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FOREWORD

The papers contained in this RECORD gain added significance in the field of new system research because the language is not "this is what we propose" but "this is what happened when we did it" or "these are the actual results achieved." Instead of speculative and tentative estimates of possible outcomes, most of these papers contain substantial documentation and dissemination of research accomplishments. Although there is still a long way to go before new systems are routinely implemented and operated in many cities, some progress is nevertheless discernible.

Roos summarizes recent and current transportation conditions in urban public transportation and recommends some public priorities and transport service parameters necessary to improve urban mobility for all. Other papers discuss demand-actuated systems, systems for extended urban areas and major activity center systems, methods of evaluation of new system concepts, and large-scale implementation of complete new systems in contrast to the more conventional incremental approach toward innovative improvements.

The emphasis of these first papers sponsored by the Committee on New Transportation Systems and Technology concerns intrametropolitan transportation systems. Future work of the committee may include innovation in intercity public transportation as well.

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NEW SYSTEMS TECHNOLOGY AND TRANSPORT POLICY

Leon Monroe Cole, University of Texas at Austin

•"EQUALITY of opportunity for all" has been widely advocated as a fundamental goal that is essential to our society. In our modern world, this goal is directly related to the provision of relatively equal access to transportation for all residents in cities, towns, and rural areas.

After decades of dramatic economic and technological advances and a great increase in population, the mobility choices available to the great majority of the U. S. population remain remarkably limited. Within the more spatially compact cities of the early 1900s, for example, transport options of the city dweller included walking, bicycle, horseback, taxicab, streetcar, and the automobile. All of these modes were practical largely because destinations were relatively close to origins. There were more numerous and useful urban transport alternatives available in that era than there are today.

Families must have adequate mobility to allow them to commute to jobs, schools, shopping, and recreation. Today, urban mobility is almost synonymous with movement by private automobile. In the large majority of modern metropolises, persons without easy access to private automobiles are disadvantaged in a mobility sense and are thus impeded from a full participation in the society at large.

Private automobile ownership continues to increase, and more than one family in every four now owns more than one automobile. This kind of personal mobility is procured, however, at heavy and increasing private and social costs. Because there is no adequate, economic alternative for traveling around and within urban areas, many multicar owners are forced to bear the increasing burdens of insurance, licensing, taxes, and increased susceptibility to traffic accidents and fatalities. Automobile ownership requirements for urban living weighs especially heavily on the modest household budgets of the low- and moderate-income families. It is also a burden on the old and the young, who do not have ready access to automobiles or the disposable income for expensive modal substitutes such as taxicabs. In the typical middle-income urban household, moreover, the housewife must spend a disproportionate amount of her time each day as a chauffeur, driving her husband to the train or bus stop, her children to school, and herself to work or shopping or meetings.

The travel alternatives needed in suburbs and cities include the provision of public transportation services that can remove the burden of multicar ownership and required personal driving yet maintain approximately the convenience and flexibility in service that the private automobile provides. Just a few years ago, the prospects for such a practical alternative to the private automobile were not good. Conventional forms of bus or rail public transit simply were not feasible substitutes for automobiles in extended metropolitan areas.

More recently, however, stimulated in large part by converted federal efforts in research and development of new systems of urban transportation (1), several possibilities of new kinds of transportation services and systems are now available and are being explored for further development work. Each of these new concepts relies on advanced technology and management practices to decrease operating and capital costs of new systems, while improving service characteristics, in order to make them more nearly competitive with the private automobile in lower density, metropolitan areas characterized by diffuse travel patterns.

Sponsored by Committee on New Transportation Systems and Technology.

Concurrent with these welcome developments in new systems and concepts, reported on in part by the papers in this Record, another public policy trend may be developing—one that could prove just as pernicious as the near exclusive reliance on the automobile for metropolitan area travel. Stated simply, the trend seems characterized by the tendency to throw good money after bad, to follow established and disastrous procedures in providing public transit service rather than to attempt significant changes.

