYN	203
AP50	SYN	205
UNL50	SYN	207
RP50	SYN	209
AP24	SYN	211
INP24	SYN	213
RP24	SYN	215
AP49	SYN	217
UNL49	SYN	221
RP49	SYN	223
AP23	SYN	227
INP23	SYN	229
RP23	SYN	235
Z18B	SYN	237
AP2	SYN	239
AP2A	SYN	241
INP2	SYN	243
RP2	SYN	245
RP2A	SYN	247
Z8	SYN	249
Z10	SYN	251
AP28	SYN	253
UNL28	SYN	255
RP28	SYN	257
AP29	SYN	259
UNL29	SYN	261
RP29	SYN	263
AP6	SYN	265
INP6	SYN	267
RP6	SYN	269
AP30	SYN	271
UNL30	SYN	273
RP30	SYN	275
AP31	SYN	277
UNL31	SYN	279
RP31	SYN	281
AP48	SYN	283
UNL48	SYN	285
RP48	SYN	287
AP22	SYN	289
INP22	SYN	291
RP22	SYN	293
AP47	SYN	295
UNL47	SYN	297
RP47	SYN	299
AP21	SYN	301
INP21	SYN	309
RP21	SYN	311
Z6A	SYN	313
AP4	SYN	315
INP4	SYN	317
RP4	SYN	319
AP27	SYN	321
UNL27	SYN	323
RP27	SYN	325

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 Z98   SYN        327
 AP5   SYN        329
 INP5  SYN        331
 RP5   SYN        333
 AP25  SYN        335
 UNL25 SYN        337
 RP25  SYN        339
 Z23A  SYN        341
 AP26  SYN        343
 UNL26 SYN        345
 RP26  SYN        347
 AP3   SYN        349
 INP3  SYN        353
 RP3   SYN        355
 Z11B  SYN        357
 Z4    SYN        359
 Z5    SYN        361
 Z1    SYN        363
 Z3    SYN        365
 SEC58 SYN        367
 Z13   SYN        369
 Z12   SYN        371
 Z9    SYN        373
 PARK  SYN        381
 APP   SYN        383
 RPP   SYN        385
*
*  REALLOCATION OF COMPUTER SPACE NEEOEO TO PERFORM RUN
*
       REALLOCATE COM,50000
*
*  DECLARATION OF MATRIX TO CONTAIN OUTPUT-TO-INPUT DISTANCES
*
 1     MATRIX     MX,51,24
*
*  INITIALIZATION OF OUTPUT-TO-INPUT OISTANCE MATRIX. THE ROW
*  VALUE INDICATES THE OUTPUT STATION ANO THE COLUMN VALUE THE
*  INPUT STATION. THE VALUE IN THAT MATRIX POSITION IS THE RANK
*  OF OISTANCES FROM THAT PARTICULAR OUTPUT (1=CLOSEST
*  24=FURTHEST). THE ROW VALUE 51 REPRESENTS THE OISTANCE FROM
*  THE PARK AREA.
*
       INITIAL    MX1(25,1),14/MX1(25,2),15/MX1(25,3),1/MX1(25,4),17
       INITIAL    MX1(25,5),6/MX1(25,6),11/MX1(25,7),2/MX1(25,8),4
       INITIAL    MX1(25,9),3/MX1(25,10),8/MX1(25,11),9
       INITIAL    MX1(25,12),10/MX1(25,13),19/MX1(25,14),12
       INITIAL    MX1(25,15),5/MX1(25,16),7/MX1(25,17),13
       INITIAL    MX1(25,18),16/MX1(25,19),18/MX1(25,20),20
       INITIAL    MX1(25,21),22/MX1(25,22),21/MX1(25,23),24
       INITIAL    MX1(25,24),23

       INITIAL    MX1(26,1),8/MX1(26,2),9/MX1(26,3),1/MX1(26,4),17
       INITIAL    MX1(26,5),2/MX1(26,6),4/MX1(26,7),3/MX1(26,8),5
       INITIAL    MX1(26,9),7/MX1(26,10),11/MX1(26,11),12
       INITIAL    MX1(26,12),13/MX1(26,13),10/MX1(26,14),16
```

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INITIAL    MX1(26,15),6/MX1(26,16),9/MX1(26,17),15
INITIAL    MX1(26,18),14/MX1(26,19),18/MX1(26,20),19
INITIAL    MX1(26,21),21/MX1(26,22),20/MX1(26,23),23
INITIAL    MX1(26,24),22


INITIAL    MX1(27,1),4/MX1(27,2),8/MX1(27,3),19/MX1(27,4),15
INITIAL    MX1(27,5),1/MX1(27,6),3/MX1(27,7),2/MX1(27,8),5
INITIAL    MX1(27,9),7/MX1(27,10),12/MX1(27,11),13
INITIAL    MX1(27,12),14/MX1(27,13),11/MX1(27,14),17
INITIAL    MX1(27,15),6/MX1(27,16),9/MX1(27,17),16
INITIAL    MX1(27,18),10/MX1(27,19),18/MX1(27,20),20
INITIAL    MX1(27,21),22/MX1(27,22),21/MX1(27,23),24
INITIAL    MX1(27,24),23


INITIAL    MX1(28,1),1/MX1(28,2),2/MX1(28,3),6/MX1(28,4),4
INITIAL    MX1(28,5),8/MX1(28,6),10/MX1(28,7),7/MX1(28,8),9
INITIAL    MX1(28,9),12/MX1(28,10),17/MX1(28,11),18
INITIAL    MX1(28,12),19/MX1(28,13),16/MX1(28,14),22
