PARAMETRIC STUDY OF ACTIVITY CENTER TRANSPORTATION SYSTEMS

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A general analytical method is used to examine the characteristics and economics of two modes of operation for short-range, automatic, captive guideway transportation systems for activity centers. Type A systems employ small vehicles, operated at short headways over a variable route network with off-line stations, and offer point-to-point service capability. Type B systems use larger vehicles on fixed routings with on-line stations and stops at all included stations. A comparison is made by using an example of a simple 2¼-mi loop and by assuming a nontransient pattern of demand. Key problems of the Type A systems are size and complexity of stations and degraded performance under peak loading. In situations of the type studied in the example, total average trip times are not significantly longer and tend to be more reliable for Type B than for Type A at high loads. Estimated operating costs are 3.7 cents per available seat-mile for Type A versus 1.9 cents for Type B based on capital costs of $25.47 million and $8.19 million respectively. In the near term (i.e., such as the example in this paper) where choice exists, Type B systems appear capable of meeting most activity center requirements at significantly lower cost.

•THE OVERALL quality of passenger transportation services, whether based on highways, airways, or railways, is a source of growing concern. It is recognized that one of the principal problem areas is massive congestion at transport nodes, which include points of intermodal transfer such as airports as well as destination points where specific transactions or activities occur such as urban centers and shopping centers. In discussions of the intrinsic problems of the nodes, as opposed to the specific role they play in a larger transport network, the nodes are usually lumped together under the generic title of activity centers.

There are three avenues to explore in seeking relief from pressures of intensified use of space within an activity center and rising values of the central core of land and facilities:

1. Expansion of the central facilities to accommodate larger volumes of traffic;
2. Improvement of traffic processing and acceleration of flows to reduce nonproductive waiting time and delays; and
3. Dispersal of service functions (e.g., parking lots) to increase overall space utilization.

Eventually, all three solutions will be constrained by the distances people are able and willing to walk and the walking conditions they will tolerate. Inevitably, the need arises for various forms of local transportation systems to remove or alleviate these constraints. For other than very short distances, for which moving sidewalks may be appropriate, the ultimate system is generally defined in terms of automatically controlled, discrete vehicles operating on an exclusive guideway network. There are two broad categories of automatic vehicle transport systems that we will refer to as Type A systems and Type B systems.

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TYPE A SYSTEMS

Type A systems consist of relatively small "personal-use" vehicles capable of operating at short headways on a variable-route network. Stations are located off the main guideway enabling demand responsive, point-to-point, nonstop service. Sufficiently fast and reliable on-vehicle switching is necessary to avoid constraining headways and line capacity.

There is considerable interest in this type of service, and a number of engineering designs have been proposed, or are under active development, that offer the requisite switching capability. There are, however, no proven fast switching systems with the demonstrated capability of providing safe, reliable passenger transportation available at present. It is generally conceded that such systems will not be widely available for at least 2 or 3 years, given an extensive program of engineering development, testing, and public demonstration.

TYPE B SYSTEMS

In Type B systems, vehicles are scheduled to operate approximately every minute on fixed routes. Stations are located on the main guideway, and vehicles do not pass one another. Fast dynamic switching is not essential. The few automatic systems that have been installed to date, or are in the advanced stages of implementation, are of the B type and involve relatively simple shuttles or continuous loop layouts that do not require dynamic switching.

Although there may be specific applications where the advantages of certain types of systems will determine which is, or is not, appropriate, it appears that in most cases the choice is not clear-cut and that the relative merits and disadvantages of each must be carefully weighed. An essential preliminary to any such evaluation is a clear definition of the primary service standards and requirements that are to be met, such as station locations and access convenience, waiting times and trip times, and comfort and safety factors. However, it is useful to have an understanding of the general capabilities of the broad categories of Type A and Type B systems to develop realistic specifications and to avoid setting uneconomic, extravagant, or specious service standards.

In this paper a general analytical method is used to examine the essential features of captive guideway systems and to highlight the difference between Type A and Type B operational modes in the context of a simple $2\frac{1}{4}$-mi loop layout.

The selection of any one example as a basis for comparision is open to the criticism that it biases the results to favor one type of system. For the near future, however, the basic loop is probably the most applicable type of layout for a wide variety of short-range service situations such as intra-airport transfer and shopping center circulation. Controls for automatic operation of loop systems are considerably more simple and less expensive than the advanced control technology to support automatic operation over exclusive, multipath networks. Where economic risk is the prime consideration, as in most commercial installations, loop systems would generally offer least risk exposure. In fact, at the present time labor intensive systems using modern buses in imaginative ways are still prime contenders in many applications (1, 2).