The nation now stands on the threshold of a new era in federal assistance to urban transportation. The Urban Mass Transportation Assistance Act of 1970 provides a truly substantial federal monetary commitment—$10 billion over a 12-year period for broad assistance to urban mass transportation programs. The danger is that the great bulk of the new money will be used to salvage, prop up, subsidize, and reinforce the conventional transit modus operandi—to furnish a 1900 style of transit service for 1970 style of cities.

Because of individual and institutional inertial, the chances of success of the innovative over the conventional approaches to public transit services are not good, even though as amply shown by the papers in this Record many new systems and technologies are now available and ready for preliminary implementation in cities.

It seems exceedingly important, therefore, for policy-makers at all levels of government to avoid the comfortable, conventional ways of furnishing inferior public transportation services at high cost to the public purse. They should instead take a firm grasp on their fear of failure and their uneasiness with the unknown and attempt reasonable new approaches and services for the developing urban public travel markets in the coming decades.

These contentions are supported by a short synthesis of the recent and current status of urban transportation and by general estimates of future needs, priorities, and trends provided in the following paragraphs. As with most synopses, this one does not presume to be complete and comprehensive. It may, however, help to establish a useful context for the subsequent papers.

URBAN TRANSPORTATION IN PERSPECTIVE

An important fact that should not be overlooked is that the historical trend toward increased use of the automobile, a long-established phenomenon that has revolutionized all transportation in the United States, is continuing. The number of people per automobile in the nation has declined from 5.3 in 1930 to 2.5 in 1965 and no doubt will drop to about 1.8 in 1975. The number of people per licensed driver has declined from more than 3 in 1930 to fewer than 2 in 1965 and probably will drop to 1.5 in 1975.

In spite of the mounting real costs of automobile ownership and operation, the basic costs per mile remain low enough to compete favorably with conventional public transportation costs, even excluding the benefits of convenience, comfort, and flexibility of service that the automobile provides. To attempt to meet such a proven, formidable competitor as the automobile with more of the same inferior conventional public transit service in modern cities seems to be the height or depth of futility and a waste of resources.

Recent and current economic, social, and spatial urbanization patterns tend strongly to favor and reinforce the automobile as the preferred mode of travel. Familiarity of these travel patterns and demand characteristics is essential if markets for new systems and services of public transportation are to be developed and exploited in the public interest.

Metropolitan Area Travel Patterns

Present demands for metropolitan area travel exhibit large variations both over time and among locations within the urban area. Trips related to the old city center or the central business district of a metropolitan area, for example, account for a small portion of total daily travel in metropolitan areas. Yet most current systems of conventional public transit are designed to serve, almost exclusively, these centrally oriented kinds of trips.

The great majority of metropolitan trips have widely scattered origins and destinations, and growing proportions of travel activity are in the suburban areas. Short trips predominate; about half are less than 2.5 miles in length in most cities. The problems of urban center congestion and commuter flows into and out of centers have focused much of the traditional urban transportation debate on urban freeways, i.e., the development of rail or bus rapid transit alternatives for dealing with activity center circulation and corridor movements. Although the problems generated by the geographic and temporal concentration of the journey to work are important, they constitute only a part of the total urban transportation problem today.

The very uneven spread over space and time of urban transportation demands gives rise to several public transit problems. Urban transportation services, except to a very limited extent, cannot be stored or inventoried as can other utilities such as water supply. Over time, capacity imbalances that favor one area over another contribute to shifts of activity from poorly served areas to better served ones; this fact has contributed in part to the relative economic decline of central business districts in recent years.

Travel to the CBD is an important, if perhaps exaggerated, dimension of urban transportation demand. As stated previously, however, trips to the CBD are a relatively small and declining proportion of total metropolitan area travel. Cordon counts of trips entering a CBD often include both trips that have destinations in the CBD and trips that are simply passing through the CBD. For years, traffic engineers have been insisting that adequate bypass or inner belt highways could eliminate a large proportion of the persons, and an even larger proportion of the vehicles, entering the CBD. Data collected in the late 1950s confirmed much of that appraisal. The data indicate, for example, that of all vehicles entering the CBD those merely passing through represented 62 percent of the total in St. Louis, 67 percent in Philadelphia, and an average of 55 percent in 67 cities polled by the then Bureau of Public Roads (2).

