SIMULATING STATION ACTIVITY IN AN ADVANCED GROUP RAPID TRANSIT SYSTEM

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ABSTRACT

Advanced Group Rapid Transit (AGRT) is a completely automated, guideway-based transit system concept that is currently being developed for the U.S. Department of Transportation. The system deploys small vehicles that are computer-controlled and dispatched in response to passenger requests for service. Passengers using the system can travel between any two stations in the network without changing vehicles.

One critical area of the total system design is the area of station operations. The effect of configurations of berths and guideway within the station and the strategies used to assign vehicles to load and unload passengers at specific berths must be considered.

This paper discusses the development and implementation of a discrete-event simulation designed for use in testing alternative station configurations and berthing strategies. The station model is flexible enough to simulate the range of possible station configurations and strategies for assigning vehicles to berths. The simulation also incorporates a high degree of detail in order to reflect differences of relatively small magnitude in station performance.

INTRODUCTION

The development of computer and automation technology has led to entirely new concepts in public transportation. Systems such as Automated Guideway Transit (AGT), Personal Rapid Transit (PRT), and Group Rapid Transit (GRT) use vehicles capable of automatic operation on guideways or roadways separate from those used by other vehicular traffic. Advanced Group Rapid Transit (AGRT) systems are entirely automated and move passengers directly from origin to destination on fairly extensive networks. The small twelve-passenger vehicles move quietly along elevated guideways, traveling at speeds of up to forty miles an hour without manual operation. The central computer arranges for a vehicle to pick up the passengers with a minimum of waiting time and organizes a route that will minimize both travel time and intermediate stops. As part of an AGRT design program sponsored by the Urban Mass Transit Administration (UMTA), Rohr Industries subcontracted to SRI International for several studies of the AGRT central management system, which controls the movement of passengers and vehicles through the system.

This paper focuses on a simulation designed to study the station operations that handle the movement of vehicles through an AGRT station. Designing these station operations is an important task because the stations must be capable of handling large numbers of vehicles at close headways. Both the physical station layout and the vehicle control algorithms must be designed to obtain the best possible performance.

Before getting further into the problem description, some basic terminology should be defined. The terms berth and gate will be used interchangeably to refer to the portion of the station where passengers can board and disembark from vehicles. Headway refers to the time interval separating vehicles in operation on the guideway. The terms link, guideway, and track will be used when discussing the system's elevated, unidirectional track. Link usually refers to a section of guideway between two switches. Two different types of switches, merge switches and demerge switches, are used on the guideway. Merge switches are employed where two separate guideway links come together with a single exit link. Demerge switches are used for the opposite purpose--where one link splits and the vehicle can exit to either the right or the left. The use of the terms "upstream" and "downstream" is exactly analogous to their use with respect to the flow of water, since vehicle flow is unidirectional.

Vehicle movement through the station can be viewed as constituting a number of distinct steps:

(1) The vehicle demerges from the mainline and decelerates.

(2) The vehicle moves into the berthing area.

(3) Passengers disembark and then others board the vehicle.

(4) The vehicle moves out of the station.

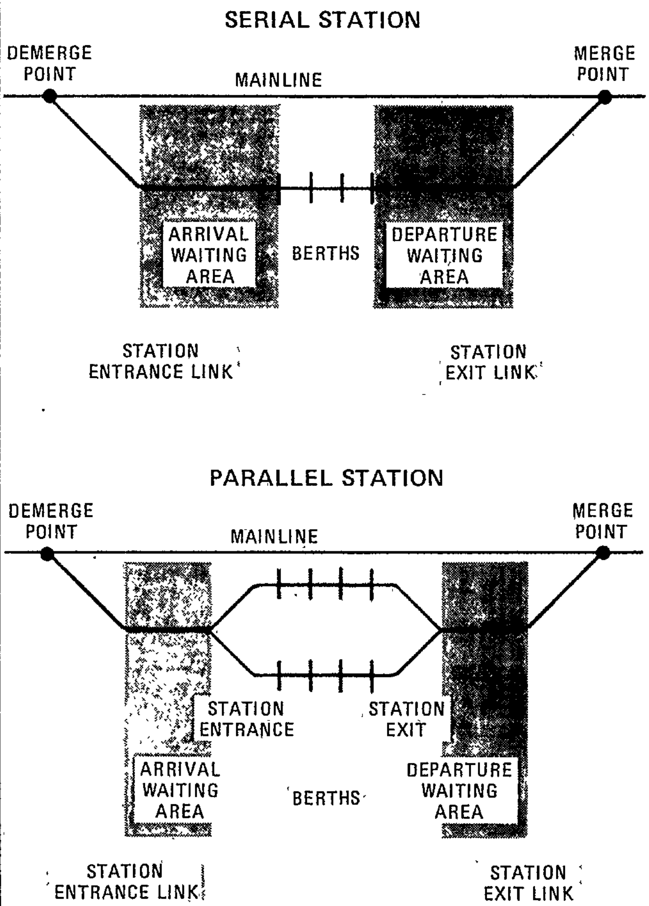
(5) The vehicle accelerates and merges back onto the mainline.