The purpose of this paper is to assist the planner in evaluating the cost and benefits associated with automatic activity center transportation systems. In this regard the emphasis is on passenger service systems—where time and cost are dominant—rather than on purely recreational applications.

The basic kinetics of automatically controlled captive vehicles operating on a guideway network have been discussed by Hajdu, et al. (3). They considered some specific examples of small-vehicle, short-headway systems with off-line stations. We follow essentially their line of development in the next section.

VEHICLE FLOW CAPACITY

The capacity flow of vehicles along a one-way, single-lane guideway is defined by

$$C = (2vaj)/(Kv^2j + Kva^2 + 2ajL) \qquad (1)$$

where

C = capacity line flow, vehicles/sec;
v = operating velocity, ft/sec;
a = maximum operating acceleration, ft/sec^2;
j = maximum operating jerk, ft/sec^3;
L = overall length of vehicle or connected train of vehicles, ft; and
K = control factor, $K > 0$.

The control factor is a convenient way to specify minimum allowable headways (separation distance between vehicles) in terms of stopping distances of the vehicles. If $K = 1$, vehicle separation never goes below the minimum distance required to detect a blockage, initiate braking, and bring a vehicle safely to rest. Minimum values for $K > 1$ represent safety factors built into the control system. If $K < 1$, there is a definite risk of collision. Thus, the designed value of K is determined by economic, risk, and reliability criteria for the system.

The maximum vehicle flow rate will occur for a critical velocity, v_c, which is obtained by differentiation of Eq. 1.

$$v_c = (2La/K)^{1/2} \tag{2}$$

Figure 1 shows how capacity flow rate and critical velocity vary with L and K by using a value of $a = 0.11$ g. These curves clearly demonstrate that the influence of K on the vehicle flow rate is more significant for small vehicles than for large vehicles. Under maximum flow conditions, small vehicles tend to be limited to speeds less than 10 mph, whereas large vehicles can readily achieve speeds greater than 10 mph.

Also shown in Figure 1 are typical operating regimes for automobiles, buses, and small and large activity center transportation systems. Estimates of passengers carried by each type of vehicle can be used to obtain an approximate theoretical upper bound on maximum passenger flows as shown in the following

Type	Units per Minute	Passengers per Unit	Passengers per Minute
Private Automobile	35	2	70
Buses	18	60	1,080
Small ACTS	20	5	100
Large ACTS	10	80	800

With regard to the small and large activity center transportation systems (ACTS), an examination of specifications for 19 systems (4) indicates that the relationship between vehicle length and maximum passengers carried is given very roughly by $P = L^2/20$. In general, for a given operational K-value and maximum capacity conditions, large vehicles will produce higher passenger flows at higher average speeds than smaller vehicles.

SYSTEM AVERAGE TRAVEL TIME

A useful measure of system performance is the system average travel time defined as

$$T = \sum_{xy} T_{xy} d_{xy} \Big/ \sum_{xy} d_{xy} \tag{3}$$

where

T_{xy} = total trip time between stations x and y, and
d_{xy} = the demand rate for the (x, y) trip.

The T_{xy} term includes (a) time spent waiting for vehicle, (b) time spent in vehicle on station trackage, and (c) time spent on a guideway between stations.

We first consider the base of a Type A system with off-line stations under steady-state conditions (i.e., system input equals system output, and demands are nontransient during the period of interest).

By using a number of simplifying assumptions and a few slight modifications, an expression for T_D (average trip time for Type A system) can be derived as described in another report (3):

$$T_D = [(s/vS) \sum_x F_x - (b_1/v)] + [(v/a) + (b_2/v) + (a/j) + t] + [(p/2)(\nu/S)] \quad (4)$$

where

- s = average guideway distance between adjacent station centers;
- b_1 = average distance on guideway between exit and entry points at a station;
- b_2 = average length of off-guideway station track;
- $S = \sum_{xy} d_{xy}$ = system passenger throughput rate [for steady-state conditions, throughput equals the sum of all trip originations/unit time (input) or sum of all trip terminations/unit time (output)].
- F_x = total number of passengers flowing on guideway link x (between x and x + 1) per unit time;
- p = average number of passengers per vehicle;
- $\nu = \sum_{xy} \delta_{xy}$; $\delta_{xy} = 1$ if $d_{xy} > 0$ and 0 if $d_{xy} = 0$; and
- t = average dwell time for vehicles at stations.