Trends Toward Diffusion of Demand

In the future, travel to the CBD is expected to continue to increase. The increase will occur at substantially slower rates than will the increase in trips wholly between other parts of the urban region. The massive relocation of homes and jobs to suburban areas has created metropolitan areas less and less dependent on one major downtown for centralized activities and functions. Not only are residences, work places, and commerce widely scattered throughout a lower density urbanized matrix, but, as these areas mature, smaller, dispersed centers are forming to take the place of many former CBD functions. In some cases even these suburban activity concentrations are beginning to show some of the signs of congestion and decline common to the CBD.

Volumes of travel between most suburban origin and destination pairs tend to be low because the diffusion of activities throughout wide areas has increased the number and location of both. High-capacity, fixed-route systems of public transportation have been losing their relevancy for many applications because of this diffusion.

The observation, however, that in the foreseeable future the chief growth in the demand for transportation will be for trips between points outside central cities (where the bulk of employment and residential growth will occur) does not necessarily lead to the conclusion that better transportation service between central cities and suburbs, or even within central cities, is unimportant. On the contrary, the demand for such service may increase in some areas because of the changing composition of employment, the growing number of central city office jobs in great metropolitan centers, the middle-class flight to the suburbs, and the growth outside central cities of job opportunities for lower income central city residents. Such changes in the composition of jobs and residents can increase the demand for transportation between central city and suburb even if overall central city employment and population are relatively unchanged. Thus the quality of transportation, which is especially poor for some groups, is a distinct matter of concern. In particular, the concentration of the poor (characterized by low education and skills) in older core areas has been occurring at the same time that job opportunities have been relocated to suburban locations, and this is one of the more serious contemporary urban transportation problems.

Demand Variations Over Time

Urban travel volumes, of course, show marked variations with time of day. Demand peaks occur twice daily, reflecting the influence of work trips in the early morning and return trips to home in the late afternoon.

If all trip purposes and travel modes are considered, roughly 45 percent of all trips in large urban areas occur during the 6 hours of peak demand—6 to 9 a.m. and 3 to 6 p.m. Usually about 10 percent of all daily person trips take place during a single peak hour from 5 to 6 p.m. The peak of travel in the morning is twice the average hourly travel; in the evening rush hour, it is 2.5 times the average. The pronounced number of work trips centering on the CBD causes a higher degree of peaking to occur there than in a predominantly residential suburb where work trips are a smaller share of the daily total.

Public transportation shows even more pronounced peaking than does travel by private automobiles; as much as 25 percent of traffic is accommodated by this mode in the peak hour. The higher peaking of transit usage places strains on capacity during the rush hour, and excess capacity occurs at other times of the day. The same phenomenon is, of course, seen in street and freeway traffic, leading to serious peak-hour capacity problems as well as off-peak underutilization.

Decline of Demand for Conventional Transit Services

Recently, ridership on conventional transit has been restricted increasingly to travel between work and home. This growing specialization in heavily peaked work trips, together with the steady outward trend of urban employment locations and decreasing residential densities, is the basis of many of the financial problems of conventional transit. In serving decreasingly relevant functions, transit has shown steadily worsening trends of patronage and profits reflected by statistics that threaten to go off the bottom of the charts. These curves, of course, have been interpreted in highway studies to support the highway construction programs, on the theory that fewer and fewer persons want public transportation (3).

Studies of user demand for travel and user preferences for travel modes have concentrated on the effects of elements such as relative speeds; purposes of trips; household-income levels; and linkages of residences to places of work, shopping, recreation, and other destinations. Gravity models and other quasi-scientific devices are used to project relationships between origins and destinations and the average length of trips. The latter is an important consideration because the average length of trip is a major determinant of the amount of transportation facilities required.

