EVALUATION OF NEW URBAN TRANSPORTATION SYSTEMS

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The large number of new urban transport systems can usefully be evaluated from an economic standpoint in terms of capital and operating costs per unit traffic flow. In this paper, we have considered a number of systems in a typical urban situation with a peak flow in either direction of 10,000 passengers per hour. It is convenient to distinguish three basic classes: continuous, network, and unconfined vehicle systems. These are embodied in eight abstract systems varying in their fundamental components or operational modes. Effective capacity of each class was found to deviate from design capacity by a factor that depends on characteristics such as headway, average velocity, and area per passenger. The physical requirements for each of the eight types of systems to meet the standard 10,000 per hour demand have been specified in terms of this effective capacity. By using a number of cost equations, basic operating and capital costs have been developed for each type of system. Capital costs were amortized over typical lifetimes to provide total annual costs for each system.

•THE growing difficulty of moving people effectively in the crowded confines of densely populated urban activity centers has generated a number of proposals for new transportation systems in recent years. These have covered a wide gamut of concepts and techniques including moving sidewalks, computer-controlled bus or jitney service, tracked air-cushion vehicles, cable-suspended vehicles, and a variety of network systems of the monorail type. A survey of these systems reveals at least forty or fifty that have reached a level of hardware development that would presumably permit at least prototype demonstration within a year or two if they were adequately funded. It is clear that a comprehensive evaluation of each of these alternatives as an urban transit system would be a monumental, if not impossible, task. There are several basic types or classifications into which these systems can be grouped and analyzed by category. We find it convenient to specify four general classes of systems as follows:

1. Continuous point-to-point systems operate on closed guideways and do not possess switching capabilities (e.g., a conveyor belt or ski lift);
2. Demand-activitated point-to-point systems operate in a closed or exclusive guideway (e.g., an elevator);
3. Although similar to class 2, these demand-activated systems possess a switching capacity and the capability of forming complex networks (e.g., conventional rail transit); and
4. Demand-activated unconfined vehicle systems differ from the first three classes in that the vehicles are not constrained to a fixed guideway and thus possess, in effect, two degrees of freedom (e.g., a conventional automobile).

Most horizontal systems of interest fall into class 1, continuous point-to-point systems (CPPS), class 3, network switching systems (NSS), or class 4, unconfined vehicle

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systems (UVS). Several additional subdivisions within each class will be discussed later.

Desirable characteristics of any transportation system include low investment and operating costs, a minimum of noise and air pollution, and minimum aesthetic intrusion and interference with land-use patterns in its environs. Many of these factors are largely questions of operational policy or design specifications, and thus they can only be discussed in the framework of a specific application. For example, out-of-pocket costs would depend on whether a system were publicly or privately owned, subsidized by local business, or supported by other economic devices (e.g., advertising). In addition, it is clearly impossible to assess realistically land, right-of-way costs, or externalities such as system impact on local real estate values.

It was proposed, therefore, to compare only the basic operational capabilities and direct costs (as opposed to external costs) of the fundamental system types by choosing a hypothetical but typical application and determining the requisite values of the major parameters in order to meet the requirements of the test case.

The application in question consists of a medium-sized downtown urban area similar to that of Milwaukee, approximately 1 mile long and ½ to ¾ mile wide. It is arbitrarily assumed that the transit systems applied here must be capable of handling peak traffic flows of 10,000 persons per hour. It will also be assumed that the peak demand is divided somewhat evenly among the 6 stations, i.e., maximum flow in one direction at any station is about 2,500 passengers per hour.

The NSS appropriate to a compact urban activity area can be assumed to use small vehicles that have a seating capacity of 2 to 8 or 10 persons each, operate either singly or in a train, and conceivably travel at speeds from 8 mph to approximately 60 mph on exclusive guideways. When operated as single vehicles with off-line loading capability (NSS-1), the service could be personalized in the same manner as taxi service, in that passengers could select and automatically be carried to their ultimate destinations without stopping at intermediate points. Delays in main-line traffic can be avoided by servicing stations and interchanges by sidings or loops sufficiently long to permit off-line acceleration and braking.

If the vehicles were operated as trains (NSS-2), network services would resemble conventional rail rapid transit where vehicles operate over scheduled routes. The frequency of arrival at any station would be determined by the number of vehicles in service at a particular time. Vehicles would stop at each station along a given route (allowing for the possibility of both local and express routes), and passengers would transfer as necessary to reach their destinations. A switching capability would allow the vehicles to optimize routes and schedules continuously (given a sophisticated monitoring and EDP system) as the demand matrix for an area changes during the course of the day, or from day to day.

The UVS employ vehicles operating on existing arteries and streets. Either vehicle hardware (e.g., the propulsion system) or mode of operation might be innovative. New concepts include computer-dispatched buses or jitneys, which operate on flexible routes, or minicars, which would be passenger-operated and made available by storage terminals and on-street drop-off points.

In terms of performance and capacity, these systems would be comparable to conventional bus or taxi fleets. Two basic subdivisions appear: relatively large vehicles (>10 passengers) operated in a public service mode (UVS-1) and small vehicles (2 to 3 passengers) operated in a private or semiprivate mode (UVS-2).

The three principal families are represented and illustrated by the following examples.