The left set of bracketed terms in Eq. 4 gives the average time spent on the guideway. This quantity can be stated in another way. Note that $\sum_x F_x$ is the total "travel product" rate in terms of passenger-link flows per unit time. Therefore, $\sum_x F_x/S$ is equivalent to the average number of links traveled per trip. By multiplying by s and by subtracting b_1 we derive the average guideway distance traveled per trip. By dividing by v we derive the average guideway travel time per trip. The middle set of terms gives the time spent on the station trackage including acceleration, deceleration, and dwell times. The right set of terms gives the average time spent waiting for a vehicle. The term S/ν is the average arrival rate of passengers for trips between a specific pair of stations. Therefore, $P\nu/S$ is the average time to accumulate a vehicle load. Then the average delay for passengers demanding that specific trip is one-half of the accumulation time. If the system operates on a truly demand basis with very small vehicles, then the waiting time (ideally) goes essentially to zero because the vehicle will be directed by the passenger (or party traveling together) as he arrives. A more likely operating policy during the peak periods will be to have a central control monitor the demand for a specific trip type rather than assign a vehicle when a reasonable load has accumulated, in which case the delay will be as stated in Eq. 4.

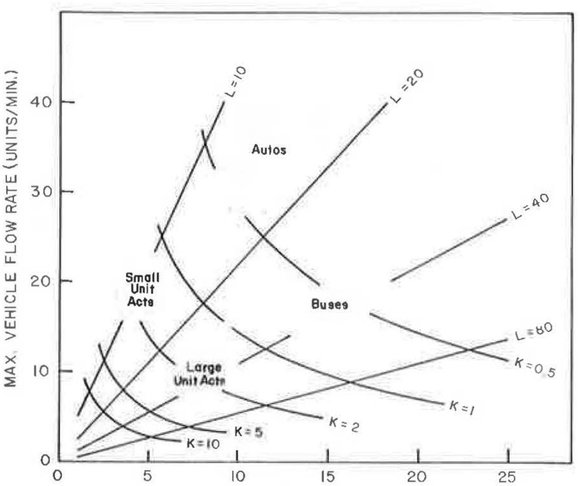


Figure 1. Maximum vehicle flow rate as function of critical velocity, length of vehicle L, and control factor K.

The validity of Eq. 4 rests on six strong assumptions:

1. Interstation distances do not vary widely;
2. Operating velocities do not significantly vary on different links because of inclines, curves, and the like;
3. Full-speed merges and exits from main guideway place a lower

bound on station track length, $b_1 > (v^2/a) + (va/j)$, providing not more than one vehicle is in the station at one time (adequate trackage and station design are required to allow a number of vehicles into a station simultaneously, and the values of a and j are limited by acceptable standards of passenger comfort and safety);

4. The average number of passenger per occupied vehicle, p, is essentially the same for each trip pair and requires that the distribution of demand throughout the system be reasonably well-balanced over a period of time;

5. Passenger demand input rates are random and not subject to severe "pulsing" (i.e., large groups arriving at once, as might occur with aircraft arrivals at an airport, for example); and

6. The balance of demand is such that vehicle "deadheading" (i.e., transfer of empty vehicles between stations) will not reduce passenger flow capacity on any link or introduce significant trip delays.

MINIMUM NUMBER OF VEHICLES REQUIRED

For the same strong assumptions underlying the expression for T_D, a lower bound for the number of vehicles required is derived as follows.

If N vehicles are occupied by an average of p passengers at any time, then there will be Np trips in progress at any time. The average time per trip spent in a vehicle is obtained from Eq. 5 as

$$T_r = T_D - (P/2)(\nu/S)$$

During this time a total of ST_r passengers must complete trips throughout the system, and this requires $Np \geq ST_r$. Therefore, a lower bound on N is given by

$$N = (ST_D/P) - (\nu/2) \quad (5)$$

For a closed-loop system, the vehicle flow rate, C, is determined by the capacity required to match demand on the link with the greatest passenger flow, defined as $F^* \geq F_x$ for all links. Then for the closed-loop, balanced system $C_p = F^*$. (If the station demand is not balanced, i.e., inputs do not equal outputs at all stations, the excess capacity on some of the links can be interpreted as deadheaded vehicle transfers.) Therefore, Eq. 5 can be restated as