The physical design of the station's network is limited by several constraints imposed by Rohr's overall system design. First, the stations will be located off the main guideway on special-purpose spurs. A station may have multiple berths and waiting areas, but it can only have one link for exiting the mainline and one for entering the mainline. The maximum number of berths in one station is six, and these may be located on one or two spurs. A gate or berth can hold only one vehicle at a time, and passenger loading and unloading both take place at the same berth. See Figure 1 for a diagram of proposed AGRT station configurations.

If the station cannot handle every vehicle as soon as it arrives, provisions must be made for space to queue waiting vehicles. It may also be necessary to provide multiple berths in the station so that passengers can load and unload from more than one vehicle at a time.

If more than one berth are to be used in a station, the question arises as to how the berths should be arranged. When they are

FIGURE 1 DIAGRAM OF AGRT STATIONS



connected in series, that is, all on the same spur, an arriving vehicle can occupy any empty berth unless it is blocked by an occupied berth upstream. Conversely, if all berths are located on individual, parallel spurs, vehicle delays occur when all berths are occupied or when a vehicle has to wait to merge back onto the station exit link (prior to merging onto the mainline). The combination of parallel and serial berths in a station combines the advantages and disadvantages of both arrangements. When all the berths in one spur are filled, arriving vehicles can be diverted to the next spur.

The development of control operations and strategies is complicated by the fact that vehicle arrivals are not deterministic and by the fact that passenger loading and unloading times will be variable. Vehicles must also be assigned to berths before entering the boarding area to allow passengers time to reach the assigned berth.

It may be more efficient in the long run if the vehicle waits for a downstream berth to be free before stopping, so as to allow more vehicles coming from behind to enter the berthing area. The trade-off will be between an extended delay for the first vehicle as opposed to a possibly shorter delay for one or more following vehicles.

The serial berthing strategy must permit determination of the amount of increased delay that is acceptable in exchange for enabling the vehicle to move one extra berth downstream, two extra berths, etc. The parallel berthing strategy determines which spur the vehicle should enter. When a station has a combination of parallel and serial berths, the strategy must also specify at which berth in a series the vehicle should stop to load and unload passengers.

There are three major criteria that an optimal station design must satisfy. First, the station must minimize the mean vehicle service time in order to minimize total passenger trip time and provide expeditious service. Vehicle service time includes station transit time, time spent waiting for vehicles ahead to move, and passenger loading and unloading times. Station transit times and waiting times are primarily functions of station design, while passenger loading and unloading times must be considered independently. Secondly, the station must minimize service irregularity in the interest of assuring consistently dependable passenger service. Vehicle rejections because a station waiting area is full must also be kept as few as possible. Rejected vehicles must bypass the station and circle around the network to get back into entering position, which can obviously entail a substantial increase in trip time for the circumnavigating passengers.

DEVELOPMENT OF THE MODEL

The development of a computer simulation was chosen as the means of modeling station operations because simulation has proven to be an efficient tool for keeping track of large numbers of interactions. Simulation also allows a high degree of detail to be incorporated into the model--a desirable factor in this context because it enables the model to reflect the step-by-step movement of vehicles through the station. Analytic methods, on the other hand, would present difficulties in representing multiple berthing algorithms and handling random arrival and loading times.