1. Low-speed moving sidewalk, CPPS-1—Conventional passenger conveyor belt electrically driven and installed in straight segments at street level between intersections, entrance and egress at ends, 1.5-mph constant speed and peak demand;

2. Modular conveyor, CPPS-1—Small unpowered capsule loads at low speed (1.5 mph) from adjacent beltway, accelerated via powered rollers or other external propulsion technique to match 15-mph motor-driven conveyor belt, and elevated partly enclosed guideway;

3. High-speed moving sidewalk, CPPS-2—Conventional conveyor belt operated over high-speed sections, access via parallel belt accelerated from low entry speed (1.5 mph) to main-belt speed (10 mph), and entry and exit stations every ¼ mile on elevated enclosed guideway;
4. Small-vehicle monorail, demand, NSS-1—small vehicles suspended from overhead I-beam guideway, rubber-tired wheels, on-board electric-motor drive, on-board switching control, central computer, and demand activated by signal from off-line station;
5. Cable-car, demand, NSS-1—Small 6-seat cars towed and supported by ski-lift type of clamps on cable guideway, central computer control, and demand activated by signal from off-line station;
6. Small vehicle monorail, scheduled, NSS-2—Small 6-seat cars joined in trains operating on regular (but variable) schedules, on-line stations, vehicles air-cushion supported, and external propulsion by linear electric motor (LEM);
7. Rental minicar, demand, UVS-1—Small 2-seat or 4-seat electric cars capable of 30 mph and self-driven by key-holding subscribers from any of a number of rental stations (parking lots); and
8. Minibus, scheduled, UVS-2—Small bus (10 seat) operated on a route run on city streets and driven by electricity or gasoline (conventional).

(Copyrighted names proposed by various developers are not used because the basic concepts described are all in the public domain, and there are several competing versions of most of the candidate types.)

These examples were tested by hypothetically implanting them in the archetypical downtown area. For purposes of comparison, the guideway systems were installed in a simple closed loop roughly 1½ miles in circumference with stops or stations at ¼-mile intervals (although this configuration does not take advantage of the scheduling and routing possibilities inherent in a switching system). All such guideway systems are assumed to be elevated above street level. The low-speed moving sidewalk is assumed to have been installed at street level in 8 block-long segments approximately 500 ft long. The entire route was a straight line 4,000 ft long in each direction. The rental minicar system is assumed to operate from a large number (~50) of parking lots or parking garages.

CAPACITY

Capacity has been defined as the average number of passengers or vehicles per hour that can be transported along a single channel. Mathematically, it may be expressed in several ways, depending on whether headway between vehicles (or passengers) is expressed in units of time or distance, as follows:

$$C_v = 3{,}600/h_t \qquad (1)$$

$$C_v = 5{,}280\ \overline{V}/h_d \qquad (2)$$

for vehicles and

$$C_{max} = 3{,}600\ (S/h_t) \qquad (3)$$

$$C_{max} = 3{,}600\ (\rho w \ell/h_t) \qquad (4)$$

$$C_{max} = 5{,}280\ (S\overline{V}/h_d) \qquad (5)$$

$$C_{max} = 5{,}280\ (\rho w \ell \overline{V}/h_d) \qquad (6)$$

for passengers, where

h_t = headway measured in sec;
h_d = headway measured in ft;

$\overline{V}$ = channel speed in mph;
S = number of seats in a vehicle or train;
ρ = number of passengers per sq ft;
C = capacity in passengers per hour;
C_v = capacity in vehicles per hour;
w = width of the belt in ft; and
ℓ = unit length (= 1 ft).

For existing urban systems (e.g., subways and buses), typical space allocations range from about 3 to 6 sq ft per passenger under peak load conditions. Thus, it seems reasonable to allow 4 to 6 sq ft per passenger throughout these calculations.

Continuous Point-to-Point Systems

For an on-line leading conveyor belt, CPPS-1, if we assume a minimum headway of 2 ft, a belt width of w ft, and a loading speed of 1.5 mph, the maximum theoretical capacity would be

$$C_{max} \sim 990 \text{ w passengers per hour}$$

For modular, low-speed loading systems, a representative capsule might have six seats and a minimum headway of 7 ft (vehicles 6 ft long separated on the low-speed segment by 1-ft gaps). Application of the passenger capacity equation in this case gives

$$C_{max} = 6{,}788 \text{ passengers per hour}$$

In the case of continuous point-to-point systems with off-line loading, CPPS-2, passengers or conveyances are accelerated off line to standard speed and then merged with main-line traffic. In principle, much higher capacities can be obtained with a system of the same dimensions as the low-speed on-line system, as long as high-capacity exits are provided to eliminate the possibility of "bunching" of passengers with common destinations during deceleration. This would restrict the capacity of high-speed beltways to the capacity of the low-speed exits along the route. The latter, of course, are functions of width, w. Thus, the maximum allowed capacity for high-speed loading and moving beltways must be less than or equal to the maximum capacity of an exit divided by the maximum fraction likely to disembark there.

Network Switching Systems

Maximum capacity for network switching systems depends on the minimum headway allowable between vehicles in the main-line traffic. This factor is generally taken to be a function of the minimum distance in which the vehicle can be stopped in an emergency, and thus it is a function of the maximum permissible deceleration. It will be assumed here that a comfortable acceleration or deceleration is 0.1 g (2.2 mph/sec), and a tolerable acceleration or deceleration is 0.2 g (4.4 mph/sec). These numbers are typical, in fact, of current transit technology.