INITIAL    MX1(28,15),11/MX1(28,16),15/MX1(28,17),21
INITIAL    MX1(28,18),3/MX1(28,19),5/MX1(28,20),13
INITIAL    MX1(28,21),20/MX1(28,22),14/MX1(28,23),23
INITIAL    MX1(28,24),24


INITIAL    MX1(29,1),1/MX1(29,2),2/MX1(29,3),6/MX1(29,4),4
INITIAL    MX1(29,5),8/MX1(29,6),10/MX1(29,7),7/MX1(29,8),9
INITIAL    MX1(29,9),12/MX1(29,10),17/MX1(29,11),18
INITIAL    MX1(29,12),19/MX1(29,13),16/MX1(29,14),22
INITIAL    MX1(29,15),11/MX1(29,16),15/MX1(29,17),21
INITIAL    MX1(29,18),3/MX1(29,19),5/MX1(29,20),13
INITIAL    MX1(29,21),20/MX1(29,22),14/MX1(29,23),23
INITIAL    MX1(29,24),24

INITIAL    MX1(30,1),1/MX1(30,2),2/MX1(30,3),7/MX1(30,4),9
INITIAL    MX1(30,5),5/MX1(30,6),4/MX1(30,7),8/MX1(30,8),10
INITIAL    MX1(30,9),12/MX1(30,10),17/MX1(30,11),18
INITIAL    MX1(30,12),19/MX1(30,13),16/MX1(30,14),22
INITIAL    MX1(30,15),11/MX1(30,16),15/MX1(30,17),21
INITIAL    MX1(30,18),3/MX1(30,19),6/MX1(30,20),13
INITIAL    MX1(30,21),20/MX1(30,22),14/MX1(30,23),23
INITIAL    MX1(30,24),24


INITIAL    MX1(31,1),1/MX1(31,2),2/MX1(31,3),7/MX1(31,4),9
INITIAL    MX1(31,5),5/MX1(31,6),4/MX1(31,7),8/MX1(31,8),10
INITIAL    MX1(31,9),12/MX1(31,10),17/MX1(31,11),18
INITIAL    MX1(31,12),19/MX1(31,13),16/MX1(31,14),22
INITIAL    MX1(31,15),11/MX1(31,16),15/MX1(31,17),21
INITIAL    MX1(31,18),3/MX1(31,19),6/MX1(31,20),13
INITIAL    MX1(31,21),20/MX1(31,22),14/MX1(31,23),23
INITIAL    MX1(31,24),24
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INITIAL    MX1(32,1),11/MX1(32,2),9/MX1(32,3),16/MX1(32,4),12
INITIAL    MX1(32,5),17/MX1(32,6),13/MX1(32,7),15/MX1(32,8),18
INITIAL    MX1(32,9),1/MX1(32,10),2/MX1(32,11),3
INITIAL    MX1(32,12),4/MX1(32,13),8/MX1(32,14),5
INITIAL    MX1(32,15),6/MX1(32,16),7/MX1(32,17),10
INITIAL    MX1(32,18),14/MX1(32,19),19/MX1(32,20),20
INITIAL    MX1(32,21),22/MX1(32,22),21/MX1(32,23),24
INITIAL    MX1(32,24),23


INITIAL    MX1(33,1),10/MX1(33,2),8/MX1(33,3),15/MX1(33,4),11
INITIAL    MX1(33,5),16/MX1(33,6),12/MX1(33,7),14/MX1(33,8),17
INITIAL    MX1(33,9),18/MX1(33,10),1/MX1(33,11),2
INITIAL    MX1(33,12),3/MX1(33,13),7/MX1(33,14),4
INITIAL    MX1(33,15),5/MX1(33,16),6/MX1(33,17),9
INITIAL    MX1(33,18),13/MX1(33,19),19/MX1(33,20),20
INITIAL    MX1(33,21),22/MX1(33,22),21/MX1(33,23),24
INITIAL    MX1(33,24),23

INITIAL    MX1(34,1),10/MX1(34,2),8/MX1(34,3),15/MX1(34,4),11
INITIAL    MX1(34,5),16/MX1(34,6),12/MX1(34,7),14/MX1(34.8),17
INITIAL    MX1(34,9),18/MX1(34,10),1/MX1(34,11),2
INITIAL    MX1(34,12),3/MX1(34,13),7/MX1(34,14),4
INITIAL    MX1(34,15),5/MX1(34,16),6/MX1(34,17),9
INITIAL    MX1(34,18),13/MX1(34,19),19/MX1(34,20),20
INITIAL    MX1(34,21),22/MX1(34,22),21/MX1(34,23),24
INITIAL    MX1(34,24),23


INITIAL    MX1(35,1),10/MX1(35,2),8/MX1(35,3),15/MX1(35,4),11
INITIAL    MX1(35,5),16/MX1(35,6),12/MX1(35,7),14/MX1(35,8),17
INITIAL    MX1(35,9),18/MX1(35,10),1/MX1(35,11),2
INITIAL    MX1(35,12),3/MX1(35,13),7/MX1(35,14),4
INITIAL    MX1(35,15),5/MX1(35,16),6/MX1(35,17),9
INITIAL    MX1(35,18),13/MX1(35,19),19/MX1(35,20),20
INITIAL    MX1(35,21),22/MX1(35,22),21/MX1(35,23),24
INITIAL    MX1(35,24),23


INITIAL    MX1(36,1),9/MX1(36,2),7/MX1(36,3),12/MX1(36,4),10
INITIAL    MX1(36,5),15/MX1(36,6),11/MX1(36,7),14/MX1(36,8),16
INITIAL    MX1(36,9),17/MX1(36,10),1/MX1(36,11),2
INITIAL    MX1(36,12),3/MX1(36,13),6/MX1(36,14),20
INITIAL    MX1(36,15),4/MX1(36,16),5/MX1(36,17),8
INITIAL    MX1(36,18),13/MX1(36,19),18/MX1(36,20),19
