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AUTOMATED GUIDEWAY NETWORK TRAFFIC MODELING

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16. Abstract In the literature concerning automated guideway transportation systems, such as dual mode, a great deal of effort has been expended on the use of deterministic reservation schemes and the problem of merging streams of vehicles. However, little attention has been focused on the problem of developing models to determine space allocation on the guideway as a function of the user service level required for satisfactory operation of the system. The problem must be addressed in the early design phase of any automative guideway system and is pertinent to site selection. This paper develops probability models and uses statistical variance analysis techniques to develop procedures which can be used to determine the required guideway space necessary to satisfy a user service level for a particular demand rate. It provides the building blocks upon which various network traffic management strategies can be developed.

The paper contains an explanation of the methodology involved, gives sample problems, and describes the simulation procedures that were employed to verify the results.

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AUTOMATED NETWORK GUIDEWAY TRAFFIC MODELING

INTRODUCTION

Network traffic management in an automated guideway system is concerned with such items as vehicle velocity, headway control, traffic congestion, space allocation, reservation procedures, and user level of service. This paper addresses the problem of "space" allocation in such a system that employs a deterministic reservation scheme[1]. It presents a procedure for developing probability models and statistical techniques that can be used to determine how much space must be allocated in a specific time interval for a given demand rate at a desired user service level along a particular route. The procedure is applicable to dual mode, personal rapid transit, and automated bus lanes. It was developed from a study of the dual mode space allocation problem, and that is the system used for illustration in this paper.

Most of the network traffic management problems are generic in nature and pertain to the general category of automated guideway systems. The problem of space allocation as discussed in this paper is one such generic problem. Adaptation to specific system configurations might require additions or slight modifications when such items as empty vehicles in a captive system or fixed route scheduling must be considered. However, such considerations do not detract from the philosophy or approach to solving the space allocation problem as presented herein. Previous work in the development of probability models concerning traffic management has been devoted to the problem of predicting passage through control points once the system utilization (expressed in probabalistic terms) has been established.[2] However, the problem of estimating system utilization (in relation to space requirements) as a function of user service level hasn't been fully explored. This problem involves not only probability modeling but also statistical variance analysis. The approach taken in this paper to achieve a suitable solution is to (1) derive probability distribution functions from the user arrival pattern, (2) define the user service levels in terms of probability estimates derived from the arrival probability distribution functions, and (3) use statistical variance

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[1] A general discussion of the concepts of automated highways and the deterministic reservation scheme can be found in References 1 and 2.

[2] Reference 10 contains a probability model for traffic flow.

analysis to calculate guideway space requirements.

The material in this paper is organized as follows: A summary of the conclusions is given and a brief introduction to the general concepts of dual mode is presented along with adequate references for further investigation. A statement of the problem is given with an explanation of the concepts involved. The approach taken to develop the probability models and perform the statistical analysis is illustrated with a sample problem of a hypothetical network. The advantages and disadvantages of the techniques are discussed and a brief description of the simulations procedures that were used to evaluate the analysis is presented. Finally, a proposed effort for future development work is outlined.

CONCLUSIONS

1. The user service level defined as the probability of entering the automated guideway unimpeded is a variable that should be included in the modeling of network traffic management schemes.

2. Vehicle space requirements on an automated guideway can be considered as a function of demand rate, system utilization and/or user service level any of which can be expressed in probabilistic terms.

3. Probability models and statistical analysis can be used to investigate various strategies of network traffic management.

4. Network traffic management policies can be developed to regulate entrance queues along a particular route so that serious congestion is avoided at those entrances that are closest to the destination point.

5. Trade-off considerations in network traffic management should include system utilization and user service level. As user service level increases, system utilization decreases.

BACKGROUND

In a dual mode system, vehicles are capable of operating on conventional streets in a manual mode and also on specially constructed guideways in a completely automated mode. For an urban area, such a system could have many advantages over a rapid transit or conventional highway system since it has many features of a door-to-door high speed transportation system. The high speed is maintained along the automated guideway portion by either a synchronous or asynchronous longitudinal control system. The work presented in this paper is predicated on a synchronous system in which a vehicle velocity profile has been determined for the automated guideway and is maintained by some means of control such as a fixed reference. Vehicles can be thought of as occupying hypothetical slots or cells along the automated guideway. The length of a slot is chosen in accordance with the system's safety, headway, and reliability requirements. The slots move along the guideway in groups called "cycles." The time a cycle travels from one point to another along the guideway can be determined from the guideway's velocity profile. The number of slots per cycle depends upon the constraints of vehicle velocity, acceleration, deceleration, and ramp design.[3] The cycle size remains constant throughout the system for any given time interval. The merging of streams of vehicles occurs at what is termed "control" points along the guideway. At such points vehicles either depart one cycle for another or cycles coalesce. Interchanges, junctions, entrance and exit ramps are control point locations. At these points traffic bottlenecks tend to occur. During a given time interval the number of slots per cycle is fixed at some constant "n". This is a critical system design parameter, consequently, a conflict could arise at control points if proper precautions are not taken.