It is clear that the number of stops per mile in any transport system influences the average speed for various cruise speeds (Fig. 1), where the average stop time, T, was taken as 30 sec (1). Hence, for the same conditions—30 sec stop time and 2.2 mph/sec acceleration—a limiting maximum cruise speed exists for any specified number of stops per mile. Because, in the hypothetical test application, the stops are to be located ¼ mile apart, the maximum cruise speed attainable by any of the NSS is about 40 mph (Fig. 2).

Demand-activated transit vehicles, NSS-1, with passengers loading off line offer the possibility of shorter headways than do vehicles that load on line. If we assume that stations have a number of off-guideway slots or sidings capable of accommodating several vehicles and that the emerging vehicles will not overload the available slots, the minimum headway measured in feet is determined by (a) the maximum tolerable acceleration of seated passengers or the quality of the emergency braking system, (b) the

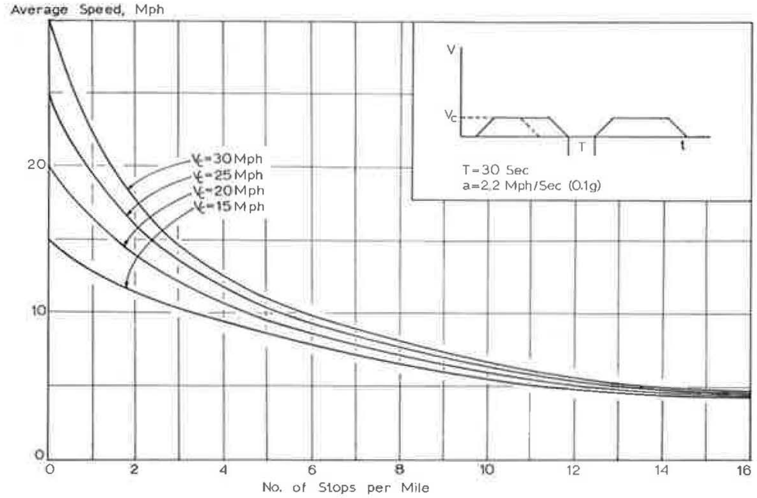

Figure 1. Influence of stop-and-go driving on average driving speed.

length of the vehicle, and (c) the cruise speed of the vehicle (limited to 40 mph). Mathematically, the minimum headway may be expressed as

$$h_{min} = 1.47K\ (V_c^2/2a_t) + L$$

where V_c is cruise speed in mph, a is maximum acceleration or deceleration in mph/sec, and L is car length in feet. The safety factor K is introduced into the equation as a coefficient of the emergency braking term. The values of K represent the ratio of the minimum allowable distance between vehicles to the minimum safe stopping distance. Motorists often presume that their observation of the behavior of vehicles several cars ahead will enable them to stop in sufficient time in the event of an emergency. By con-

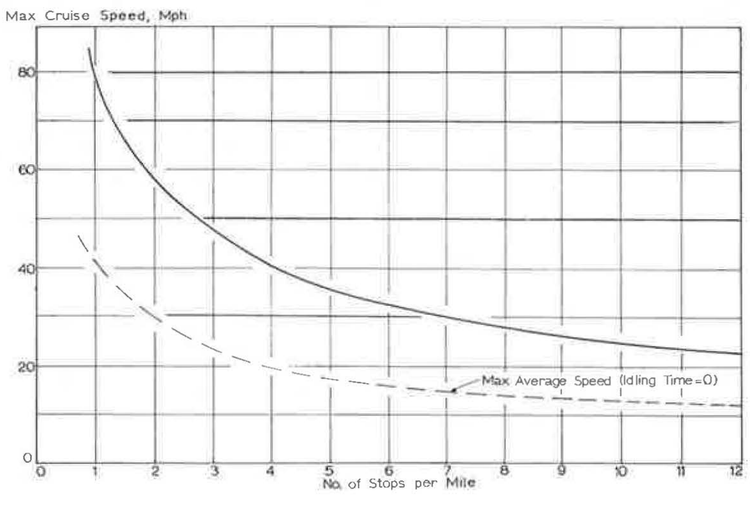

Figure 2. Limiting cruise and average speeds in stop-and-go driving.

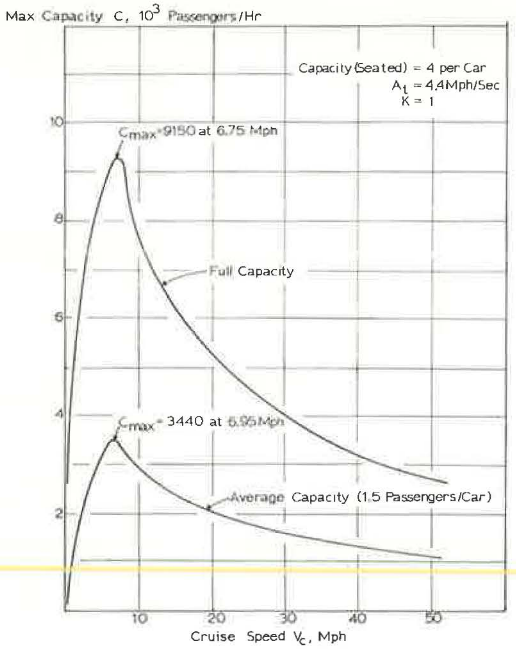

Figure 3. Maximum capacity versus speed for demand-activated transit vehicle, NSS-1.