INITIAL    MX1(36,21),22/MX1(36,22),21/MX1(36,23),24
INITIAL    MX1(36,24),23


INITIAL    MX1(37,1),6/MX1(37,2),4/MX1(37,3),9/MX1(37,4),7
INITIAL    MX1(37,5),12/MX1(37,6),8/MX1(37,7),11/MX1(37,8),13
INITIAL    MX1(37,9),14/MX1(37,10),16/MX1(37,11),17
INITIAL    MX1(37,12),18/MX1(37,13),3/MX1(37,14),20
INITIAL    MX1(37,15),1/MX1(37,16),2/MX1(37,17),5
INITIAL    MX1(37,18),10/MX1(37,19),15/MX1(37.20),19
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INITIAL     MX1(37,21),22/MX1(37,22),21/MX1(37,23),24
INITIAL     MX1(37,24),23

INITIAL     MX1(38,1),3/MX1(38,2),2/MX1(38,3),6/MX1(38,4),4
INITIAL     MX1(38,5),9/MX1(38,6),5/MX1(38,7),8/MX1(38,8),10
INITIAL     MX1(38,9),12/MX1(38,10),15/MX1(38,11),16
INITIAL     MX1(38,12),17/MX1(38,13),1/MX1(38,14),20
INITIAL     MX1(38,15),11/MX1(38,16),14/MX1(38,17),19
INITIAL     MX1(38,18),7/MX1(38,19),13/MX1(38,20),18
INITIAL     MX1(38,21),22/MX1(38,22),21/MX1(38,23),24
INITIAL     MX1(38,24),23

INITIAL     MX1(39,1),3/MX1(39,2),2/MX1(39,3),6/MX1(39,4),4
INITIAL     MX1(39,5),9/MX1(39,6),5/MX1(39,7),8/MX1(39,8),10
INITIAL     MX1(39,9),12/MX1(39,10),15/MX1(39,11),16
INITIAL     MX1(39,12),17/MX1(39,13),1/MX1(39,14),20
INITIAL     MX1(39,15),11/MX1(39,16),14/MX1(39,17),19
INITIAL     MX1(39,18),7/MX1(39,19),13/MX1(39,20),18
INITIAL     MX1(39,21),22/MX1(39,22),21/MX1(39,23),24
INITIAL     MX1(39,24),23

INITIAL     MX1(40,1),5/MX1(40,2),6/MX1(40,3),11/MX1(40,4),8
INITIAL     MX1(40,5),13/MX1(40,6),9/MX1(40,7),12/MX1(40,8),14
INITIAL     MX1(40,9),15/MX1(40,10),18/MX1(40,11),19
INITIAL     MX1(40,12),20/MX1(40,13),24/MX1(40,14),1
INITIAL     MX1(40,15),2/MX1(40,16),3/MX1(40,17),4
INITIAL     MX1(40,18),7/MX1(40,19),10/MX1(40,20),17
INITIAL     MX1(40,21),21/MX1(40,22),16/MX1(40,23),23
INITIAL     MX1(40,24),22

INITIAL     MX1(41,1),4/MX1(41,2),5/MX1(41,3),10/MX1(41,4),7
INITIAL     MX1(41,5),12/MX1(41,6),8/MX1(41,7),11/MXI(41,8),13
INITIAL     MX1(41,9),14/MX1(41,10),17/MX1(41,11),18
INITIAL     MX1(41,12),19/MX1(41,13),24/MX1(41,14),21
INITIAL     MX1(41,15),1/MX1(41,16),2/MX1(41,17),3
INITIAL     MX1(41,18),6/MX1(41,19),9/MX1(41,20),16
INITIAL     MX1(41,21),20/MX1(41,22),15/MX1(41,23),23
INITIAL     MX1(41,24),22

INITIAL     MX1(42,1),4/MX1(42,2),5/MX1(42,3),10/MX1(42,4),7
INITIAL     MX1(42,5),12/MX1(42,6),8/MX1(42,7),11/MX1(42,8),13
INITIAL     MX1(42,9),14/MX1(42,10),17/MX1(42,11),18
INITIAL     MX1(42,12),19/MX1(42,13),24/MX1(42,14),21
INITIAL     MX1(42,15),1/MX1(42,16),2/MX1(42,17),3
INITIAL     MX1(42,18),6/MX1(42,19),9/MX1(42,20),16
INITIAL     MX1(42,21),20/MX1(42,22),15/MX1(42,23),23
INITIAL     MX1(42,24),22

INITIAL     MX1(43,1),1/MX1(43,2),2/MX1(43,3),7/MX1(43,4),4
INITIAL     MX1(43,5),9/MX1(43,6),5/MX1(43,7),8/MX1(43,8),10
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INITIAL     MX1(43,9),11/MX1(43,10),14/MX1(43,11),15
INITIAL     MX1(43,12),16/MX1(43,13),23/MX1(43,14),18
INITIAL     MX1(43,15),20/MX1(43,16),22/MX1(43,17),24
INITIAL     MX1(43,18),3/MX1(43,19),6/MX1(43,20),12
INITIAL     MX1(43,21),17/MX1(43,22),13/MX1(43,23),21
INITIAL     MX1(43,24),19

INITIAL     MX1(44,1),7/MX1(44,2),9/MX1(44,3),13/MX1(44,4),10
INITIAL     MX1(44,5),14/MX1(44,6),11/MX1(44,7),12/MX1(44,8),15
INITIAL     MX1(44,9),17/MX1(44,10),20/MX1(44,11),21
INITIAL     MX1(44,12),22/MX1(44,13),18/MX1(44,14),24
INITIAL     MX1(44,15),16/MX1(44,16),18/MX1(44,17),23
INITIAL     MX1(44,18),1/MX1(44,19),2/MX1(44,20),3
INITIAL     MX1(44,21),5/MX1(44,22),4/MX1(44,23),8