$$N = (ST_D C/F^*) - (\nu/2) \quad (6)$$

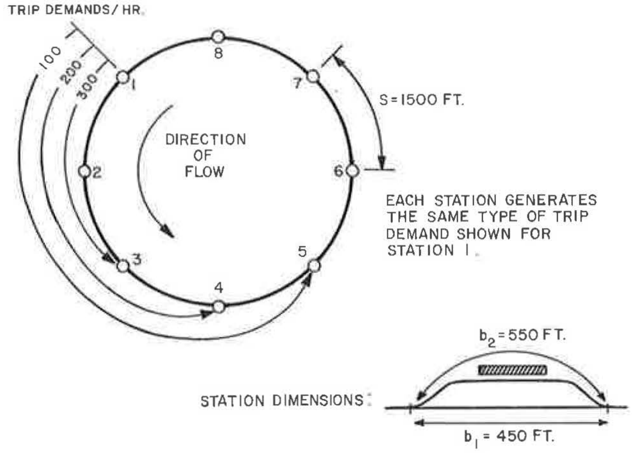
ANALYSIS OF TYPE A SYSTEMS

Equations 1, 4, and 6 form the basis of analyzing a transport system for a specific pattern of demands and geographic layout, providing it is reasonably compatible with the stated assumptions. If T_D is taken as the principal measure of system performance, a lower bound for any set of parameter values can be found to exist by putting the equation $C_p = F^*$ into Eq. 1, differentiating with respect to v, and setting equal to zero. A critical velocity v_M for minimum T_D is thus given by

$$v_M^2 = a\,[(s/S)\sum_x F_x - b_1 + b_2 + (LF^*\nu/2S)]/[1 + (F^*\nu k/4S)] \quad (7)$$

The highly structured example shown in Figure 2 can be used to illustrate the relationships among the quantities T_D, C, N, and associated parameters. This might be a part of a two-loop circulation system, each loop independent, with flows in opposite directions. Stations are assumed to be nonlimiting for flows of passengers or vehicles. Values for a and j are based on the detailed study of the effect of acceleration and jerk on acceptable levels of passenger comfort reported by Gebhand (5). Vehicle length over track L is taken as 12 ft. As defined, these parameters imply three constraints:

1. $v \leq 30$ mph = 44 ft/sec (because b_2 = 550 ft);



DEMAND PARAMETERS:

S = 4800 PAX/HR = 1.33 PAX/SEC

F* = 1600 PAX/HR = 0.445 PAX/SEC

ν = 24

OPERATING PARAMETER:

a = 0.125g = 4.0 ft/sec^2

j = 0.091g/sec = 2.9 ft/sec^3

t = 20 secs

Figure 2. Example of a single-loop system.

2. C_p = 1,600 passengers/hr = 0.445 passengers/sec; and
3. $p \leq 7$.

From Eq. 7, v_M exceeds 40 mph for all cases of interest and therefore is nonlimiting. In Eq. 10 we assume the maximum vehicle capacity is given by $P = L^2/20 \approx 7$ passengers.

Inserting the example parameter values into Eqs. 1, 4, and 6 and using constraint 2 we obtain

$$1/C = 0.125\ Kv + 0.69K + (12/v) \tag{8}$$

$$T_D = (4{,}100/v) + (v/4) + (4/C) + 21.4 \tag{9}$$

$$N = 3T_DC - 12 \tag{10}$$

In Eq. 8 it is usually more convenient to express C in its reciprocal form, which gives the headway time between vehicles on the main guideway.

Equations 8, 9, and 10 are conveniently displayed in the manner shown in Figure 3. Any point on the graph represents a basic solution to the sample problem in terms of six variables. The value of T_D is strongly dependent on v and, for a given v, is relatively insensitive to changes in K and headways (I/C). The absolute lower limit for T_D is indicated by the heavy line. Due to the station track length limitations, however, the actual lower limit for this example is given by the v = 30 mph line. In fact, the benefits of lower T_D values at the expense of higher speeds diminish very rapidly for speeds faster than 30 mph. The influence of K on headways varies with v, being somewhat weaker in the lower ranges of v and becoming more significant as v approaches its