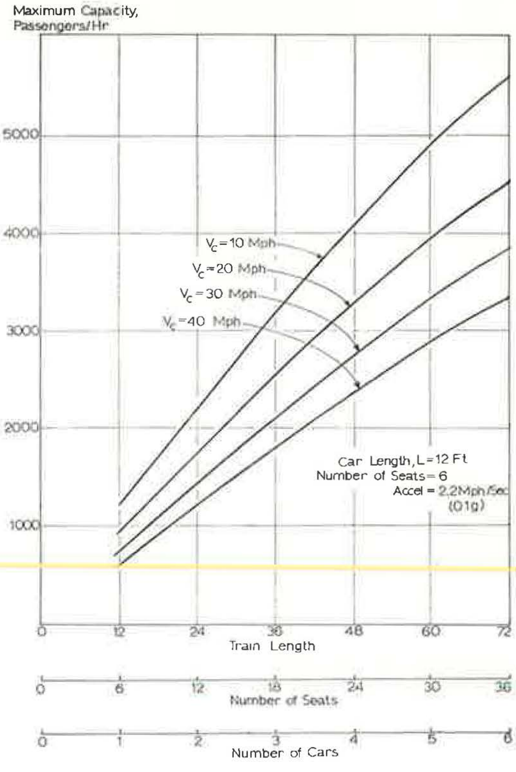

Figure 4. Maximum capacity of NSS-2.

trast, rapid rail transit vehicles operate with K-values from 2.5 to 4 or higher. These relationships are expressed by the curves shown in Figures 3 and 4, with the specific qualifications shown in each case.

For a typical demand-activated network system, NSS-1, two capacity curves are plotted—one assumes that all seats are occupied and the other allows for the fact that, in a passenger-selected destination system, the average occupancy of individual vehicles will probably be close to 1.5, typical of automobiles. For cruise speeds up to 40 mph, which is the range envisioned for personal transit systems in the application being considered, the capacity corresponding to an average occupancy of 1.5 passengers per vehicle drops from 3,400 passengers per hour at 7 mph, to 2,000 at 20 mph, and to about 1,200 at 40 mph. For fully loaded cars (during a rush hour and in a scheduled operating mode), capacity ranges from 9,150 passengers per hour at the optimum 7-mph speed to about 3,000 per hour at the maximum 40-mph cruising speed. During rush hour, vehicles would presumably be limited to speeds attainable by the continuous point-to-point systems. During off-peak hours, reduced demand would permit greater headways and higher speeds that would result in quicker travel times.

For scheduled (transit) vehicles, NSS-2, operating either singly or in trains and loading on line, the minimum headway, expressed in units of time, is determined by the sum of (a) the time required for the train to travel the deceleration distance at comfortable deceleration and jerk rates for its passengers; (b) the time required to accelerate the preceding vehicle or train clear of the station; (c) the station dwell time; and (d) the transport time required to notify the entering train that the previous train has cleared the station.

Maximum capacity is seen to increase with train length and decreasing cruise speed (Fig. 4). For short train lengths, maximum capacity is approximately 1,000 passengers per hour and is relatively insensitive to variations in cruise speed as compared to variations in train length. In a train 6 cars long (72 ft), for example, the capacity is 3,400 passengers per hour at 40 mph as compared with 5,000 per hour at 10 mph. Clearly, it is preferable to increase capacity by increasing train length rather than by reducing speed.

Unconfined Vehicle Systems

Maximum capacity in the case of unconfined vehicles is rather difficult to estimate on the basis of headway between vehicles, unless it is assumed that the vehicles travel in a special "bus lane" on the regular city streets. If such is not the case, however, it becomes easier to estimate headway on a time basis. Meeting the specified 10,000-passenger-per-hour corridor demand then becomes a matter of having enough vehicles available.

For the rental minicar system, UVS-1, it is reasonable to assume that the number of "stations" (i. e., garages or parking lots) for a small-vehicle rental system is about 50 and that the maximum hourly demand is 20,000 passengers per hour—corresponding to two major corridors—divided more or less equally among the 50 termini. Therefore, as many as 500 persons per hour move through each station. If we assume an average loading of 1.5 passengers per vehicle and approximately 30 sec for subscribers with keys to check out and load each car, the flow through each checkout point would be limited to about 180 passengers per hour. This would require three such checkout points at each terminal and an inventory of about 50 minicars per terminal, or a minimum of about 2,500 for the system, to allow for average trip times of at least 10 min at peak periods.

It will be assumed that the UVS-2 consists of small "conventional" 10-passenger minibuses running on a scheduled route in the streets. If each bus takes 30 sec to load, then 120 buses or 1,200 passengers can load at one point in an hour. Thus each of the 8 stations (per corridor) with a single off-street loading point could handle the anticipated peak load.

EFFECTIVE CAPACITY

We have discussed capacity in an abstract fashion, as though all traffic flows were smooth and rather idealized. It was noted that most vehicular systems will tend to be drastically underutilized if individual passengers are allowed to specify the ultimate trip destination and skip intermediate stops. However, other more subtle constants, due to fluctuations in demand, maximum waiting time requirements, and other factors, were not fully taken into account.