Gravity models and variants thereof depend on assumptions of free-flowing transportation. Projections based on gravity models tend to be self-fulfilling in that transportation facilities created in growing metropolitan areas themselves tend to generate traffic. At least one checkup on traffic projections, however, suggests that conventional projections of travel demand might be a dubious base for determining investment in urban transportation facilities. References to projections made by the Washington, D.C., area mass transportation study in 1957 of volume of travel into the District show that in 1965 the variable associated with an increase in travel demand, including suburban population and downtown employment, had increased substantially over projected levels. However, travel across District lines had fallen short of projections by approximately 25 percent.

Several things had happened to throw the projections off. The principal factor was that certain highways, projected in 1957 to be completed by 1965, actually had not been completed. In their absence, alternative utility locational patterns and travel linkages emerged, and the average length of trip was considerably below that projected in 1957. There is no reason to believe that the region was any worse off in 1965 regarding income and productivity, employment growth, or even travel congestion than it would have been if all highways projected for completion by 1965 had in fact been completed.

State highway departments and the federal agencies have until relatively recently paid little attention to the special design problems of urban transportation (this situation is changing) and have tended to adhere to the principle of building as cheaply as possible regardless of social costs imposed on urban communities at large. There seems to have been an assumption that, because nearly everybody of consequence owns an automobile, there is a single-minded public devotion to perpetual construction of highways.

Growing public appreciation of the social costs imposed by past policies of highway design and construction (particularly damages to existing neighborhoods and aesthetic values) and growing public protests can, however, be expected to hasten the change in attitude already under way among highway administrators and concerned public officials.

As yet, however, forms of public transportation relevant to the characteristics of modern urban travel demands simply have not been developed, and their absence leaves a significant gap in the alternatives available for urban mobility. New departures need to be sought that will serve the fundamental characteristics of widely dispersed origins and destinations, predominantly short trips, and individual or small group service.

NEW TRANSPORTATION SYSTEMS FOR URBAN MOBILITY: SERVICE REQUIREMENTS

The intraurban transportation problems of each metropolitan area are likely to be peculiar to that area. The problems derive from the area's size, density, growth rates and trends, configuration, topography, composition of employment and other constellations of activity, income levels, existing transportation systems, organizational and political structure, and the quality of planning and community leadership. (Important distinctions exist not only among metropolitan areas but also among kinds of transportation services.) Urban transportation problems, therefore, cannot be discussed as though they were solely a choice between private automobiles and conventional public transportation, or some sort of combination of only those two types of services.

One important distinction, for example, is between small cities (500,000 population or less) and large metropolitan centers. The small cities see their main problem as one of providing adequate road space and parking facilities. This much of the problem, for most small cities, is quite manageable if the cities remain small. The principal deficiencies in such cities are likely to affect those citizens who cannot drive or afford to own private automobiles. In small cities, public transportation is now usually limited to school trips and work trips to the center.

The characteristics of conventional transit and rail commutation systems make it difficult for these systems to carry people from highly concentrated residential areas in older city cores to highly dispersed job locations in the suburbs. Even where public transit is available, this service is frequently costly in both time and money. Thus conventional transit may require a 2-hour journey each way from the Watts section of Los Angeles to major employment centers in the metropolitan area; in Pittsburgh it may take 2 hours from the Hill district, a low-income black residential area, to O'Hare Township Industrial Park, a rapidly developing industrial area (the trip by automobile takes 20 min).

Although this sort of dilemma is classified as a transportation deficiency, the primary solution in the long run should take the form of either moving jobs closer to people or making it possible for people to move closer to jobs. As things now stand, locating any large number of new jobs suitable for low-skilled people in or near ghetto areas is likely to be costly and impracticable. The second solution is currently blocked by suburban barriers against blacks, other minority groups, and the poor in general.

Many situations that appear to be solely transportation deficiencies may be resolved by nontransportation measures. Where such alternatives exist, transportation solutions may be more costly; in some cases they should be regarded only as temporary expedients. One of the most common examples is the separation of central-city ghettos from the suburban-located industrial jobs that ghetto residents might perform.

Many of the problems that now appear so formidable may well be solved in the future by the battery of antipoverty and related measures designed to raise the productivity and cultural status of currently disadvantaged groups. This suggests that public transportation solutions, perhaps, should be regarded as temporary and ameliorative. Moreover, the solution to some urban transportation problems may lie in changing the conditions and controls under which different modes operate rather than in creating new technology alone.