Figure 1 shows an example of the merging of two cycles between the main stream and an entrance. At points A1 and A2 which are equally distant from the merge point C, the system detects the position of vehicles within cycles by means of a wayside computer. In the example shown in Figure 1, slots 1, 2, and 4 are occupied at point A1 on the main guideway. On the entrance ramp at position A2, slots 1, 2, 2 and 7 are occupied. The total number of vehicles in both cycles doesn't exceed the cycle limit. However, the vehicles must be rearranged within the cycles so that at point C a collision will not occur. This is accomplished at point B2 on the entrance ramp where the vehicle occupancy is shifted from slots 1, 2, 4 and 7 to slots 3, 5, 6 and 7. Therefore, at point C the merge can be successfully accomplished. The task of preventing more than a specified number of vehicles to occupy slots within cycles at control points so that guaranteed passage will occur without queuing or "waiting" lines forming within the network is the function of a "deterministic" reservation system. In such a system, vehicles are not permitted on the automated guideway until passage can be reserved through all the control points contained along the desired route. Consequently, vehicles must wait at the entrance ramps until passage is obtained.

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[3] For a general discussion of dual mode concepts see References 3 through 6.

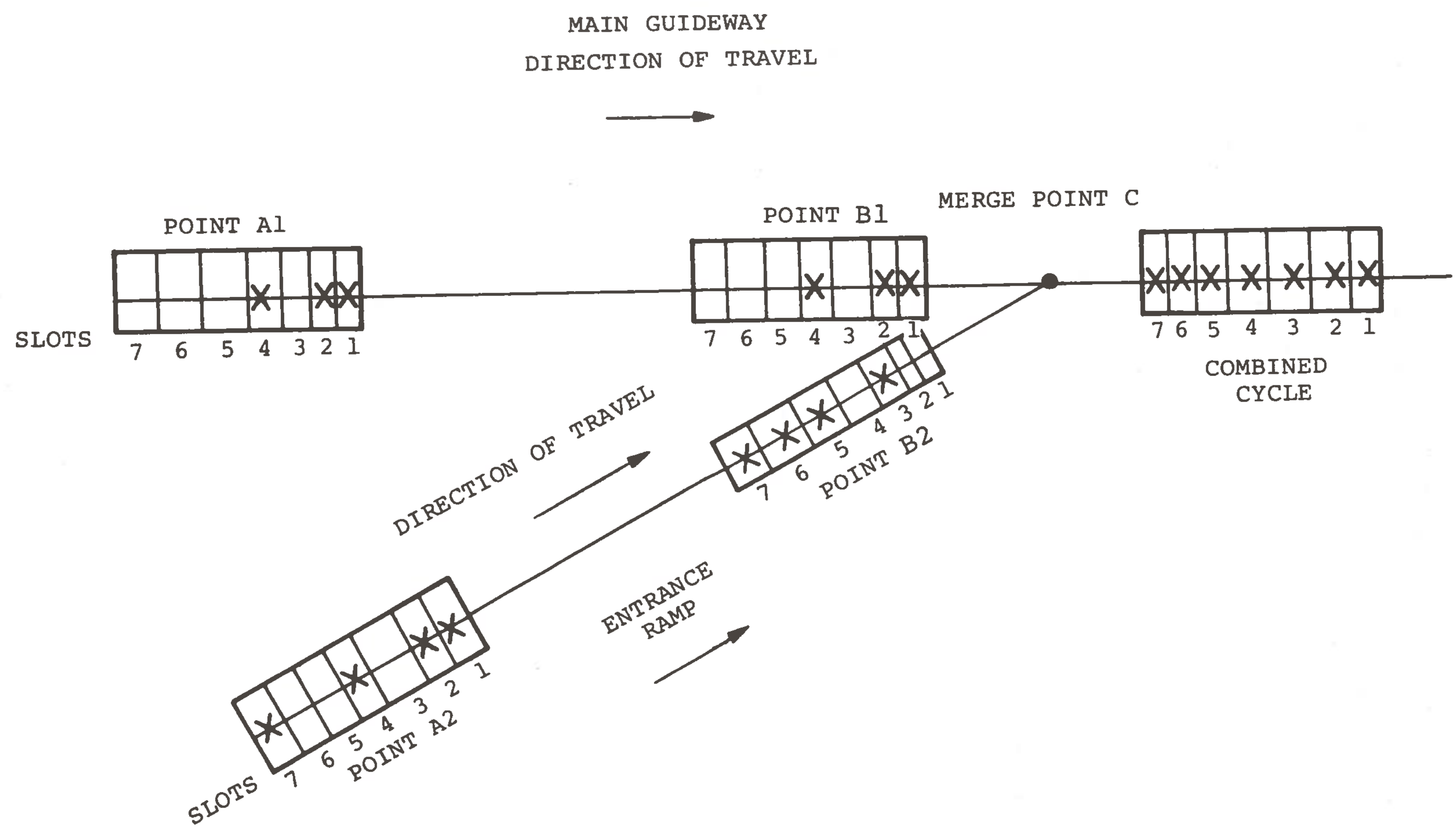

Figure 1. Vehicle Merging

STATEMENT OF THE PROBLEM

In a deterministic system, the problem of space allocation can be posed by the question, "How much space must be allocated in a specific time interval for a given demand rate at a desired user service level along a particular route?"

Time Interval

In most urban ground transportation systems, traffic congestion usually varies with the time of day and peaks around what is commonly referred to as "rush" hours. Upon studying a particular system, it often becomes apparent that the heaviest traffic along a particular route occurs within some specified time interval (Δt). Estimates of such time intervals are essential to the design of any new system since they represent the heaviest system load or "worst" case.