The maximum capacity primarily depends on physical characteristics such as acceleration, cruise speed, space allocation, and dimension that do not substantially affect the level of service provided the user. A more useful measure of the effective capacity of a system is the route demand that it can serve without causing unreasonable delay to any of its users (not counting mechanical failures). Obviously, if the average route demand is equal to the maximum capacity, then some potential passengers at some stations are likely to have to wait for a very long time for service.

The effects of congestion on the average waiting time in minutes per passenger at a station may be approximated by the classical Poisson arrival-exponential waiting time equation involving the level of service or instantaneous capacity C of a system, the average route traffic d, and the ratio of the station demand to the average route demand f^2.

$$t_w = (1/C)\ \{60/[1 - (1 + f)(d/c)]\} \tag{7}$$

Instantaneous capacity C is used instead of maximum capacity C_{max} in the equations because for generic systems of the switching network and unconfined types the capacity of the system may be adjusted to respond to fluctuating demand by changing the number of vehicles in service or, equivalently, the average headway between vehicles in service. Of course, for continuous systems, the instantaneous capacity is simply equal to the maximum capacity, and the only possible adjustment is to shut down the system.

Personal transit systems, on the other hand, require that the user wait both for a vehicle to arrive at the station and for the vehicle to merge into the on-line vehicle traffic. By decreasing the instantaneous capacity below maximum, the available merging time is increased, which effectively decreases the necessary merging time. On the other hand, if the instantaneous capacity (i.e., frequency of service) is too low, the station waiting time becomes too long.

The kind of effect that congestion can have on waiting time is generally shown in Figure 5, in which average waiting time from Eq. 7 is plotted as a function of channel utilization (fraction of capacity) for several values of the ratio of station traffic to channel traffic. Thus, it seems reasonable to define effective capacity as the level of channel utilization that causes no unreasonable delay in the trip time. The criteria of unreasonable delay are somewhat ambiguous, but differences in operational methodology suggest that the definition be tailored to each specific system.

Continuous Point-to-Point Systems

The effective capacity of continuous point-to-point systems with off-line loading depends on whether or not admission to the system is explicitly controlled. If vacancies are monitored (e.g., electronically) and passengers are admitted selectively to occupy the vacant seat or space, then the effective capacity will be governed by the average waiting time for admission, e.g., $\frac{1}{2}$ min when the station traffic is 10 percent of the channel traffic. The effective capacity corresponding to a volume of 10,000 passengers per hour is found to be 89 percent of the instantaneous capacity C for the modular system and 89.5 percent for the moving beltway (Fig. 5).

The other possibility is that admissions are not controlled, in which case the probability of locating a space must be high or passengers will occasionally be conveyed through the merge cycle without locating a space. For a low-speed loading (1.5 mph) system with a parallel entry beltway, a potential passenger will be transported through a 60-ft station in 0.45 min. If we assume that he can move relative to the belt in either direction at a similar speed, he will be able to search a 60-ft section—equivalent to an optional time delay of up to 0.45 min. In this case, the effective capacity will again be 89 percent of the instantaneous capacity. For a high-speed conveyor (10 mph) with a 150-ft platform, a passenger would be transported through the merge cycle in 0.17 min, with the potential leeway of approximately 0.05 min by moving along the feeder belt at 1.5 mph in either direction. To ensure that he should be able, on the average, to locate a space within the given time requires that the effective capacity be 80 percent (or less) of the instantaneous capacity.

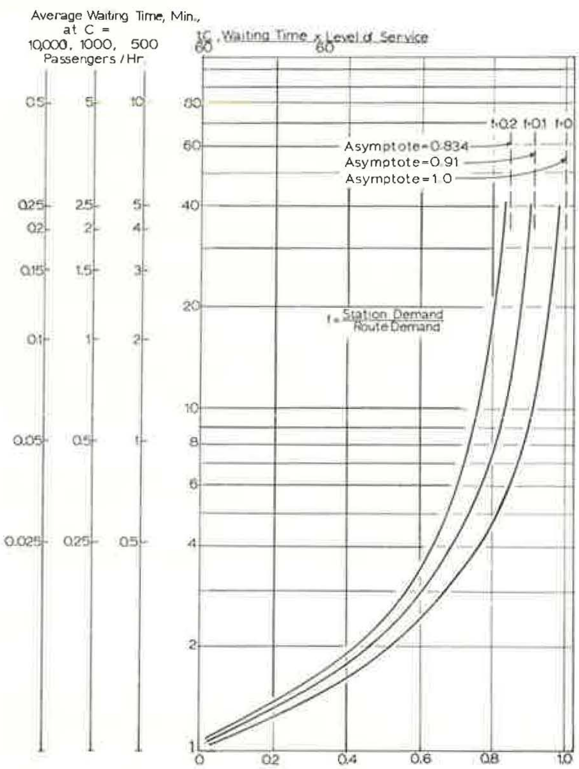

Figure 5. Congestion versus waiting time.

In view of the fact that only 80 to 90 percent of instantaneous (maximum) capacity in continuous systems can be achieved in practice (depending on circumstances), it is evident that the capacity must be increased by 10 to 20 percent to accommodate an actual peak load of 10,000 passengers per hour.