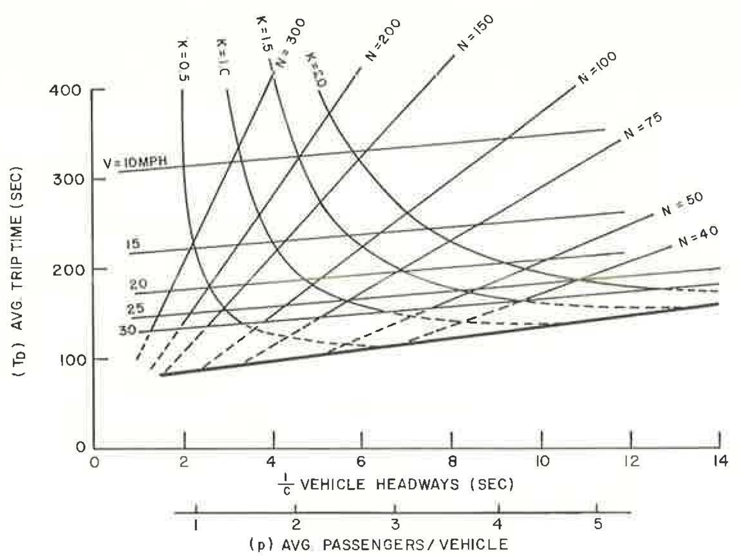


Figure 3. Operating characteristics of Type A system.

limiting values. For the demand levels in this problem and the operation modes of $1 < K < 2$, the average passenger load per vehicle is well within the upper bound of $P = 7$, and there is a comfortable allowance available for random peaking. For example, at the point defined by $V = 30$ mph and $K = 1.5$, p is a bit over 4 for an average occupancy factor of about 60 percent. If variations in demand are reasonably proportionate throughout the system, the same graph can be used for different demand levels by adjusting the position of the p-scale according to $C_p = F^*$. If a significant amount of vehicle deadheading is to be anticipated, this can be incorporated by artificially inflating F^* (in effect creating a phantom demand). The number of vehicles and their average occupancy are significantly influenced by headways, or K values. For example, at $V = 25$ mph, reducing K from 1.5 to 1.0 requires that N increase from 50 to 75 vehicles and p drop from 3.75 to 2.5.

The values of T_D shown in Figure 3 reflect the average guideway distance traveled, which is expressed in Eq. 4 by the terms $(s/S) \sum_x F_x$ and in the example equals 2.67 links. Other trip times, such as maximum and minimum trip times for the system, are calculated by replacing the terms in Eq. 4 with the appropriate guideway distances traveled. For instance, in the example, the maximum trip covers 4 links and has a trip time of 46 sec more than the averages at a speed of 30 mph shown in Figure 3. The minimum trip is 2 links giving a trip time of 23 sec less than averages at 30 mph.

The values of T_D for various values of the parameter set in the preceding analysis are strictly lower bounds in that they result from perfectly operating (i.e., fully predictable) procedures. In actual practice, stochastic variation of key variables will introduce significant additional waiting times. These will fall into two categories: (a) delays in matching the arrival of demands with vehicles and (b) delays in merging vehicles onto a busy guideway. We have conveniently defined away a third operational delay by stating that the station design will be nonconstraining to passenger or vehicle flows. This problem is discussed elsewhere (3). It will, of course, be a major consideration in an actual design situation especially with regard to the economics of providing adequate overflow track, vehicle control, and switching in stations.

The passenger and vehicle matching delay is a difficult one to analyze because it depends to a large extent on the available demand monitoring capability and control and the particular methods of vehicle assignment. For present purposes, we will assume that normal delays from this source are at least partially absorbed by the expression for "load accumulation time," which was incorporated into Eq. 4.

The delay encountered by vehicles attempting to merge onto a crowded guideway can be approached by the method described in the Appendix. Merge delays have been calculated for the present example and are shown in Figure 4 as a function of headways and for a range of guideway velocities. For example, at V = 30 mph and for headways of 8 sec the calculated value of T_D is increased by 15 percent from 158 to 182 sec when the merge delay is accounted for.

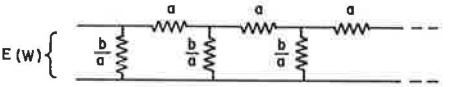


Figure 4. Expected guideway merge delays for Type A system.

ANALYSIS OF TYPE B SYSTEMS

For Type B systems the vehicle flow rates are defined by Eq. 1 with the additional constraint that vehicle headways are limited by on-line station stops. The constraint is given in terms of station dwell time and safe distance as

$$1/C \geq t + (v/a) + (a/j) + (L/v) \tag{11}$$

From Eqs. 1 and 11 the closest separation distance between vehicles is defined by K as

$$K \geq [2taj/(vj + a^2)] + 2 \tag{12}$$

If all vehicles stop at all stations, the system average trip time is

$$T_L = [(s/v) + (v/a) + (a/j) + t](\sum_x F_x/S) + (1/2C) \tag{13}$$

The first bracketed group of terms in Eq. 13 is the travel time between adjacent stations, which is multiplied by the average number of links traveled per trip to obtain average ride time. The term 1/2C is the average wait for a vehicle when vehicle flow rate is C vehicle per unit time.