Demand Rate

Repeated observations of Δt will reveal that the number of vehicles occurring within this interval is not constant, but forms what is referred to as a "distribution" of arrivals. This arrival pattern can be converted into a probability distribution function. The Poisson distribution is commonly used to describe arrival rates.[4] If the probability of exactly K arrivals in $T = \Delta t$ is denoted by $P_K(T)$, the Poisson distribution is expressed by the equation:

$$P_K(T) = \frac{(\lambda T)^K}{K!} \cdot e^{-\lambda} \qquad (1)$$

where:

the parameter λ is a constant that indicates the mean arrival rate and is often referenced to simply as the traffic rate. The average rate of arrivals in the time interval is given by λT. A typical graph of the Poisson distribution with a mean value of $\lambda T=4$ is shown in Figure 2.

User Service Level

This parameter is one of the most difficult to estimate. No objective function has yet been developed that will yield an easy answer. A discussion of what constitutes a satisfactory level of service is beyond the scope of this paper. It is

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[4]Reference 7 contains a discussion on probability distributions. Reference 8 gives Molina's Poisson tables and Reference 9 discusses arrival rates.

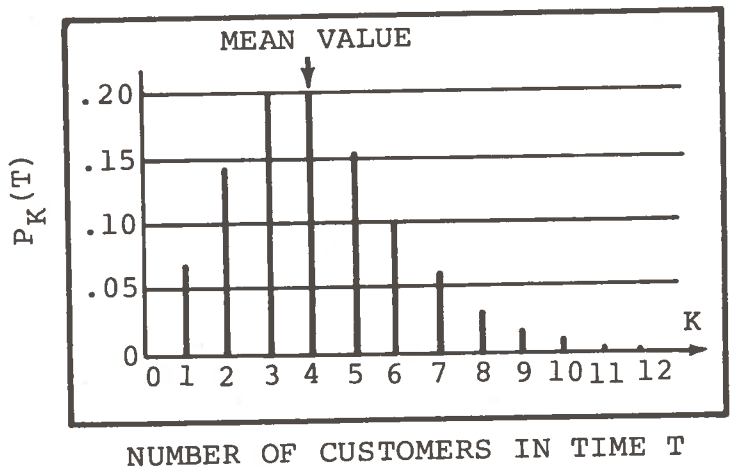

Figure 2. Poisson Arrival Distribution

sufficient for purposes herein to say that the level of service provided must satisfy users. In an urban dual mode system it could be quite likely that the potential user of such a system will have an alternate route to follow other than the automated guideway. Consequently, the user service level must be high if the system is to be successfully operated. At the network entrances, it is the probability of entering the system with a guaranteed reservation. Being a probability estimate denoted herein as P, it ranges in value from 0 to 1. The higher the value, the greater the probability and the less chance of queuing.

Routes

A route is composed of one destination point which could be an exit or another control point such as an intersection and one or more guideway entrances which are referred to simply as control points in the remainder of this paper. For each such control point along a given route, an associated λ and P value can be established.

CALCULATION OF USER SERVICE LEVEL

A route may contain "n" control points. If a service level

P_R is assigned to the entire route, then the calculation of equal P values for the control point can be obtained from the following equation which is derived from the multiplication law concerning mutually exclusive events.[5]

$$P = \sqrt[n]{P_R} \qquad (2)$$

hence:

$$P_R = (P)^n \qquad (3)$$

If it is predetermined that a specific control point must have a specified value, P_i, then:

$$P_R = (P_i)\ (P)^{n-1} \qquad (4)$$

This equation can be expanded to include several cases

$$P_R = (P)^{n-L} \times P_1 \times P_2 \times P_3 \ldots P_L \qquad (5)$$

where:

L = the number of predetermined values

STATISTICAL VARIANCE ANALYSIS[6]

Statistical variance analysis is used to compute the desired space required (S_p) in T interval by use of the equation:

$$S_p = X_1 + X_2 + X_3 \ldots X_n \qquad (6)$$

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[5]An introduction to probability theory is found in Reference 11.

[6]The term "variance" as used in this paper is more akin to the procedure of statistical tolerance analyses found in quality control work. It is not taken to mean the second moment about the mean of a distribution which is defined as:

$$m2 = \frac{1}{n} \sum_{i=1}^{h} (X_i - \bar{X})^2 f_i$$

The statistic actually used is a percentile of a distribution.

Where:
X is a value associated with the user service level at control points and can be derived from the accumulative probability distribution of the arrival distribution. The accumulative probability distribution of the Possion distribution given in Equation (1) is:

$$F(X:\lambda) = \sum_{K=0}^{X} \frac{(\lambda T)^K}{K!} \cdot e^{-\lambda T} \qquad (7)$$

It computes the probability of obtaining X or less arrivals in the T interval. Molina has calculated tables so that the values of λ, X, and P are easily obtainable.

PROBLEM

The use of the above probability and statistical concepts in solving the stated problem can best be illustrated by the following problem:

Calculate the space required S_p, when $P_R = .95$ (service level along route), given:
$\lambda = 5$ (mean arrival rate in T interval)
$n = 4$ (number of control points along route),
and all the user service levels at the control points along the route[7] are considered to be equal. Figure 3 shows a line haul system where this might be applicable. The system has four entrances. One control point is located at each entrance. From Equation (2) P can be calculated:

$$P = \sqrt[4]{.95}$$

$$P = .987$$

Molina's tables can now be used to obtain an X value since both P and λ are known. Entering the tables with a P of .987 and a λ of 5, an approximation of 10 is obtained for X.