INITIAL     MX1(44,24),6

INITIAL     MX1(45,1),6/MX1(45,2),8/MX1(45,3),13/MX1(45,4),10
INITIAL     MX1(45,5),14/MX1(45,6),11/MX1(45,7),12/MX1(45,8),15
INITIAL     MX1(45,9),17/MX1(45,10),20/MX1(45,11),21
INITIAL     MX1(45,12),22/MX1(45,13),18/MX1(45,14),24
INITIAL     MX1(45,15),16/MX1(45,16),18/MX1(45,17),23
INITIAL     MX1(45,18),9/MX1(45,19),1/MX1(45,20),2
INITIAL     MX1(45,21),4/MX1(45,22),3/MX1(45,23),7
INITIAL     MX1(45,24),5

INITIAL     MX1(46,1),5/MX1(46,2),6/MX1(46,3),10/MX1(46,4),8
INITIAL     MX1(46,5),12/MX1(46,6),4/MX1(46,7),11/MX1(46,8),13
INITIAL     MX1(46,9),15/MX1(46,10),19/MX1(46,11),20
INITIAL     MX1(46,12),21/MX1(46,13),18/MX1(46,14),24
INITIAL     MX1(46,15),14/MX1(46,16),17/MX1(46,17),23
INITIAL     MX1(46,18),7/MX1(46,19),9/MX1(46,20),1
INITIAL     MX1(46,21),22/MX1(46,22),16/MX1(46,23),3
INITIAL     MX1(46,24),2

INITIAL     MX1(47,1),2/MX1(47,2),3/MX1(47,3),8/MX1(47,4),5
INITIAL     MX1(47,5),10/MX1(47,6),6/MX1(47,7),9/MX1(47,8),11
INITIAL     MX1(47,9),13/MX1(47,10),18/MX1(47,11),19
INITIAL     MX1(47,12),20/MX1(47,13),17/MX1(47,14),23
INITIAL     MX1(47,15),12/MX1(47,16),16/MX1(47,17),22
INITIAL     MX1(47,18),4/MX1(47,19),7/MX1(47,20),14
INITIAL     MX1(47,21),1/MX1(47,22),15/MX1(47,23),24
INITIAL     MX1(47,24),21

INITIAL     MX1(48,1),3/MX1(48,2),4/MX1(48,3),9/MX1(48,4),6
INITIAL     MX1(48,5),11/MX1(48,6),7/MX1(48,7),10/MX1(48,8),12
INITIAL     MX1(48,9),14/MX1(48,10),18/MX1(48,11),19
INITIAL     MX1(48,12),20/MX1(48,13),17/MX1(48,14),23
INITIAL     MX1(48,15),13/MX1(48,16),16/MX1(48,17),22
INITIAL     MX1(48,18),5/MX1(48,19),8/MX1(48,20),15
INITIAL     MX1(48,21),2/MX1(48,22),1/MX1(48,23),24
INITIAL     MX1(48,24),21
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        INITIAL     MX1(49,1),3/MX1(49,2),4/MX1(49,3),8/MXI(49,4),6
        INITIAL     MX1(49,5),10/MX1(49,6),2/MX1(49,7),9/MX1(49,8),11
        INITIAL     MX1(49,9),13/MX1(49,10),18/MX1(49,I1),I9
        INITIAL     MX1(49,12),20/MX1(49,13),17/MX1(49,14),23
        INITIAL     MX1(49,15),12/MX1(49,16),I6/MX1(49,17),22
        INITIAL     MX1(49,18),5/MX1(49,19),7/MX1(49,20),14
        INITIAL     MX1(49,21),21/MX1(49,22),15/MX1(49,23),I
        INITIAL     MX1(49,24),24

        INITIAL     MX1(50,1),4/MX1(50,2),5/MX1(50,3),9/MX1(50,4),7
        INITIAL     MX1(50,5),I1/MXI(50,6),3/MX1(50,7),10/MX1(50,8),12
        INITIAL     MX1(50,9),14/MXI(50,10),19/MX1(50,11),20
        INITIAL     MX1(50,I2),21/MX1(50,I3),18/MX1(50,14),24
        INITIAL     MX1(50,15),13/MX1(50,16),17/MX1(50,17),23
        INITIAL     MX1(50,18),6/MX1(50,I9),8/MX1(50,20),15
        INITIAL     MX1(50,21),22/MX1(50,22),16/MX1(50,23),2
        INITIAL     MX1(50,24),1


        INITIAL     MX1(5I,1),14/MX1(51,2),15/MX1(51,3),1/MXI(51,4),17
        INITIAL     MX1(51,5),6/MX1(5I,6),1I/MX1(51,7),2/MXI(51,8),4
        INITIAL     MX1(51,9),3/MX1(51,10),8/MX1(51,11),9
        INITIAL     MX1(51,12),10/MX1(51,13),19/MXI(51,14),12
        INITIAL     MX1(51,15),5/MX1(51,I6),7/MX1(51,17),13
        INITIAL     MX1(51,18),16/MX1(5I,19),18/MX1(51,20),20
        INITIAL     MX1(51,21),22/MX1(51,22),21/MX1(51,23),24
        INITIAL     MXI(51,24),23
*
*  DISPATCH FUNCTIONS FOR THE INPUTS. FUNCTION NUMBER REPRESENTS
*  INPUT STATIONS AND THE FUNCTION CUMMULATIVE PROBABILITY
*  CORRESPOINDS TO THE OUTPUT STATION. A RANDOM NUMBER GENERATOR
*  PRODUCES VALUE TO BE USED IN THE FUNCTION.