As in the Type A system, a critical velocity exists that gives the minimum T_L.

$$v_M^2 = a\,(2s\sum_x F_x + LS)/(2\sum_x F_x + S) \tag{14}$$

The total number of vehicles required for the Type B system is

$$N = (S/F^*)\,[T_LC - (1/2)] \tag{15}$$

By using the parameter values for the example shown in Figure 2, we can compare the operating characteristics of a Type B system with the results for the Type A system. For the Type B system, an upper limit of L = 40 ft is used for overall vehicle length in anticipation of larger average passenger loads. The resultant operating and constraint equations are used to plot the curves shown in Figure 5.

Solution points for the example problem lie above the heavy line. The left side of this curve reflects the capacity constraint given by Eq. 11; the right side is obtained from Eqs. 1 and 14. The point for minimum average trip time (T_L = 181 sec) occurs for v = 48.7 mph and 1/C = 39.9 sec. This minimum point is obtained by finding the maximum v from Eq. 13, which, in turn, gives 1/C from Eq. 11.

In general, Type B systems are operated as a continuous, sequential flow of vehicles, and merge delays do not arise as for the Type A systems. Therefore the values fo T_L

do not need correction. Both types of systems will experience some variation in trip times because of variable station dwells, with Type B systems being more susceptible to uncertainties from this source.

COMPARISON OF TYPE A AND TYPE B SYSTEMS

The essential characteristics of the two approaches to solving the loop problem in the example are as follows

Characteristic	Type A	Type B
Waiting time, sec	26	20
Ride time, sec	126	161
Merge delays, sec	21	—
Total trip time, sec	173	181
Maximum speed, mph	30	48.7
Headways, sec	6.5	39.9
Number of vehicles	59	12
Average number of passengers per vehicle	2.9	17.8

Values for the Type B operation are taken from the minimum T_L point. For the Type A system, the comparable operational point is assumed to be given by the intersection of the curves, shown in Figure 3, for K = 1 and v = 30. (Actually, for a K = 1 type of operation the guideway speed limit is approximately 51 mph. However, for full-speed guideway exits and merges, this speed would require approximately 1,500 ft of acceleration and deceleration track, which is the distance between stations.)

The total trip times are not much different for either type of system. The average ride time for Type A systems is less, but there are offsetting delays caused principally by guideway procedures under loaded conditions. In general, the Type A system will provide shorter trip times, but service is likely to degrade rapidly as peak demands build up, depending on the sophistication of the demand monitoring and control capabilities. In contrast, trip times on the Type B system will be more or less constant under all conditions. For local area services, for which loop layouts are appropriate, the trip time differences between the two types of system are small, typically about a minute or less. As distances increase and trip end points become more diffuse, the Type A systems offer more pronounced advantages in terms of lower trip times.

ECONOMIC FACTORS

Type A systems can offer some definite advantages in operational flexibility and lower trip times, but these benefits are obtained at higher costs compared with Type B systems. It is difficult to estimate relative costs with precision because of the limited amount of operating experience with any type of automated system. Also, each installation will be specially designed to meet a given pattern of service demands in the context of some specific terrain and on-site construction problems.

An order of magnitude estimate of comparative costs of the two types of systems has been developed from several sources, some of which are proprietary and therefore not included as references. Major differences in the applications

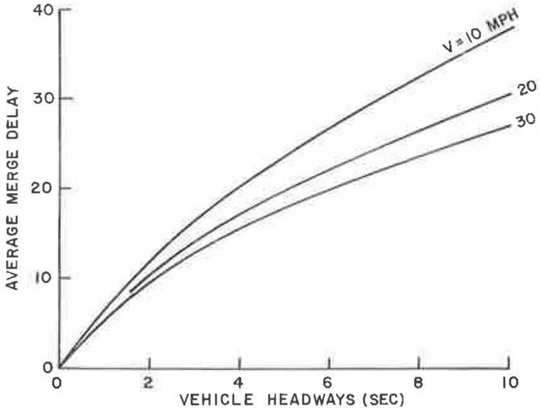


Figure 5. Operating characteristics of Type B system.

described by the data sources required considerable modification and normalization of major cost components. For example, special site preparation costs are offset as far as possible, and all guideway costs were adjusted to be representative of fully elevated systems. Right-of-way costs and nonrecurring charges associated with system installation and testing are not included.