Our specific objective in developing this simulation was to study the effects of different station configurations and berthing strategies on the capability of the station to handle vehicle traffic. Once the simulation was running, the goal was to select different patterns of vehicle arrivals at a station and conduct a series of experiments with each one. The purpose of the experiments was to determine for each arrival pattern those combinations of berthing strategy and configuration that minimize both the mean total time vehicles spend in the station and the variance in service times.

The sequence of activities involved in station operations included in the model was limited to the following:

(1) The vehicle demerges from the mainline onto the station entrance link.

(2) The vehicle is assigned to a berth.

(3) The vehicle waits until the upstream-most berth is free, allowing it to enter the station.

(4) The vehicle enters the station and proceeds as quickly as possible toward the assigned berth.

(5) The vehicle arrives in the assigned berth.

(6) Passengers disembark and others board the vehicle.

(7) The vehicle departs the station.

The merging of vehicles back onto the mainline was excluded from the model because the performance of a station itself is independent of the factors that would cause vehicles to back up on the exit link. Incorporating this process into the model would have been a task of considerable magnitude, so that its exclusion simplified the model greatly. A related simplification was the decision to model the arrival waiting area as if its vehicle holding capacity were infinite. This averted the problem of reflecting vehicle rejections, but made it possible nevertheless to determine a station's maximum throughput.

Because individual vehicle activities in the station take different amounts of time, the variable time increment, or discrete event, method of simulation was employed in the station model. Because of the transient nature of vehicles in the model as opposed to the station's permanence, events were designed to occur when vehicles reached specific locations in the station. Four different types of events encompass the complete gamut of vehicle movements. One of these four types of events occurs when a vehicle (1) arrives at the station, (2) enters the station, (3) arrives at the downstream end of a berth, or (4) departs the station.

The physical station network comprises a system of guideway, berths, and possibly switches. No matter what specific configuration might have been considered, there are certain features all stations have in common. Every station has one link entering from the mainline, an arrival waiting area, and a number of berths. The variable features of a station are the number of berths, the number of vehicles held by the waiting area, and the number of spurs on which the berths are located. Parallel stations require some facilities that serial stations do not. After leaving the arrival waiting area, vehicles must pass through a demerge switch at the station entrance before entering the berthing area. Similarly, they must go through a merge switch after leaving the berths, but prior to exiting the station.

To allow the same model to represent both parallel and serial stations, two new parts of the station network, a station entrance and a station exit, were defined. In a serial station these two parts really have no meaning and can be given very brief transit times. In parallel stations, where they are meaningful, they can be given realistic transit times. The station entrance encompasses the demerge switch, as well as the guideway between the waiting area and the first berth on each spur. The station exit includes the guideway between the last berth on each spur and the demerge switch. The station exit handles merge conflicts between vehicles trying to leave the station, as only one vehicle can be in the exit at a time.

Any station configuration can be completely described in this model by defining three variables. The first two are the number of berths in the station and the number of spurs. Alteration of these variables in the input data set makes it possible to experiment with different station configurations. The third variable is the average minimum time it takes a vehicle to move through a specific portion of the station guideway.

The serial and, if needed, the parallel strategy to be employed in each run are indicated by the user with input parameters. The serial strategy is defined by specifying what increase in delay, if any, is acceptable in exchange for enabling the vehicle to load passengers farther downstream. This acceptable delay threshold must be specified for each berth in the station. It was more difficult to define parallel strategies parametrically, so four different alternatives were programmed directly into the model. When assigning a vehicle to a berth, the program branches to the logic for the parallel strategy indicated by the user in the input data set.

The following four parallel strategies, which were felt to represent a reasonable range when in combination with various serial strategies, were incorporated into the model:

(1) Fill one side of the station first, then the other.

(2) Send each vehicle to the opposite spur of the preceding vehicle.

(3) Send the vehicle to the spur that enables the vehicle to berth as far as possible downstream.

(4) Send the vehicle to the spur that minimizes the delay projected for the vehicle.