This means that given an average arrival rate of $\lambda = 5$, 10 or less arrivals could be expected within any one T interval.

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[7]An insight into the problem of calculating distances from control points is found in Reference 12.

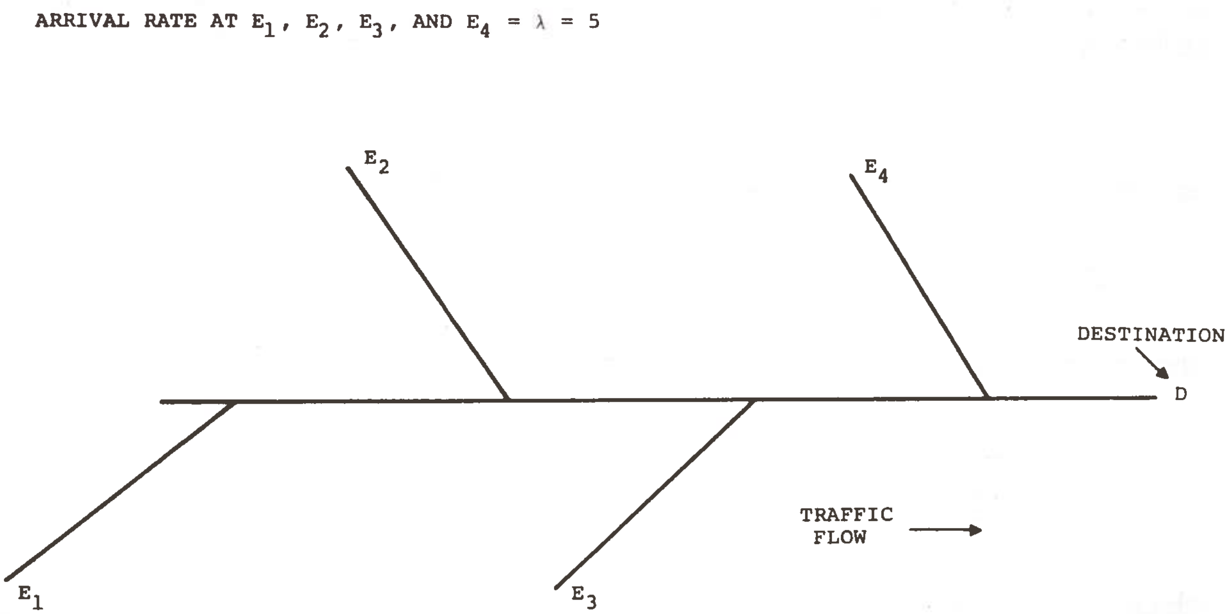

Figure 3. Line Haul Network

The space required is given by Equation (6).

$$Sp = 10 + 10 + 10 + 10$$
$$Sp = 40$$

Therefore, 40 slots must be available in the T interval so that the above conditions can be satisfied. These slots can be grouped into cycles according to the conditions and restrictions given in Reference 6. For a $\lambda = 5$, Molina's tables have an upper limit of 14. This means that no more than 14 arrivals should occur within a T interval (the probability of more than 14 arrivals is extremely small). To solve the problem in a non-statistical manner, that is, setting $P = 1$, the upper limit of 14 would be used and Equation (6) would yield a value of 56. The difference between the two methods amounts to 16, (56-40), which represents a considerable saving of space and an increase in system utilization, defined as:

$$u = \frac{\text{average arrival rate}}{\text{slot capacity}} = \frac{\sum_{i=1}^{n} \lambda}{Sp} \qquad (8)$$

for a given T interval. This is analagous to the "traffic intensity ratio" used in queuing theory.[8] The non-statistical approach would give an expected system utilization of

$$\frac{20}{56} = .36$$

as compared to the statistical approach of

$$\frac{20}{40} = .5$$

the numerator of 20 is calculated from Equation (8) as:

$$\sum_{i=1}^{n} \lambda = 5 + 5 + 5 + 5 = 20$$

This sample problem represented by Figure 3 was simulated on a digital computer using 40 slots per T interval and 10 intervals between merge points. The simulation was conducted until approximately 2000 vehicles per entrance were served. Actually, a total of 7,488 vehicles entered the system for which statistics were gathered.

The results of the simulation are presented in Figure 4. The number of vehicles queued per T interval is given for each entrance along with the number of vehicles that entranced serviced. The only queuing occurred at the fourth entrance (E_4) where one vehicle had to wait one T interval before entering the network. The system utilization can be calculated as 100 minus the percentage of empties which is given as 40.88, therefore, 100-40.88 = 59%. This is much larger than the calculated value of 50%. The probability of queuing in this example is very low. The influence of upstream traffic flow on downstream entrances which is common to stochastically operated highways is also evident here. In this case, the upstream entrance rates have an influence on the downstream entrances with respect to slot occupancy. In Figure 3, the occupancy of a group of slots increases as it moves from E_1 to D. Assume 40 slots are available in T interval at E_1. With a $\lambda = 5$, only 14 (from Molina's tables) at the most could be filled from arrivals at E_1. Another 14 could be added at E_2. Queuing wouldn't begin until E_3. Hence, the probability of queuing increases as the control points become closer to the destination.