Network Switching Systems

There are two dimensions to the average time required by personal transit systems, NSS-1, to serve a passenger: He must first wait for an empty vehicle to arrive and then, after loading, wait for that vehicle to be merged with the on-line traffic. If the demand is comparable to the instantaneous capacity but much less than the maximum capacity, then the wait time is long and the merge time is short; the opposite is true when the instantaneous capacity approaches the maximum capacity. Mathematically, this relationship is expressed by

$$t = (60/C_{max}) \left([\alpha/(1 - \rho_s - f\rho)] + \{\beta/[\rho_s - (1 + f)\rho]\} \right) \qquad (8)$$

where

ρ_s = ratio of instantaneous to maximum channel capacity,
ρ = ratio of traffic to maximum channel capacity,
α = average number of passengers per vehicle,
β = factor associated with the possibility of vehicles being stored at the station, and
f = ratio of station traffic to average channel traffic.

Equation 8 is shown plotted in dimensionless form in Figure 6 for f = 0, α = 1.5, and β = 0.5 to illustrate the compromise that must be made between wait time and merge time. If the passenger waiting time is always to be minimized (the low points on the curves), the appropriate instantaneous capacity must be chosen (which will also tend to minimize operating costs). Thus, for a given elapsed time and maximum capacity an effective capacity can be found. The ratios of this capacity to maximum capacity, d/C_{max}, are the U-shaped curves shown in Figure 7. For example, if the cruise speed is consistent with a maximum physical capacity of 1,000 persons per hour, then the effective capacity is approximately 70 percent of the maximum capacity (or 700 persons per hour) if the maximum delay time is not to exceed 1 min. If the speed is such that the maximum capacity is 500, the effective capacity is about 50 percent of the maximum, or 250 passengers per hour if the same criterion for time is used.

If maximum channel capacity is 10,000 per hour, the effective capacity will be about 90 percent of instantaneous capacity for an average delay time of about 0.25 min. In addition, instantaneous channel capacity at that point is about 90 percent of maximum. The curves

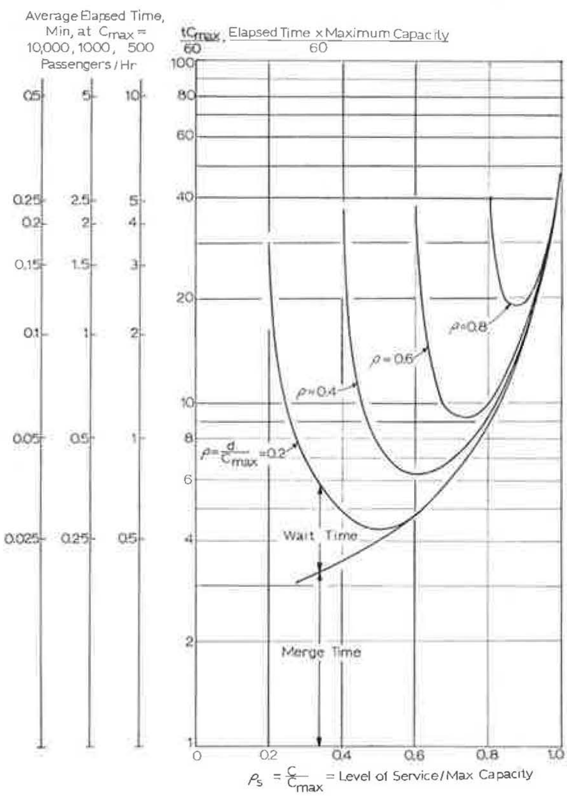

Figure 6. Average station time for NSS and personal transport.

shown in Figure 7 do not take into account the density of station use (or congestion), which would tend to reduce the effective capacity further in any case. Thus, we can perhaps expect effective capacity to be less than 80 percent of maximum design capacity.

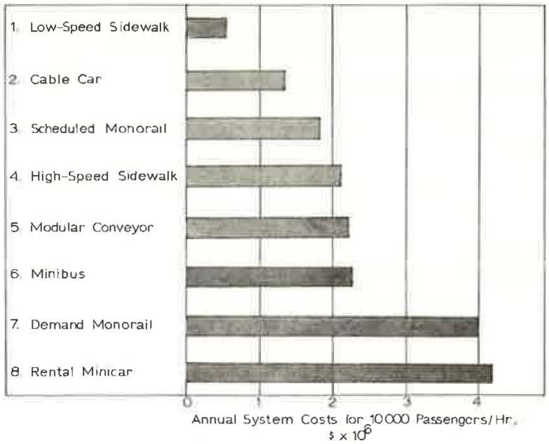

Figure 7. Rank ordering of annual system costs.

The NSS-1 are designed, however, as personal transit vehicles. They, accommodate only a few persons (e.g., up to 4), and they respond to station demand and, like a taxicab, carry the passenger to his destination with no intermediate stops. As shown previously, however, the 4-passenger car system cannot handle volumes of 10,000 passengers per hour with practical headways. Increasing the vehicle capacity will increase channel capacity, although it also tends to increase car length and thus headway. If, for example, the vehicle capacity is raised to 10 per car and the car length to perhaps 10 ft, the maximum system passenger capacity becomes 14,000 per hour at the optimum speed of approximately 7 mph. If this system is operated at 90 percent of maximum capacity and perhaps 80 percent effective capacity, it will achieve the 10,000 per hour requirement of the test case. However, the cars must be filled to capacity; thus, during peak-load hours, the system cannot operate strictly as a demand-mode personal transit system. In effect, the system must stop at nearly every station, with consequent reductions in speed. During nonpeak hours, when the demand is typically 35 to 50 percent of maximum, it can return to the personal mode.