Four variables are used to describe each vehicle entering the system. These comprise the time the vehicle arrives at the station entrance link, the size of the vehicle, the number of passengers that will disembark, and the number of passengers that will board at this station. Input data describing each vehicle as it arrives at the point of demerging into the station entrance link are used to drive the entire simulation. This is the only place where passengers are of concern in the model, because their effect on vehicle movement is limited to delaying the vehicle at the berth while they board or disembark.

The output variables of the model were selected to reflect the relative efficiency of a given combination of station configuration and berthing strategy. A measure of vehicle throughput is obtained by tallying the total number of vehicle arrivals and departures at the station. To calculate the mean service time the total time spent in the station is accumulated as each vehicle departs the station. The average and maximum size of the queues is needed to determine how long waiting areas must be to avoid rejection of vehicles. Additional data on such factors as average occupancy of the berths and average vehicle waiting times provide insights into the system's behavior, although such output is not actually essential to the model's purpose.

IMPLEMENTATION OF THE STATION MODEL

The entire station simulation was programmed in FORTRAN IV, primarily because of previous experience with that language. A modular structure was used with a main program and thirteen subroutines, each performing a relatively complete function. Data were passed extensively from one subroutine to another through labeled common blocks.

The subroutines in the model can be categorized by three main functions. The first function is maintaining the event calendar, the second is processing the four types of station events, and the last is performing various simulation housekeeping tasks, such as initializing variables and producing reports.

The main program calls a subroutine to read in all the data and initialize variables so that the station is unoccupied and ready to begin. At that point the main program calls the event processor, which selects the first event. The event scheduled to occur next in time is removed from the event calendar, whereupon simulated time is advanced to the time of that event. An event code determines which subroutine is called to do the main processing for that type of event. That subroutine may call other subroutines to handle portions of the event processing.

Vehicle movement through the station is simulated by scheduling events that occur when the vehicle arrives at the mainline demerge point, at the upstream end of the station entrance, at the downstream end of each berth and, finally, at the downstream end of the station exit. The progress of each vehicle is thus tracked through the event calendar. The station entrance, the station exit, and every berth all have their respective entries in the event array, each indicating the number of the vehicle that is currently occupying it.

The station model is organized so that, in most cases, the occurrence of an event will generate the occurrence of another event. When a vehicle arrives at the demerge point, it is scheduled to enter the station if no other vehicles are waiting to enter. A vehicle's arrival also results in the scheduling of its immediate successor's arrival. When the vehicle enters the station, the entrance of the next waiting vehicle is similarly scheduled. As the vehicle exits a berth, its arrival at the end of the next berth is scheduled. When the vehicle reaches the last berth in the series, its departure from the station is scheduled. The only event that does not trigger another event is a vehicle's departure from the station.

Vehicle assignment to a specific berth for loading and unloading passengers takes place while the vehicle is in the waiting area. Vehicles must be assigned to berths before entering the station, so that passengers can reach the appropriate berth before the vehicle does. Berth assignment is determined by the estimated locations of other vehicles at the time the vehicle in question will enter the station.

Assignment in a serial station is based on the array defining the serial strategy. The values in the array specify the maximum additional delay commensurate with the capability of loading and unloading in each particular berth, in preference to accepting a berth farther upstream. The total estimated delay for assigning the vehicle to each berth in the series is calculated. The berth farthest downstream for which increased delay is less than the acceptable delay threshold is then selected.

In assigning a vehicle to a berth in a parallel station, it is also necessary to consider the parallel strategy. When the parallel strategy has automatically selected a spur, the vehicle is then assigned to the berth indicated by the serial strategy on that spur. If the parallel strategy allows a choice between spurs, the serial strategy is employed to select the most acceptable berth on each spur. The choice between the two most acceptable berths is then made according to the parallel strategy.

Once the model had been programmed, debugged, and tested, it was necessary to validate it. This was very difficult because there are no analogous systems in existence from which data could be collected for comparison purposes. The only data available were results of an earlier simulation of station operations in a personal rapid transit system, discussed in a paper by K. J. Liopiros. (3) After modifying the station model to match the conditions of Liopiros's model as closely as possible, a series of runs was made. The results of these runs were within ten percent of those Liopiros obtained with his model.

The validity of the station model was obviously not actually confirmed by these experiments. Nevertheless, they did demonstrate that the model was reasonable.