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[8]Reference 7 presents a general discussion of queuing theory

TOTAL SERVED = 7488

PERCENTAGE OF EMPTIES = 40.88

SERVED = 1853

INTERVAL	QUEUE	ENTRANCE	1
1	0		

SERVED = 1899

INTERVAL	QUEUE	ENTRANCE	2
1	0		

SERVED = 1875

INTERVAL	QUEUE	ENTRANCE	3
1	0		

SERVED = 1861

INTERVAL	QUEUE	ENTRANCE	4
1	1		

Figure 4. Interval = 40

The accummulative probability distribution function at each control point starting from the furthest one away from the destination point can be described as:

$$P_j = F(X:\lambda) = \sum_{K=0}^{Xj} \frac{\left(\sum_{i=1}^{j} \lambda iT\right)^K}{K^1} \cdot e^{-(\sum_{i=1}^{j} \lambda_i T)} \qquad (9)$$

However, in actual application, the arrival distribution (f(x)) would first be summed and then the accummulative probability distribution derived from the aggregate at each control point. When the Posson distribution is employed, Xj values can easily be obtained from Molina's tables by entering the tables with the aggregate of the sum of the λ_i values to the control point of interest.

Still using a P of .987, new λ and X values are obtained. This data is presented in Figure 5. The system utilization is now calculated to be $\frac{20}{30}$ = .66.

Entrance	$\sum \lambda$	X
1	5	10
2	10	17
3	15	24
4	20	30

$\lambda = 5$

$P = .987$

Figure 5. Accumulative Variance Analyses

The X value of 30 for E_4 now becomes the number of slots (S_p) per T interval. A network simulation was performed and the results are given in Figure 6. Queuing occurs at E_4 as might be anticipated. 68 vehicles waited one T interval, 8 waited 2 intervals, and 4 waited 3 intervals. The system utilization is up to .73. However, this is accomplished at the expense of the users who are closest to the destination point. It is desirable to spread the queuing as equally as possible among the control points. One approach could be to impose the X values given in Figure 5 as accumulative limits at their respective entrances. As a result, no more than 10 vehicles could enter the system from E_1 during any one T interval and no more than an accumulative total of 24 would be permitted to pass beyond E_3. This total of 24 is composed from those already in the group as it arrives at E_3 and those users at E_3 who are requesting entrance at that particular T interval. Simulation was performed using the X limits in Figure 5. It was found that better results were obtained when the model was slightly calibrated by increasing the limit at E_2 from 17 to 19. The

TOTAL SERVED = 7488

PERCENTAGE OF EMPTIES = 27.02

SERVED = 1853

INTERVAL	QUEUE	ENTRANCE	1
1	0		
2	0		
3	0		

SERVED = 1899

INTERVAL	QUEUE	ENTRANCE	2
1	0		
2	0		
3	0		

SERVED = 1875

INTERVAL	QUEUE	ENTRANCE	3
1	0		
2	0		
3	0		

SERVED= 1861

INTERVAL	QUEUE	ENTRANCE	4
1	68		
2	8		
3	4		

Figure 6. Interval = 30

results are given in Figure 7. The number of users in the queue at E_4 has been reduced by 50%. However, the total system queue has increased by the same amount. Yet, all the entrance queues are about equal in size ranging from around 1 1/2 to 3% of the vehicles served. This would yield a minimum service level of .97 which is in the desirable range.

PROCEDURE

The procedures used thus far can be summarized as follows:

1. Determine a desired user service level.
2. Determine the number of control points along a given route.
3. Determine the demand rate in T interval for each one of the control points.
4. Classify or group (as required) control points with respect to travel time from the destination. Control points with equal travel time should fall into the same classification or group. Each group then represents control points with equal travel times from the destination.

   In either of the examples shown in Figure 8, if entrances E_1 and E_3 were equal in travel time from the destination point, then they could be grouped together in one classification. Likewise, the same holds true for E_2 and E_4.
5. Sum control point arrival distribution within each classification.
6. Obtain aggregate totals of the classification distributions starting with the furthest one from the destination point.
7. Derive accumulative probability distributions for each classification.
8. Find the value X on the accumulative probability distribution that corresponds to the user service level.
9. Use X as the limit for the number of arrivals permitted for each classification during the T interval.

   The minimum number of slots per T interval that must be available along the desired route is equal to the X value at the classification closest to the destination point. If the Poisson distribution is assumed for step 7, then step 5 is concerned with obtaining the required λ_i values for Equation (9) which can be used to perform steps 6 and 8.