For scheduled systems, the effective capacity is a function of the maximum capacity as a consequence of its dependence on train length and speed (Fig. 4). Thus, for a ratio of station traffic to channel traffic, f = 0.1, the effective capacity will be roughly 90 percent of maximum.

Unconfined Vehicle Systems

Effective capacity for these systems is something of a misnomer. Here, congestion has the effect of increasing loading time and running time and thus requiring more vehicles. For the UVS-1 (the minicar), the optimum number of vehicles is that which results in zero (or, at least, a very small) inventory of vehicles at each terminal point during hours of peak traffic. This implies knowledge of the average length of each trip (in minutes) as a function of general traffic conditions. During off-peak hours, vehicles not in use are automatically available. Thus, waiting time is minimal when demand is low and increases as demand approaches capacity. However, quantitative calculations in this case have not been made. In the case of UVS-2 (minibus) each vehicle completes its 1.5-mile run in approximately 9 min at an average speed of perhaps 10 mph. With 2 buses loading per minute, only 18 are needed per terminal or 108 for the system. Congestion would increase the loading time in the terminal and also reduce the average speed in traffic. Thus, it seems probable that buses with considerable excess capacity would actually be required to meet the 10,000-passenger-per-hour peak demand. Again, numerical calculations have not been carried out.

System Specifications

It is now possible, in view of the effective capacities of each type of system, to specify the quantitative requirements of each of the typical systems listed previously, as demanded by the cost equations (Tables 1 and 2).

TABLE 1

QUANTITATIVE REQUIREMENTS FOR CPPS

System	Single-Channel Belt Length (miles)	Hours of Operation per Year	Belt Speed (mph)	Live Load (tons/ft)	Spec. Weight (lb/ft)	No. of Modules Required	Effective Belt Width (ft)	Module Size (ft)	No. of Module Passengers
Low-speed sidewalk, CPPS-1	1.5	7,300 (20/day)	1.5	0.15	350	—	12	—	—
Modular conveyor, CPPS-1	1.5	7,300	15	0.2	450	100	8	7×8	10 to 12
High-speed sidewalk, CPPS-2	1.5	7,300	10	0.15	350	—	6	—	—

COSTS

With the derivation of fairly reliable values for major system parameters in each of the cases, it becomes possible to develop meaningful cost figures. Only major cost elements such as capital equipment costs, e.g., vehicles and guideways, and fundamental operating costs, e.g., maintenance and energy expenditures, will be considered here.

The cost equations were developed from extensive examination of many pertinent industry and literature sources (3). Space does not permit their inclusion in this paper; however, the results of their application are given in Tables 3 through 6.

The parametric values for each system are given in Tables 1 and 2. In general, right-of-way or land costs were disregarded. These are locally variable and can only be considered in a specific case. All guideway systems, including the modular conveyor and the high-speed beltway, were assumed to be elevated, with stations at ¼-mile intervals.

All systems were assumed to operate for 20 hr per day (typical of actual urban systems), with peak loads of 10,000 passengers per hour occurring for two periods of 5 days a week, 2 hr each in the morning and afternoon and loads equal to 40 percent of peak for the remainder of the operating hours. Operation for 20 hr at 40 percent load

TABLE 2

QUANTITATIVE REQUIREMENTS FOR NSS AND UVS

System	Live Load (tons/ft)	No. of Trains (bays/station)	Avg Speed (mph)	Vehicle Length (ft)	Vehicle Width (ft)	Vehicle Gross Weight (tons)	Avg Annual Mileage per Car	No. of Cars in System
Monorail, demand, NSS-1	0.044	2	—	10	6	1.75	26,000	200
Monorail, scheduled, NSS-2	0.044	1	—	10	6	2	26,000	175
Cable car, NSS-1	0.038	2	—	10	6	1.5	26,000	200
Minicar, demand, UVS-1			10 to 12	15	7	3	~15,000	250 (?)
Minibus, scheduled, UVS-2			10 to 20	8	4	1	~15,000	5,000 (?)

TABLE 3

COSTS OF CPPS

Cost Item	Low-Speed Sidewalk			Modular Conveyor			High-Speed Sidewalk		
	Total	Annual	Life (years)	Total	Annual	Life (years)	Total	Annual	Life (years)
Capital									
Conveyor belt	4×10^6	4×10^5	50	4.4×10^6	4.53×10^5	50	3×10^6	3.09×10^5	50
Motors and cables	0.33×10^6	0.3×10^5	50	0.7×10^6	0.643×10^5	50	0.644×10^6	0.6×10^5	50
Vehicles	N. A.			0.35×10^6	0.03×10^5	20	N. A.		
Elevated structure	N. A.			7.8×10^6	5.142×10^5	75	7×10^6	5.46×10^5	50
Heating and air conditioning	N. A.			N. A.			1.3×10^6	1.37×10^5	50
Stations	N. A.			5.4×10^6	4.3×10^5	25	5.4×10^6	4.3×10^5	25
Total	4.33×10^6	4.66×10^5		18.65×10^6	14.61×10^5		17.34×10^6	14.82×10^5	
Operating									
Energy and power	46×10^3			266×10^3			194×10^3		
Passenger supervision	N. A.			340×10^3			340×10^3		
Maintenance	8.9×10^3			91×10^3			80×10^3		
Total	54.9×10^3			697×10^3			614×10^3		

was presumed for Saturdays and Sundays. Thus, the total number of assumed operating hours per year is 7,300.