Track lengths for the two systems are about the same; however, layouts differ to reflect the special capabilities of each. The layout of the Type A systems is essentially several separate clusters of stations with services provided within and between clusters. Fast switching capability enables use of off-line stations and point-to-point service. The arrangement of the Type B guideway is a complex of connected loops serving equidistant stations. Vehicle headways enable on-line switching between loops, if required, without significant service interruption.

The results, given in Table 1 show principal system descriptors, capital costs, and annual operating expenses. A significant measure of the systems is the "transport product," given as annual available seat-miles. The Type A system produces 174 million seat-miles with 290 twelve-seat vehicles operated up to 25 mph. The Type B system produces 117 million seat-miles with 36 thirty-four-seat vehicles operated at 35 mph.

The greatest capital cost difference is in the guideway, with the Type A system incurring almost 4 times the cost of the Type B. Allocated costs of vehicles and control mechanisms are about $26,000 each for Type A and about $58,000 each for Type B. Total costs for Type A vehicles, however, are more than three times the costs of Type B. The average allocated cost of stations is about $155,000 for the Type A system, compared with about $46,000 for Type B. This difference reflects the greater space needed to handle larger numbers of small vehicles at stations. The service patterns are such that the Type B system requires more station installations, and the total station costs are not substantially different.

The major components of annual operating costs come to $6.43 million for Type A and $2.23 million for Type B. A useful measure of systems costs is in terms of cost per available seat mile, which is 3.7 cents versus 1.9 cents for Type A and Type B respectively. Therefore, from this preliminary analysis a Type A system would be expected to cost approximately twice as much as a comparable Type B system.

TABLE 1

COMPARATIVE COSTS OF A TYPE A SYSTEM AND A TYPE B SYSTEM

Item	System A	System B
Characteristic		
Track length, mi	7.8	8.5
Number of stations	11	26
Number of vehicles	290	36
Maximum number of passengers per vehicle	12	34
Maximum speed, mph	25	35
Vehicle-miles per year, millions	14.5	3.44
Available seat-miles per year, millions	174	117
Capital costs, $ millions		
Guideway, sensors, power distribution, 58 and 49 percent	14.75	3.99
Vehicles, controls, spares, 30 and 25 percent	7.61	2.07
Stations, 7 and 14 percent	1.70	1.18
Maintenance facilities, 5 and 12 percent	1.41	0.95
Total	25.47	8.19
Annual operating costs, $ millions		
Operation and maintenance	2.41	0.95
Capital charges, at 8 percent	2.04	0.66
Depreciation		
Vehicles and controls, 10 to 0 years	0.76	0.21
Other, 25 to 0 years	0.72	0.25
Insurance and miscellaneous, at 2 percent	0.50	0.16
Total	6.43	2.23
Available seat-mile costs, cents	3.7	1.9

CONCLUSIONS

The major advantage of Type A systems is their dispersability where demand patterns or terrain impose limiations on the service quality of loop systems with on-line stations. Also, Type A systems can rapidly adjust to changes in level and distribution of demand that can significantly improve passenger throughput. The lower capacity vehicles offer more privacy (except under extreme peak-demand conditions); but the question is, How much premium do passengers put on privacy for a trip of a few minutes duration? Trip times can be lower; however, service time degrades rapidly when guideways are loaded, which gives rise to typical congestion problems. The serious problem of small directly routed vehicles is the control of passenger flows at stations. Under light loads (typically portrayed in artists concepts), the system can be quite efficient and convenient to use. However, the organization of inbound and outbound passengers and vehicles going to multiple destinations when platforms are very crowded must be carefully considered if conflict and occasional chaos is to be avoided. It is difficult to conceive of economic, adequate crowd controls without some form of policing.

Obviously, Type A systems can operate in either the Type A or the Type B mode, in which case vehicles could be entrained to the necessary capacity, depending on demand loads. However, the higher cost of engineering a Type A system must then be supported entirely on the benefits derived from efficient operations during off-peak periods. The operation and maintenance component of operational costs is about 40 percent, and something less than this is variable cost affected by adjustable levels of operation.