TOTAL SERVED = 7488

PERCENTAGE OF EMPTIES = 27.02

SERVED = 1853

CYCLE	QUEUE	ENTRANCE 1
1	29	
2	0	

SERVED = 1899

CYCLE	QUEUE	ENTRANCE 2
1	35	
2	2	

SERVED = 1875

CYCLE	QUEUE	ENTRANCE 3
1	48	
2	0	

SERVED = 1861

CYCLE	QUEUE	ENTRANCE 4
1	38	
2	0	

Figure 7. Accumulative Variance Analysis, Interval = 30

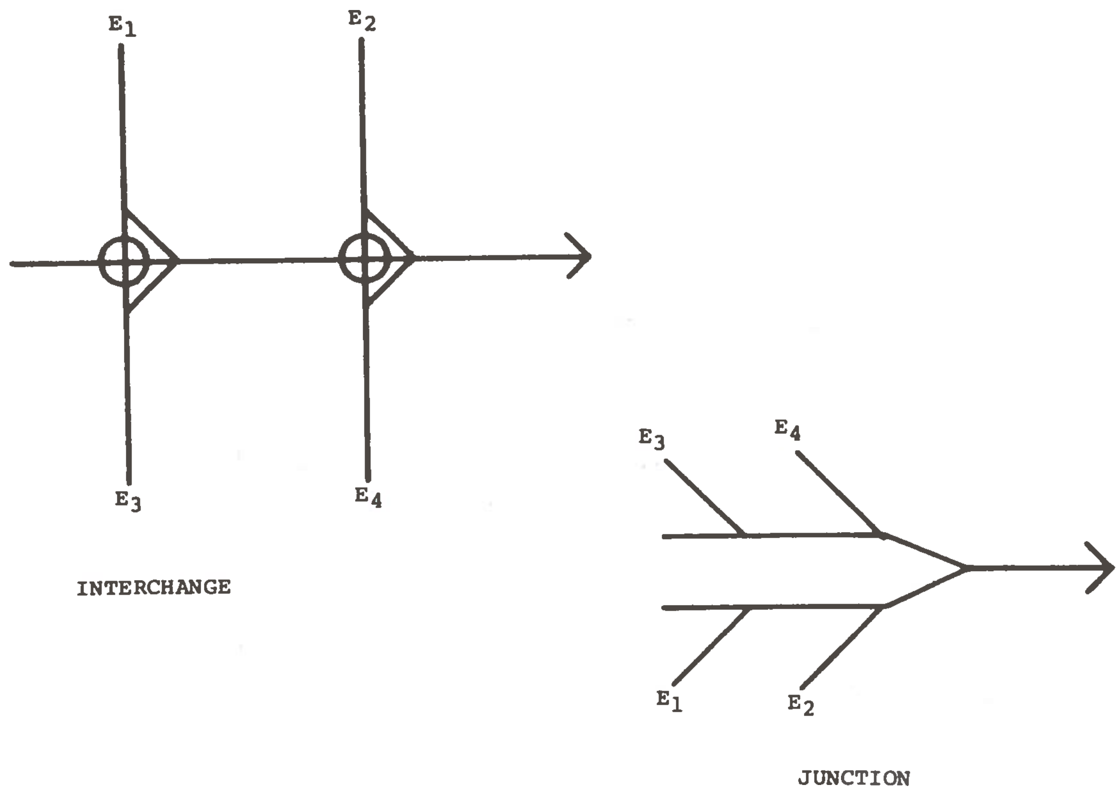


Figure 8. Network Configurations

Algorithms were developed for a digital computer to simulate (1) the various types of control points that could be found on a dual mode network, (2) space allocation as a function of system queuing and utilization, and (3) simple automated highway networks. The computer input consists of:

1. The number of control points
2. The number of slots per time interval
3. Limits (if desired) on the number of accumulative arrivals per control point or classification
4. Network configuration stated in terms of time intervals between control points
5. Number of time interval replications
6. An accumulative probability distribution of arrivals for each control point.