Private vehicles, given the considerable improvements that are possible with continued development effort, will probably be the major service for urban mobility for years to come. However, a failure of public transportation to provide a full range of services in the future will deprive much of the population of mobility and choice if trends such as those previously described are allowed to continue unchanged.

The forms of future public transportation that are needed are not, however, merely refinements of the narrowly conceived functions of rail rapid transit or express bus service for commuters or minimal local bus service for the elderly and indigent who lack resources or capabilities for choice. The potential for meeting a great many of the needs for urban transportation services by new kinds of public services does exist. These means may be at hand for providing such services through functional innovation and application of advanced technology in new systems concepts.

The requirements for new transportation services are based not only on the anticipated changes in urban travel demand characteristics, but also on a recognition of the fundamental changes that are occurring within urban society as a result of rising personal incomes, shifts in economic emphasis from goods to services, social and psychological attitudes, government financing and taxing policies, and many other dynamic variables. Thus, there should be an emphasis on service and performance characteristics, such as convenience, comfort, cost, and travel time, in programs for new public transportation services.

Adequacy and ubiquity of coverage for needed services are the first concerns in developing new transportation systems. Ideally, a set of new urban transportation systems should complement one another, as well as the existing transportation modes, in providing mobility for all urban dwellers. Combinations and variations of the same basic kinds of systems might serve all cities—present and future—regardless of size, arrangement, and other characteristics. The combined systems could provide service between all origins and destinations within urban areas.

Automobiles, buses, taxis, and rail transit systems perform many services well, and they will undoubtedly be improved by the application of existing technology and by evolutionary technical advances. It is not reasonable to expect that new future systems will replace all existing systems. Instead, the priorities for new systems should be to provide (a) service where none is currently available, (b) better service where present service is deficient, and (c) new alternatives for those who are adequately served today but who will require improved services in the future.

Of many possible new system developments that could help meet these priorities in the near future, the following three general system examples constitute a representative cross section. The type of service that each provides is described briefly. More detailed research is reported on in subsequent papers in this volume.

Demand-Actuated System

Demand-actuated public transit systems (4) have routes and schedules that are both flexible and ubiquitous. The dial-a-bus or dial-a-ride is a hybrid between an ordinary bus and a taxi. It picks up passengers at their doors or at a nearby bus stop shortly after they have telephoned for service. A central computer, part of the system for monitoring the location of each vehicle, keeps track of the location of the vehicles, the passenger loads, and the destinations. It selects the right vehicle and dispatches it to the caller according to an established optimal routing program. Thus, the system readily links many origins to many destinations. The diffused pattern of trip origins and destinations that this system most readily serves is dominant in low-density suburbs.

The cost of a taxi ride can be reduced by sharing the ride, and basically the dial-a-bus system is designed to accomplish this reduction. Data suggest that, depending on demand, door-to-door transit can serve its passengers almost as fast as a private taxi but at one-quarter to one-half the price and at only slightly more than the fare for a conventional bus.

A major point is that the dial-a-bus might do what no other transit system now does—accommodate door-to-door travel demand at the time of the demand. This means that the system would attract more off-peak business than does conventional transit. If it does attract enough passengers, the off-peak revenue would help dial-a-bus avoid the same financial problems of conventional transit, which is used heavily only 3 or 4 hours per day. It could also help reduce dependence on automobiles, particularly the second car in urban households.

The report by Stevens and Bacalis on modification of such services in a new town and case study reports by Gustafson, Curd, and Golob on economic analyses and user preferences for such demand-actuated systems discuss most informatively the future practicality of demand-actuated systems. Potential demand for similar kinds of service in Canada is discussed by Archer and Shortreed.

Extended Area Systems

Extended area systems consist of small vehicles, each carrying about the same number of persons as an automobile. These vehicles travel over an exclusive right-of-way or guideway network, either routed over a standard network or automatically routed individually from origin to destination at network stations.