The Type B system tends to be more efficient under heavy loading, especially in the area of station flow control. For instance, in the preceding example the Type A system takes a station dwell time of 20 sec to transfer a typical loading of four passengers, while the Type B is assumed to transfer a typical loading of 30 passengers in the same time period.

Trip times of Type B loop systems are not significantly greater than those of Type A. An asset to the harried, peak-period passenger is that trip times are more predictable, and only minimal decisions are required in selecting the destination point. Information on times between vehicle arrivals and estimated times to destinations is easier to process and display as anxiety-reducing measures.

Each of the two broad categories of transportation systems discussed in this paper can be applied to a wide range of requirements, and each will have a role to play in future activity center developments. For the near term, and for configurations such as the example in this paper where the choice exists, the Type B system appears capable of meeting most local area service requirements at significantly lower cost.

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APPENDIX

ESTIMATION OF MERGE DELAYS

The total length of the main guideway, denoted by λ, is divided into $\lambda C/V$ time cells, each of which represent the space required by a vehicle operating under headway constraint $(1/C)$ at speed V. If each of the N vehicles in the system spend an average of T_s

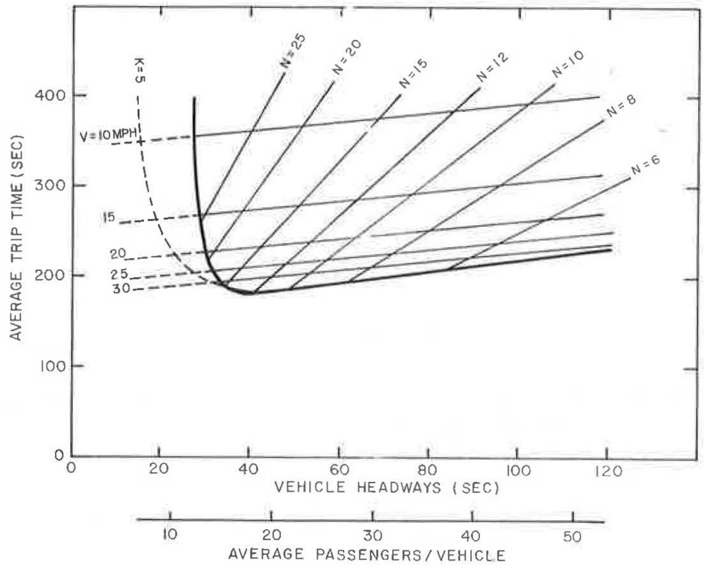

Figure 6. An infinite resistive ladder network with effective resistance of E(W).

sec on the station lines and T_G sec on the guideway in the course of a trip and all vehicles are in continuous operation, the average number of vehicles on the guideway at any time is $N\ [T_G/(T_G + T_S)]$. Therefore, if the cells are filled in a random way, the probability that a cell is occupied is

$$Pr(occ) = [(NT_G)/(T_G + T_S)]\ (v/\lambda C) \leq 1$$

We now assert that a vehicle preparing to merge onto the guideway makes a series of Bernoulli trials on the approaching cells and seizes the first empty one. Then the average number of trials required to find an empty cell is given by $Pr(occ)/[1 - Pr(occ)]$ (6). Because the rate at which cells approach is (1/C), the expected waiting time at a merge point is, as a first approximation,

$$E(W) = (1/C)\{Pr(occ)/[1 - Pr(occ)]\}$$

However, because we postulate a closed system, any delay incurred in merging will necessarily entail an increase in Ts to Ts + E(W), which reduces the guideway occupancy rate. The time spent on the guideway occupying a cell T_G will remain the same. Thus, E(W) is defined as the limit of a recursion equation of the form

$$E(W) = \lim_{K \to 00} [b/(A + D^K)]$$

$$D_K = b/(a + D^{K-1})$$

This form is precisely analogous to the resistance of an infinite, resistive ladder network as shown in Figure 6. (This analogy was pointed out by Dennis F. Wilkie of the Transportation Research and Planning Office at Ford Motor Company.) The solution for E(W) is known to be of the form

$$E(W) = \{(b/a)[a + E(W)]\}/\{(b/a) + [a + E(W)]\}$$

which is quadratic in E(W) with the solution

$$E(W) = [(a^2/4) + b]^{1/2} - (a/2)$$

In terms of the parameters defined here and for the transit system example,

$$a = T_S + T_G [1 - (Nv/\lambda C)]$$

$$b = NvT_G/\lambda C^2$$

Values for E(W) in the context of the example in this paper have been calculated for v-values of interest and are shown in Figure 4.

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