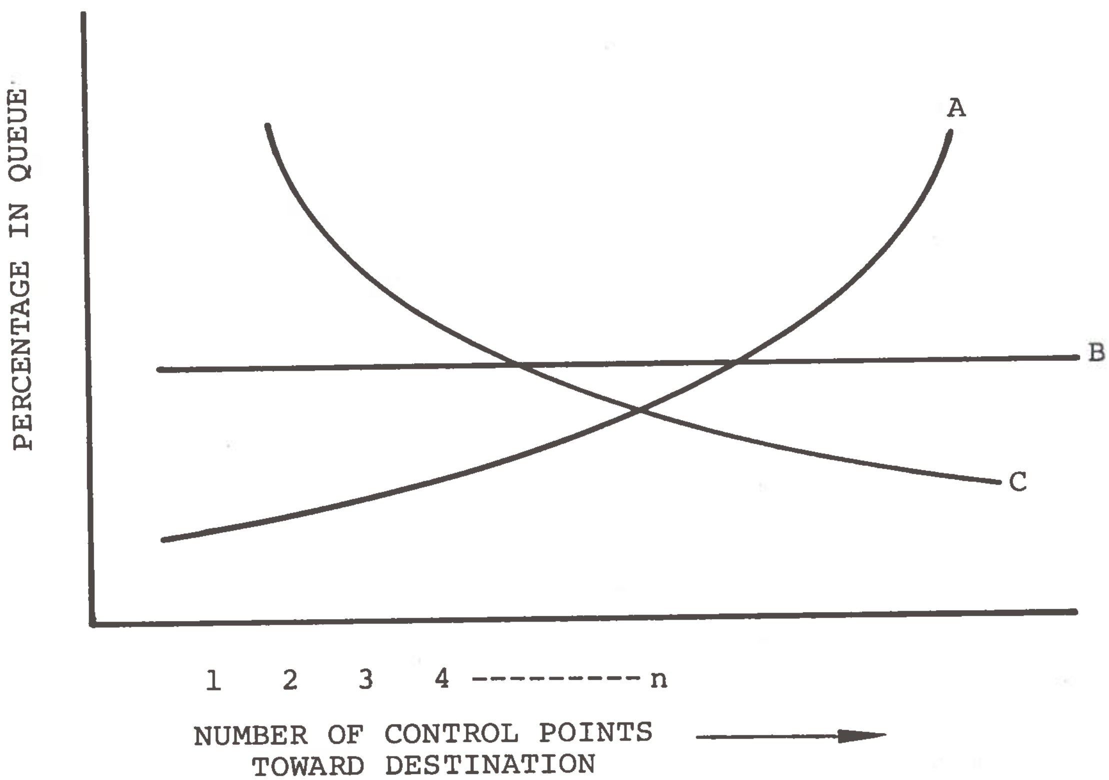
The computer output contains the information given in Figure 6. The program is written in FORTRAN to be translated by a FORTRAN G Compiler. It requires approximately 30k of core to execute. A Monte Carlo technique is used in the simulation. Independent random numbers are generated for each control point. The first set of random numbers generated is used in conjunction with the arrival distribution to determine the number of arrivals that will occur in the time interval at each control point. From this set of numbers a probability distribution of arrival sequences is derived and a second set of random numbers is generated so that the arrival sequence can be determined. This procedure can be used to simulate vehicles arriving at the network entrances in a random sequence and requesting passage through control points along their route. A "warm up" period is alloted to the random number generator before any numbers are actually used. The simulated network is brought to a stable state by not recording any data until the network has been completely loaded at least once. This means that at least one group of users from the entrance furthest from the destination point has arrived at the destination point before any statistics are collected. Since the simulation is dimensionless: devoid of time, distance, and velocity, it represents the minimum effort required to solve this type of problem. Only interval units between control points are considered. As users request space, the reservation procedure checks to see if space is available at that particular entrance in the current time interval. If it is, then that interval's reservation total is increased. If it isn't, then the next interval is checked and so on until space is found and a reservation can be made. Consequently, the simulation program can be considered as a discrete group or interval simulator as opposed to most automated guideway simulators which are discrete vehicle simulators. The groups move through the network. Tables are provided to keep track of the necessary statistics at each control point. Figure 8 shows some additional network configurations that were simulated to illustrate the statistical variance approach of solving the space allocation problem. The configurations consist of an example of two interchanges and that of a junction where two streams of traffic must be coalesced.

DISCUSSION

Figure 9 gives a brief summary of the advantages and disadvantages of the space allocation procedures discussed in this paper. The accumulative statistical variance procedure is the best prospect for providing a standard user service level over the entire network without penalizing the user because of control point locations, or entrances. Figure 10 illustrated this by showing queuing as a function of the number of control points from the destination point along a particular route. By

Procedures	Queuing	Disadvantages	Advantages
Stochastic	Average	Penalizes down stream entrances	maximizes system utilization
Variance Analyses	Minimized	Decreases system utilization	maximizes user service level
Accumulative Variance Analyses	Increases		optimizes system

Figure 9. Comparison of Space Allocation Procedures



A. STOCLASTIC PROCEDURE

B. ACCUMULATIVE VARIANCE PROCEDURE

C. VARIANCE PROCEDURE

Figure 10. Queuing Results of Space Allocation Procedures

lowering the user service level to .88 and still using a $\lambda = 5$ with the system configuration given in Figure 3, the effect of queuing in a purely stochastic procedure can be better observed. From Molina's tables, an X value of 25 was obtained from a $\lambda = 20$ and a P of .88. A simulation was performed and the results are shown in Figure 11. The queuing starts at entrance 2 at .2% of the vehicles served

$$\left(\frac{1}{1889}\right)$$

and rises to almost 20%

$$\left(\frac{277}{1861}\right)$$

at entrance 4. This latter amount could become highly objectionable to users at E_4 once they realize that they were being penalized because of entrance location. Figure 12 shows the results after the accumulative variance analyses procedure was employed. The queuing percentages at all entrances have been adjusted to satisfy the user service level of .88 which was the objective in this example. In actuality, an automated guideway would be analyzed route by route. The statistical variance analysis may not have to be confined to a deterministic reservation or a synchronous procedure. If queue space was provided within the automated network, the statistical procedures may be applicable to non-deterministic systems. Further work would be required to verify this point.

FUTURE WORK

The probability model (9) that has been developed and the associated procedures for its use in solving automated guideway space allocation problems present a good foundation for the further exploration of traffic management schemes. The illustrative problems that were presented herein were an attempt to verify concepts rather than to demonstrate wide spread applicability. There is no doubt that more work of this nature has to be done. Little attention has been devoted to the problem of allocating space for alternate paths or to the case when control points are associated with two or more routes. In addition, the performance parameters of the system, such as headway and velocity, must be elaborated upon. After the required number of slots in a desired time interval has been calculated, it must be determined that this number doesn't exceed the system's constraints of headway, velocity, vehicle performance, and station configuration. Mathematical models can be derived that express the functional characteristics of