These values were calculated for the capital costs of necessary guideways, stations, and vehicles and for the various basic operating costs (energy and maintenance, for example, and, in the case of the minibus system, vehicle operating personnel). Capital costs were then amortized over typical lifetimes in each component case, and the resulting annual costs were combined with operating costs to yield total annual costs for each system.

Figure 7 shows the rank ordered by the total annual costs of each system. The low-speed moving sidewalk, which has the lowest annual costs, must be considered in reality only a pedestrian aid. For relatively "long" distances (i.e., more than a few hundred

TABLE 4

COSTS OF NSS

Cost Item	Monorail, Demand			Monorail, Scheduled			Cable Car		
	Total	Annual	Life (years)	Total	Annual	Life (years)	Total	Annual	Life (years)
Capital									
Vehicles	0.3×10^6	26×10^3	20	0.5×10^6	43.5×10^3	20	0.26×10^6	22.6×10^3	20
Guideway	1.8×10^6	114×10^3	50	3.3×10^6	240×10^3	50	1.3×10^6	90×10^3	50
Guideway auxiliaries	0.835×10^6	60×10^3	30	0.835×10^6	60×10^3	30	0.835×10^6	60×10^3	30
Stations	6.4×10^6	400×10^3	50	6.4×10^6	400×10^3	50	3.4×10^6	200×10^3	50
Total	9.34×10^6	600×10^3		11×10^6	743.5×10^3		5.8×10^6	373.6×10^3	
Operating									
Energy and power	26×10^3			26×10^3			43×10^3		
Guideway maintenance	48×10^3			48×10^3			22.6×10^3		
Automation train operation	$2{,}000 \times 10^3$			390×10^3			675×10^3		
Station operation	$1{,}000 \times 10^3$			307×10^3			60×10^3		
Yards and vehicle maintenance	328×10^3			328×10^3			52×10^3		
Total	3.4×10^6			1.1×10^6			0.853×10^6		

TABLE 5

COSTS OF UVS

Cost Item	Minibus			Minicar		
	Total	Annual	Life (years)	Total	Annual	Life (years)
Capital						
Vehicles	1.6×10^6	90×10^3	12	13×10^6	$1{,}550 \times 10^3$	12
Data devices	N. A.			0.066×10^6	7.9×10^3	12
Yards	0.499×10^6	32×10^3	50	N. A.		
Garage	N. A.			4.32×10^6	552×10^3	40
Total	2.1×10^6	1.2×10^5		17.4×10^6	2.1×10^6	
Operating						
Energy and power	172×10^3			1×10^6[a]		
Conduction of transportation	1.77×10^6			N. A.		
Information systems	N. A.			0.09×10^6		
Garage	47.8×10^3			0.95×10^6		
Total	1.99×10^6			2.04×10^6		

[a]These were calculated for gasoline engines. If a battery electric system were used, actual operating costs might be somewhat higher; the cost of the battery amortized over its expected cycle life becomes an operating expense to which must be added recharge costs. Other maintenance costs, however, may be considerably lower for the electrically powered system.

TABLE 6

ANNUAL OPERATING AND CAPITAL COSTS

System	Cost
Low-speed sidewalk, CPPS-1	5.21×10^5
Modular conveyor, CPPS-1	2.2×10^6
High-speed sidewalk, CPPS-2	2.1×10^6
Monorail, demand, NSS-1	4.0×10^6
Monorail, scheduled, NSS-2	1.84×10^6
Cable car, NSS-1	1.23×10^6
Minicar, UVS-1	4.14×10^6
Minibus, UVS-2	2.11×10^6

yards) trip time becomes rather long. It would require 20 min, for example, to travel a half-mile on such a system. Although one would gain time by walking on the moving sidewalk itself, it has been found that, in fact, not more than 30 percent of users actually do so in existing installations (4). Trip time and theoretical capacity for higher speed moving sidewalks are greatly improved, but effective capacity is still limited to that of their low-speed loading segments. The half-mile trip time for the other systems is on the order of 2 or 3 min. Moreover, the required width of the low-speed moving sidewalks necessitates, in practice, two parallel channels in each direction.

The rental minicar costs, which were the highest, reflect the large number of cars assumed for the system and other major uncertainties. Actually, there is no reliable method of evaluating the vehicle requirements in this case without further data on average trip and lengths of rental times for such a system. The vehicles, of course, are self-driven; thus, computer control and scheduling are difficult. However, the minicar system, because its vehicles are not constrained to a fixed route and guideway, can service a considerably larger area than can the guideway systems. For this same reason, its costs cannot realistically be compared with the others on a fixed-mileage route basis. In this case, the costs simply indicate the probable size of such a system to service an urban area with the indicated traffic density.

The conclusion can also be drawn from this paper that a small-vehicle personal transit system cannot adequately meet a 10,000-passenger-per-hour traffic load when operated in a demand mode, unless more than one guideway is available in the peak direction. Depending on the specific application, this might not necessarily mean two guideways in each direction; a total of three might suffice, with one being used in alternate directions at different peak hours, because peak loads tend to be in opposite directions in the morning and evening.

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