*
*
 1     FUNCTION    RN1,D9
.014,28/.495,29/.569,47/.643,48/.717,44/.791,45/.865,49/.939,50/1.0,46

 2     FUNCTION    RN1,D8
.216,27/.340,47/.464,48/.588,44/.712,45/.836,49/.960,50/1.0,46

 3     FUNCTION    RN1,D8
.632,43/.685,47/.738,48/.791,44/.844,45/.897,49/.949,50/1.0,46

 4     FUNCTION    RN1,D2
.500,38/1.0,39

 5     FUNCTION    RN1,D8
.073,30/.207,47/.341,48/.475,44/.609,45/.743,49/.878,50/I.0,46

 6     FUNCTION    RN1,D9
.007,43/.467,29/.537,47/.614,48/.691,44/.768,45/.845,49/.922,50/1.0,46
```

```
 7      FUNCTION   RN1,D8
.417,35/.500,47/.583,48/.666,44/.749,45/.832,49/.915,50/1.0,46

 8      FUNCTION   RN1,D7
.143,47/.286,48/.429,44/.572,45/.715,49/.858,50/1.0,46

 9      FUNCTION   RN1,D7
.143,47/.286,48/.429,44/.572,45/.715,49/.858,50/1.0,46

 10     FUNCTION   RN1,D8
.641,26/.692,47/.743,48/.794,44/.845,45/.896,49/.947,50/1.0,46

 11     FUNCTION   RN1,D8
.820,43/.845,47/.869,48/.893,44/.917,45/.941,49/.965,50/1.0,46

 12     FUNCTION   RN1,D8
.821,43/.847,47/.873,48/.899,44/.925,45/.951,49/.977,50/1.0,46

 13     FUNCTION   RN1,D8
.064,27/.899,31/.916,47/.933,48/.950,44/.967,45/.984,49/1.0,50

 14     FUNCTION   RN1,D8
.708,43/.750,47/.792,48/.834,44/.876,45/.918,49/.960,50/1.0,46

 15     FUNCTION   RN1,D1
1.0,43

 16     FUNCTION   RN1,D1
1.0,43

 17     FUNCTION   RN1,D1
1.0,43

 18     FUNCTION   RN1,D18
.029,41/.072,40/.104,42/.119,36/.141,37/.319,38/.497,39/.575,35
.582,34/.596,33/.610,34/.698,25/.769,26/.781,28/.785,29/.915,31
.944,30/1.0,46

 19     FUNCTION   RN1,D18
.029,41/.072,40/.104,42/.119,36/.141,37/.319,38/.497,39/.575,35
.582,34/.596,33/.610,34/.698,25/.769,26/.781,28/.785,29/.915,31
.944,30/1.0,46

 20     FUNCTION   RN1,D22
.009,41/.022,40/.031,42/.035,36/.044,37/.069,38/.094,39/.117,35
.119,34/.123,33/.127,34/.144,25/.165,26/.166,29/.296,31/.316,30
.430,47/.544,48/.678,44/.772,45/.886,49/1.0,50

 21     FUNCTION   RN1,D18
.029,41/.072,40/.104,42/.119,36/.141,37/.319,38/.497,39/.575,35
.582,34/.596,33/.610,34/.698,25/.769,26/.781,28/.785,29/.915,31
.944,30/1.0,46
```

```
 22    FUNCTION   RN1,D18
.029,41/.072,40/.104,42/.119,36/.141,37/.319,38/.497,39/.575,35
.582,34/.596,33/.610,34/.698,25/.769,26/.781,28/.785,29/.915,31
.944,30/1.0,46

 23    FUNCTION   RN1,D18
.029,41/.072,40/.104,42/.119,36/.141,37/.319,38/.497,39/.575,35
.582,34/.596,33/.610,34/.698,25/.769,26/.781,28/.785,29/.915,31
.944,30/1.0,46

 24    FUNCTION   RN1,D18
.029,41/.072,40/.104,42/.119,36/.141,37/.319,38/.497,39/.575,35
.582,34/.596,33/.610,34/.698,25/.769,26/.781,28/.785,29/.915,31
.944,30/1.0,46
*
*  CONVERSION OF VEHICLE STATUS (EITHER LOADED=1 OR UNLOADED=0)
*  TO A SAVEVALUE WHICH STORES TOTAL TRAVELLING TIME FOR BOTH.
*
 25    FUNCTION   PF4,D2
0,76/1,77
*
*  BOOLEAN VARIABLES WHICH ARE USED AT DECISION POINTS TO
*  DETERMINE A VEHICLE' ROUTE.
*
 1     BVARIABLE  PF2'E'9+PF2'E'32
 2     BVARIABLE  PF2'E'40+PF2'E'14+PF2'E'41+PF2'E'42+PF2'E'15+PF2'E'16_
+PF2'E'17+PF2'E'43
 3     BVARIABLE  PF2'E'15+PF2'E'16+PF2'E'17+PF2'E'43
 4     BVARIABLE  PF2'E'18+PF2'E'19+PF2'E'20+PF2'E'21+PF2'E'22+PF2'E'23_
+PF2'E'24+PF2'E'44+PF2'E'45+PF2'E'46+PF2'E'47+PF2'E'48_
+PF2'E'49+PF2'E'50+PF2'E'1
 5     BVARIABLE  PF2'E'2+PF2'E'28+PF2'E'29+PF2'E'6+PF2'E'30+PF2'E'31
 6     BVARIABLE  PF2'E'18+PF2'E'19+PF2'E'20+PF2'E'21+PF2'E'22+PF2'E'23_
+PF2'E'24+PF2'E'44+PF2'E'45+PF2'E'46+PF2'E'47+PF2'E'48_
+PF2'E'49+PF2'E'50+PF2'E'1
 7     BVARIABLE  PF2'E'1

 8     BVARIABLE  PF2'E'18+PF2'E'19+PF2'E'20+PF2'E'21+PF2'E'22+PF2'E'23_
+PF2'E'24+PF2'E'44+PF2'E'45+PF2'E'46+PF2'E'47+PF2'E'48_
+PF2'E'49+PF2'E'50
 9     BVARIABLE  PF2'E'2+PF2'E'28+PF2'E'29+PF2'E'6+PF2'E'30+PF2'E'31_
+PF2'E'18+PF2'E'19+PF2'E'20+PF2'E'21+PF2'E'22+PF2'E'23_
+PF2'E'24+PF2'E'44+PF2'E'45+PF2'E'46+PF2'E'47+PF2'E'48_
+PF2'E'49+PF2'E'50+PF2'E'1
 10    BVARIABLE  PF2'E'28+PF2'E'29+PF2'E'30+PF2'E'6+PF2'E'31
 11    BVARIABLE  PF2'E'28+PF2'E'29
 12    BVARIABLE  PF2'E'6+PF2'E'30+PF2'E'31+PF2'E'1_
+PF2'E'18+PF2'E'19+PF2'E'20+PF2'E'21+PF2'E'22+PF2'E'23_
+PF2'E'24+PF2'E'44+PF2'E'45+PF2'E'46+PF2'E'47+PF2'E'48_
+PF2'E'49+PF2'E'50