TOTAL SERVED = 7488

PERCENTAGE OF EMPTIES = 15.90

SERVED = 1853

INTERVAL	QUEUE	ENTRANCE 1
1	0	
2	0	
3	0	
4	0	

SERVED = 1899

INTERVAL	QUEUE	ENTRANCE 2
1	1	
2	0	
3	0	
4	0	

SERVED = 1875

INTERVAL	QUEUE	ENTRANCE 3
1	44	
2	5	
3	0	
4	0	

SERVED = 1861

INTERVAL	QUEUE	ENTRANCE 4
1	277	
2	61	
3	15	
4	11	

Figure 11. Interval = 25

TOTAL SERVED = 7488

PERCENTAGE OF EMPTIES = 15.36

SERVED = 1853

INTERVAL	QUEUE	ENTRANCE 1
1	150	
2	0	

SERVED = 1899

INTERVAL	QUEUE	ENTRANCE 2
1	135	
2	25	

SERVED = 1875

INTERVAL	QUEUE	ENTRANCE 3
1	211	
2	0	

SERVED = 1861

INTERVAL	QUEUE	ENTRANCE 4
1	189	
2	14	

Figure 12. Accumulative Variance Analysis, Interval = 25

these parameters. An optimization procedure could then be developed that optimizes the system with respect to demand rate and user service level. Of course, this is what is really needed to adequately explore network traffic management strategies and enable one to identify the impact of such interrelationships. A development effort is being proposed in the area of network traffic management analysis that will include functional modeling, system simulation, system optimization and trade-off analyses. An outline of such an effort is presented in Figure 13.

The variable "Inspection Times" found in the Input column refers to time required for vehicle inspection before they enter the automated guideway. Note that the concept is that vehicles should be thoroughly checked with respect to their electrical system, acceleration performance, and tires along with other pertinent items before they enter the system. The literature relating to automated highways, dual mode and personal rapid transit systems, contains many functional models that might be applicable. The integration of these models into an analytical procedure for evaluation has not yet been accomplished. Reference 13 is an excellent presentation of what could be considered as the present state-of-the-art in automated roadway network simulation. The existing system simulation programs for personal rapid transit systems seem to generally lack the necessary means to be easily adapted to network traffic management problems. They either are designed to simulate a particular operating system or cannot be easily adapted to the slot in cycle concept. Consequently, a simulation effort far more extensive than the one outlined in this paper needs to be undertaken. The analytical procedures presented herein can be used in such a future effort to investigate ways to maximize system performance under varying constraining situations for anticipated demand levels and user service levels. However, a trade-off analysis concerning system speed and capacity versus desired safety, reliability, and utilization would have to be considered as well as system design versus land availability and costs.

The output from such an analysis should lead to a definite conclusion with respect to any proposed dual mode system configuration and answer such questions as which type of network control strategy is best and under what conditions.

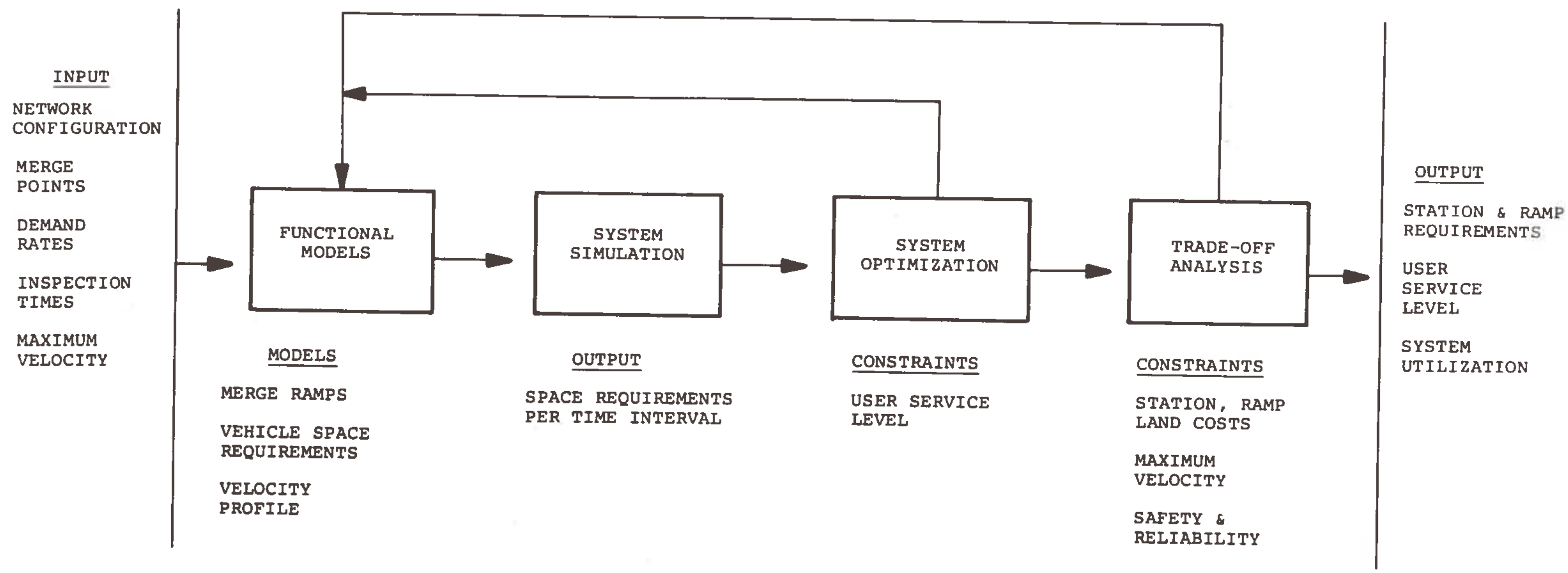


Figure 13. Dual Mode Network Traffic Management Analyses

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