EXPERIMENTAL DESIGN

The objective of the experiments performed with the station model was to select the combination of station configuration and berthing strategy that has the best, or lowest, mean vehicle service time for a given vehicle arrival rate. The initial step of the experiment involved eliminating from consideration those configurations whose capacity was insufficient to handle the vehicle arrival rate, as well as configurations with substantial excess capacity. Finally, the remaining station configurations and strategies were investigated to determine the vehicle service time characteristics.

Each simulation run lasted exactly one hour and was divided into six ten-minute subruns. Statistics were reintialized at the end of each subrun. Both the length of the transient period and the length of the period of correlation between subruns were estimated before the ten minute subruns were determined upon. It was felt that the effects of neither a transient period nor correlation would be significant when averaged over that time period.

Three different vehicle arrival rates--400, 600, and 800 vehicles per hour--were used in the simulation experiments. These rates were chosen to represent a broad range of possibilities that would allow experimentation with almost all the potential station configurations and strategies.

CONCLUSIONS

The experiments made with the station simulation suggest some general conclusions about station operations. The first conclusion is that the variation in the total amount of time vehicles spend in the station increases drastically as the vehicle arrival rate approaches the station's maximum capacity. The arrival of one or two additional vehicles in a ten-minute subrun might have a substantial impact on the mean service time for that period. Such fluctuation of service times is undesirable from the standpoint of providing consistently dependable service for passengers.

Serial berthing strategies also tend to have very little effect on the mean service time, except when the station is very close to capacity. In such cases the proper choice of a strategy may mean the difference between ever-increasing queues and reasonable service times. The decrease in service times was never sufficient, however, to enable use of a station with fewer berths.

There is some evidence of a direct relationship between the magnitude of the optimal acceptable delay threshold used in the serial strategy and the station's traffic density. The closer the station is to capacity, the higher is the delay threshold (up to a point) that provides the most efficient performance. This seems reasonable because, if the station has excess capacity and can process vehicles significantly faster than they arrive, there will be fewer advantages derived from delaying a vehicle to allow it to berth farther downstream. The utilization of berths will be maximized at the expense of longer vehicle waiting times.

It is more difficult to make general statements about the four parallel strategies investigated using the station model. The first parallel strategy, which fills one side of the station at a time, seems to provide good service in a wide range of circumstances. On the other hand, it appears possible that in some cases its performance might be equaled or even excelled by the fourth strategy, which attempts to minimize the total delay for each vehicle. In other situations, however, the fourth strategy apparently results in very poor service. The only one of the four that is clearly inferior under most conditions is the third strategy, which tries to berth vehicles as far downstream as possible.

As can be expected, the utility of adding another berth to a station declines rapidly as the total number of berths in the station increases. Both the absolute change in the maximum vehicle throughput and the percentage increase in the station's capacity decline significantly. For example, adding a second berth to a station increases station capacity by over fifty percent, while adding a sixth berth increases the capacity by only seven percent. This indicates that it may be more cost-effective to have a greater number of smaller stations in areas where the volume of traffic would require a large number of berths.

Differences in the capacities of parallel and serial stations with the same number of berths were surprisingly small. This is probably due to the vehicle control stipulation that a vehicle cannot enter the station until the first berth in the series is free--a requirement that was introduced to handle potential vehicle conflicts at the demerge switch. This situation dominates performance as the station gets closer to capacity; it prevents vehicles from entering the parallel station as frequently as they would a serial station under comparable circumstances.

It is readily apparent that station performance is dominated by the number of berths in the station. Beyond that, neither alternative--making the station parallel instead of serial or using different berthing strategies--will reduce vehicle service times substantially. On the other hand, some berthing strategies are clearly inefficient and will actually reduce station capacity.

Finally, it is encouraging to note that the least complex configurations and control algorithms seem to provide very adequate performance. More intricate algorithms and more costly configurations of berths may decrease mean vehicle service times slightly, but the decreases in service time appear to be so inconsequential that it is probably not worth the extra cost and effort to upgrade the system. The simpler station designs appear preferable, since their effect would be to decrease the costs involved in developing an advanced group rapid transit system while still providing excellent service to passengers.

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