 13    BVARIABLE  PF2'E'46+PF2'E'20+PF2'E'23+PF2'E'49+PF2'E'24+PF2'E'50_
+PF2'E'6+PF2'E'30+PF2'E'31
 14    BVARIABLE  PF2'E'6+PF2'E'30+PF2'E'31+PF2'E'1_
+PF2'E'18+PF2'E'19+PF2'E'20+PF2'E'21+PF2'E'22+PF2'E'23_
+PF2'E'24+PF2'E'44+PF2'E'45+PF2'E'46+PF2'E'47+PF2'E'48_
```

```
+PF2'E'49+PF2'E'50
 15     BVARIABLE  PF2'E'21+PF2'E'22+PF2'E'47+PF2'E'48
 16     BVARIABLE  PF2'E'4+PF2'E'27+PF2'E'5
 17     BVARIABLE  PF2'E'5+PF2'E'28+PF2'E'29+PF2'E'6+PF2'E'30+PF2'E'31_
+PF2'E'18+PF2'E'19+PF2'E'20+PF2'E'21+PF2'E'22+PF2'E'23_
+PF2'E'24+PF2'E'44+PF2'E'45+PF2'E'46+PF2'E'47+PF2'E'48_
+PF2'E'49+PF2'E'50+PF2'E'1+PF2'E'2
 18     BVARIABLE  PF2'E'3+PF2'E'26+PF2'E'5
 19     BVARIABLE  PF2'E'5+PF2'E'28+PF2'E'29+PF2'E'6+PF2'E'30+PF2'E'31_
+PF2'E'18+PF2'E'19+PF2'E'20+PF2'E'21+PF2'E'22+PF2'E'23_
+PF2'E'24+PF2'E'44+PF2'E'45+PF2'E'46+PF2'E'47+PF2'E'48_
+PF2'E'49+PF2'E'50+PF2'E'1+PF2'E'2
 20     BVARIABLE  PF2'E'7+PF2'E'8+PF2'E'9+PF2'E'32+PF2'E'33+PF2'E'34_
+PF2'E'35+PF2'E'36+PF2'E'10+PF2'E'11+PF2'E'12+PF2'E'37_
+PF2'E'40+PF2'E'14+PF2'E'41+PF2'E'42
 21     BVARIABLE  PF2'E'15+PF2'E'16+PF2'E'17+PF2'E'43
 22     BVARIABLE  XF1'G'0+XF2'G'0+XF3'G'0+XF4'G'0+XF5'G'0+XF6'G'0_
+XF7'G'0+XF8'G'0+XF9'G'0+XF10'G'0+XF11'G'0+XF12'G'0_
+XF13'G'0+XF14'G'0+XF15'G'0+XF16'G'0+XF17'G'0_
+XF18'G'0+XF19'G'0+XF20'G'0+XF21'G'0+XF22'G'0_
+XF23'G'0+XF24'G'0
*
*
*  MACROS SHOULD BE INSERTED HERE
*
*
*  GENERATOR OF THE VEHICLES.
*
*
        GENERATE  100,5,,22,,6PF
        SAVEVALUE 91+,1,XF
        ASSIGN    1,XF91,PF
        ASSIGN    2,51,PF
        SEIZE     Z248
        QUEUE     (Z248+1)
        QUEUE     350
        SAVEVALUE (PF1+50),0,XF
*
*  MAIN PROGRAM REPRESENTING THE GUIDEPATH THE VEHICLES WILL
*  FOLLOW
*
 J37    ADVANCE   0

 TRVL   MACRO     PF1,3,Z24A,Z248
        TEST E    BV1,0,J1

 INPT   MACRO     50,IN78,Z24A,7,AP7,RP7,INP7,12,14,IN7A
 INPT   MACRO     50,INBB,RP7,B,APB,RP8,INPB,15,2,IN8A
 OUTPT  MACRO     RPB,33,AP33,RP33,UNL33,2,1,50,033A,0338
 OUTPT  MACRO     RP33,34,AP34,RP34,UNL34,1,27,50,034A,0348
 OUTPT  MACRO     RP34,35,AP35,RP35,UNL35,15,11,50,035A,0358
        TRANSFER  ,J2

 J1     ADVANCE   0
 OUTPT  MACRO     Z24A,32,AP32,RP32,UNL32,41.7,50,032A,0328
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INPT    MACRO      50,IN9B,RP32,9,AP9,RP9,INP9,7,41,IN9A
OUTPT   MACRO      RP9,35,AP35,RP35,UNL35,15,11,50,O35C,O35D
J2      TEST E     BV2,1,J3

OUTPT   MACRO      RP35,40,AP40,RP40,UNL40,36,2,50,O40A,O40B
INPT    MACRO      50,IN14B,RP40,14,AP14,RP14,INP14,2,8,IN14A
OUTPT   MACRO      RP14,41,AP41,RP41,UNL41,8,10,50,O41A,O41B
OUTPT   MACRO      RP41,42,AP42,RP42,UNL42,10,9,50,O42A,O42B
INPT    MACRO      50,IN15B,RP42,15,AP15,RP15,INP15,10,4,IN15A
INPT    MACRO      50,IN16B,RP15,16,AP16,RP16,INP16,44,21,IN16A
        TRANSFER   ,J5

J4      ADVANCE    0
INPT    MACRO      50,IN15D,RP37,15,AP15A,RP15,INP15,29,4,IN15C
J39     ADVANCE    0
INPT    MACRO      50,IN16D,RP15,16,AP16,RP16,INP16,44,21,IN16C
J5      ADVANCE    0
INPT    MACRO      50,IN17B,RP16,17,AP17,RP17,INP17,21,9,IN17A
OUTPT   MACRO      RP17,43,AP43,RP43,UNL43,9,14,50,O43A,O43B
TRVL    MACRO      PF1,15,DT,RP43
J29     TEST E     BV4,0,J6

TRVL    MACRO      PF1,22,Z11,DT
        TRANSFER   ,J10

J6      ADVANCE    0
TRVL    MACRO      PF1,22,SEC53,DT
        TRANSFER   ,J11

J3      ADVANCE    0
OUTPT   MACRO      RP35,36,AP36,RP36,UNL36,6,2,50,O36A,O36B
INPT    MACRO      50,IN10B,RP36,10,AP10,RP10,INP10,2,3,IN10A
INPT    MACRO      50,IN11B,RP10,11,AP11,RP11,INP11,3,2,IN11A
INPT    MACRO      50,IN12B,RP11,12,AP12,RP12,INP12,3,10,IN12A
OUTPT   MACRO      RP12,37,AP37,RP37,UNL37,11,34,50,O37A,O37B
        TEST E     BV3,0,J4

OUTPT   MACRO      RP37,38,AP38,RP38,UNL38,6,31,50,O38A,O38B
J40     ADVANCE    0
OUTPT   MACRO      RP38,39,AP39,RP39,UNL39,31,3,50,O39A,O39B
INPT    MACRO      50,IN13B,RP39,13,AP13,RP13,INP13,2,1,IN13A
        TEST E     BV5,0,J7

TRVL    MACRO      PF1,24,SEC43,RP13
        TEST E     BV6,1,J8

TRVL    MACRO      PF1,22,SEC53,SEC43
J11     TEST E     BV7,1,J12

INPT    MACRO      50,IN1B,SEC53,1,AP1,RP1,INP1,6,1,IN1A
J19     TEST E     BV8,1,J13

TRVL    MACRO      PF1,6,TD,RP1
OUTPT   MACRO      TD,44,AP44,RP44,UNL44,52,1,50,O44A,O44B
        TRANSFER   ,J14
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J12     ADVANCE    0
TRVL    MACRO      PF1,6,SEC3,SEC53
OUTPT   MACRO      SEC3,44,AP44,RP44,UNL44,52,1,50,D44C,D44D

J14     ADVANCE    0
INPT    MACRO      50,IN18B,RP44,18,AP18,RP18,INP18,6,24,IN18A
OUTPT   MACRO      RP18,45,AP45,RP45,UNL45,24,1,50,D45A,D45B
INPT    MACRO      50,IN19B,RP45,19,AP19,RP19,INP19,1,21,IN19A
        TEST E     BV13,1,J23

J28     ADVANCE    0
OUTPT   MACRO      RP19,46,AP46,RP46,UNL46,42,5,50,D46A,D46B
INPT    MACRO      50,IN20B,RP46,20,AP20,RP20,INP20,4,36,IN20A
OUTPT   MACRO      RP20,50,AP50,RP50,UNL50,35,1,50,D50A,D50B
INPT    MACRO      50,IN24B,RP50,24,AP24,RP24,INP24,1,42,IN24A
OUTPT   MACRO      RP24,49,AP49,RP49,UNL49,41,1,50,D49A,D49B
INPT    MACRO      50,IN23B,RP49,23,AP23,RP23,INP23,1,69,IN23A
        TEST E     BV14,1,J24
TRVL    MACRO      PF1,2,Z188,RP23
        TRANSFER   ,J25

J8      ADVANCE    0
TRVL    MACRO      PF1,22,Z11,SEC43
J10     ADVANCE    0
INPT    MACRO      50,IN2B,Z11,2,AP2,RP2,INP2,15,3,IN2A
J15     TEST E     BV9,1,J16

INPT    MACRO      50,IN2F,RP2,2,AP2A,RP2A,INP2,4,4,IN2E
J17     TEST E     BV10,1,J18

TRVL    MACRO      PF1,28,Z8,RP2A
        TEST E     BV11,1,J20

TRVL    MACRO      PF1,9,Z10,Z8
OUTPT   MACRO      Z10,28,AP28,RP28,UNL28,15,2,50,D28A,D28B
J32     ADVANCE    0
OUTPT   MACRO      RP28,29,AP29,RP29,UNL29,2,13,50,D29A,D29B
        TEST E     BV12,1,J21

TRVL    MACRO      PF1,2,Z188,RP29
J25     ADVANCE    0
INPT    MACRO      50,IN6D,Z188,6,AP6,RP6,INP6,2,2,IN6C
J22     ADVANCE    0
OUTPT   MACRO      RP6,30,AP30,RP30,UNL30,2,2,50,D30A,D30B
OUTPT   MACRO      RP30,31,AP31,RP31,UNL31,2,10,50.D31A,D31B
INPT    MACRO      50,IN1F,RP31,1,AP1,RP1,INP1,10,1,IN1E
        TRANSFER   ,J19

J23     TEST E     BV15,1,J26

J27     ADVANCE    0
OUTPT   MACRO      RP19,48,AP48,RP48,UNL48,37,1,50,D48A,D48B
INPT    MACRO      50,IN22B,RP48.22,AP22,RP22,INP22,1,24,IN22A
OUTPT   MACRO      RP22,47,AP47,RP47,UNL47,24,1,50,D47A,D47B
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INPT    MACRO     50,IN21B,RP47,21,AP21,RP21,INP21,1,39,IN21A
TRVL    MACRO     PF1,15,OT,RP21
        TRANSFER  ,J29

J16     ADVANCE   0
PLACE   MACRO     RP2,51,APP,RPP,PARK,1,1,PLC1,PLC2
TRVL    MACRO     PF1,36,Z6A,RPP
        TEST E    BV16,1,J30

INPT    MACRO     50,IN4B,Z6A,4,AP4,RP4,INP4,20,4,IN4A
OUTPT   MACRO     RP4,27,AP27,RP27,UNL27,3,4,50,027A,027B
        TEST E    BV17,1,J31

TRVL    MACRO     PF1,14,Z9B,RP27
INPT    MACRO     50,IN5B,Z9B,5,AP5,RP5,INP5,18,4,IN5A
J35     ADVANCE   0
OUTPT   MACRO     RP5,28,AP28,RP28,UNL28,15,2,50,028C,028D
        TRANSFER  ,J32

J30     ADVANCE   0
OUTPT   MACRO     Z6A,25,AP25,RP25,UNL25,6,6,50,025A,025B
TRVL    MACRO     PF1,11,Z23A,RP25
J36     TEST E    BV18,1,J33

OUTPT   MACRO     Z23A,26,AP26,RP26,UNL26,18,5,50,026A,026B
INPT    MACRO     50,IN3B,RP26,3,AP3,RP3,INP3,4,4,IN3A
        TEST E    BV19,1,J34

TRVL    MACRO     PF1,36,Z11B,RP3
INPT    MACRO     50,IN5D,Z11B,5,AP5,RP5,INP5,18,4,IN5C
        TRANSFER  ,J35

J31     ADVANCE   0
TRVL    MACRO     PF1,11,Z4,RP27
TRVL    MACRO     PF1,30,Z5,Z4
J41     ADVANCE   0
TRVL    MACRO     PF1,11,Z23A,Z5
        TRANSFER  ,J36

J33     ADVANCE   0
TRVL    MACRO     PF1,15,Z24B,Z23A
        TEST E    BV20,0,J37

TRVL    MACRO     PF1,22,Z1,Z24B
        TEST E    BV21,1,J38

INPT    MACRO     50,IN15F,Z1,15,AP15,RP15,INP15,29,4,IN15E
        TRANSFER  ,J39

J38     ADVANCE   0
OUTPT   MACRO     Z1,38,AP38,RP38,UNL38,6,31,50,038C,038D
        TRANSFER  ,J40

J34     ADVANCE   0
TRVL    MACRO     PF1,11,Z3,RP3
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TRVL    MACRO       PF1,30,Z5,Z3
        TRANSFER    ,J41

J13     ADVANCE     0
TRVL    MACRO       PF1,6,SEC5B,RP1
INPT    MACRO       50,IN2D,SEC5B,2,AP2,RP2,INP2,15,3,IN2C
        TRANSFER    ,J15

J7      ADVANCE     0
TRVL    MACRO       PF1,22,Z13,RP13
INPT    MACRO       50,IN2H,Z13,2,AP2A,RP2A,INP2,4,4,IN2G
        TRANSFER    ,J17

J18     ADVANCE     0
INPT    MACRO       50,IN1D,RP2A,1,AP1A,RP1,INP1,25,1,IN1C
        TRANSFER    ,J19

J21     ADVANCE     0
TRVL    MACRO       PF1,22,Z12,RP29
INPT    MACRO       50,IN2J,Z12,2,AP2,RP2,INP2,15,3,IN2I
        TRANSFER    ,J15

J20     ADVANCE     0
TRVL    MACRO       PF1,25,Z9,Z8
INPT    MACRO       50,IN6B,Z9,6,AP6,RP6,INP6,2,2,IN6A
        TRANSFER    ,J22

J24     ADVANCE     0
TRVL    MACRO       PF1,22,Z12,RP23
INPT    MACRO       50,IN2L,Z12,2,AP2,RP2,INP2,15,3,IN2K
        TRANSFER    ,J15

J26     ADVANCE     0
        TRANSFER    .5,,J27
        TRANSFER    ,J28


*
*  GENERATION OF JOBS FOR EACH INPUT. FROM GIVEN DATA THE
*  NUMBER OF JOBS INPUTTED AT EACH INPUT STATION WAS KNOWN
*  AND THE GENERATE BLOCKS BELOW CREATED JOBS AT A UNIFORM
*  RATE TO SIMULATE A SHIFT'S WORTH.
*
       GENERATE    224,22
       SAVEVALUE   1+,1,XF
       TERMINATE

       GENERATE    394,39
       SAVEVALUE   2+,1,XF
       TERMINATE

       GENERATE    1263,126
       SAVEVALUE   3+,1,XF
       TERMINATE
```

```
GENERATE   2400,240
SAVEVALUE  4+,1,XF
TERMINATE

GENERATE   3512,351
SAVEVALUE  5+,1,XF
TERMINATE

GENERATE   966,97
SAVEVALUE  6+,1,XF
TERMINATE

GENERATE   12000,1200
SAVEVALUE  7+,1,XF
TERMINATE

GENERATE   13714,1371
SAVEVALUE  8+,1,XF
TERMINATE

GENERATE   13714,1371
SAVEVALUE  9+,1,XF
TERMINATE

GENERATE   3692,369
SAVEVALUE  10+,1,XF
TERMINATE

GENERATE   1180,118
SAVEVALUE  11+,1,XF
TERMINATE

GENERATE   324,32
SAVEVALUE  12+,1,XF
TERMINATE


GENERATE   610,61
SAVEVALUE  13+,1,XF
TERMINATE

GENERATE   1358,136
SAVEVALUE  14+,1,XF
TERMINATE

GENERATE   1800,180
SAVEVALUE  15+,1,XF
TERMINATE

GENERATE   1152,115
SAVEVALUE  16+,1,XF
TERMINATE
```

```
      GENERATE   1152,115
      SAVEVALUE  17+,1,XF
      TERMINATE

      GENERATE   435,44
      SAVEVALUE  18+,1,XF
      TERMINATE

      GENERATE   435,44
      SAVEVALUE  19+,1,XF
      TERMINATE

      GENERATE   288,29
      SAVEVALUE  20+,1,XF
      TERMINATE

      GENERATE   435,44
      SAVEVALUE  21+,1,XF
      TERMINATE


      GENERATE   435,44
      SAVEVALUE  22+,1,XF
      TERMINATE

      GENERATE   435,44
      SAVEVALUE  23+,1,XF
      TERMINATE


      GENERATE   435,44
      SAVEVALUE  24+,1,XF
      TERMINATE






*
*  CLOCK TO REGULATE ONE SHIFT OR 28800 SECONDS OF TIME.
*
      GENERATE   ,,,2
      LOGIC S    2
      SEIZE      CLCK
      ADVANCE    28800
      RELEASE    CLCK
      TERMINATE  1
      START      1
      RESET
      START      1
      END
```

A STUDY OF IMPLEMENTATION AND EVALUATION TECHNIQUES OF ADVANCED GUIDED VEHICLE SYSTEMS

by

ANTHONY SHOEMAKER READ

B.S., North Carolina State University, 1983

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ABSTRACT

This thesis proposes a standardized approach for the pre-installation design and evaluation of Advanced Guided Vehicle Systems (AGVS).

The first step was to develop an evaluation tool. Using GPSS-H, a transaction based simulation language, unique macros were developed that emmulated certain features of a AGVS. The macros pieced together like building blocks provided a facsimile of an actual system.

A simple system was evaluated by using the statistics gathered by the GPSS-H package. From these statistics the concepts of system utilization, system efficiency, and reserve capacity were developed.

Procedural steps were developed to be able to create a workable AGVS. A real-life situation was used and the techniques developed were loadfeet directioning, vehicle estimating, cutoff implementation, and block division. From the development of these techniques a proposal for a guidepath layout and the number of vehicles required was obtained.

The implementation of both the procedural steps and the evaluation techniques were applied to a more complicated system. Again the problem was a real-life situation. The procedural steps were applied and a workable AGVS was developed. Each step was evaluated using the GPSS-H macros and its effect monitored through the number of vehicles needed, system utilization, and system efficiency.