"Personal rapid transit" would provide travelers the important advantages of minimum waiting time at the origin station and private, secure accommodations. At the heart of the concept is the premise that personal transit would serve a metropolis, except perhaps for its lowest density outskirts, with a network or grid of transit lines, each perhaps a mile or two apart. This would provide accessibility and service to the profusion of origins and destinations in metropolitan areas by being more responsive to the requirements of varying population densities and future land-use patterns.

Basic issues concerning the feasibility of personal rapid transit systems, as for all new systems, are not limited merely to technological ones; they include the questions of cost and safety as well. These questions cannot be answered with absolute precision at this time, but indications are that personal rapid transit can be many times safer than the private automobile and yet cost no more than modern transit systems proposed in areas of low- to medium-volume travel demands.

The case of personal rapid transit is advocated in the paper by Sobey and Cone, and an analysis of a particular system of dual-mode transport is presented by Fichter.

Major Activity Center Systems

In all major activity centers—such as a large shopping district, a new community, an airport, an exhibition area, an industrial park, universities, or other places where large numbers of people congregate in a limited space—the movement of people and goods is today noticeably inadequate. There are several types of automated circulation systems that offer the potential for moving large numbers of people over short trips in a relatively small area. They are capable of doing so safely, comfortably, economically, and with a minimum of waiting. Because modal separation is imperative under the congested conditions of travel in activity centers, such systems must nearly always operate on some kind of exclusive guideway.

Three principal types of automated circulation systems are moving belts, "capsule transit," and network cab transit. Horizontal conveyor belts have been in use for a long time. Although they have many advantages—such as low cost, no waiting, and no operators—these belts move slowly. Capsule transit systems involve small cars or individual capsules propelled by belts or rollers or cables. Network cab transit also uses individual cars or automatically controlled capsules.

Major activity center circulation systems concepts and technologies are discussed in the papers by Stern and Maund, and Harmathy describes a novel automatic circulation system.

Finally, methods for preliminary evaluation of proposed new urban transportation systems are presented by Ayres, McKenna, and Walker. Hamilton argues for more rapid implementation of large-scale dual-mode systems rather than for continuation of the more generally assumed incremental, less capital intensive approach to provisions of new systems and technologies.

CONCLUSION

The papers contained in this Record and research on similar topics reported elsewhere make it abundantly clear that the necessary technologies and skills for these systems, or variants thereof, already exist. Much more work needs to be done, however, before the benefits of these new systems and transport service concepts can be realized in local communities.

As with any new undertaking, departures from previous tradition, especially in a tradition-minded field such as public transit, entails considerable unknowns and even risks. Relatively large public and private investments, even for dial-a-ride systems, must be made. In such instances, risk-sharing seems reasonable, and to most people the logical agency to support such risks is the federal government. An increased federal effort and a neutralized policy that does not simply put more dollars into old ratholes but stimulates innovative experiment and testing and demonstration are greatly needed if a range of urban mobility services is to be provided that is in accord with the needs of the people and the capabilities of this nation.

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TRANSPORTATION FOR A NEW TOWN

Robert D. Stevens and George J. Bacalis, The Bendix Corporation

Columbia, Maryland, is a new town currently under construction in the Baltimore-Washington corridor. The transportation system for this town includes a street network, a pathway network, and a proposed innovative transit system. The transit system design evolved from a systematic study of Columbia's needs versus available technology. Transit ridership was forecast for several alternate transit configurations involving various sizes of buses and various new types of transit systems. Scheduled and demand-actuated methods of operating were examined. The alternate transit configurations were evaluated from a number of standpoints including service provided, riders attracted, capital costs, operating costs, and financial feasibility. The recommended transit system would consist of 300 six-passenger vehicles operating automatically on 17 miles of two-way exclusive right-of-way and ten 25-passenger buses operating as a feeder service to the automatic system. A majority of the trip origins and destinations in Columbia would be within a 3-min walk of one of the 46 stations on the exclusive right-of-way. The system would attract around 17 percent of the trips and is financially feasible.

•NEW TOWNS, when properly planned, can offer an attractive alternative to the all too common metropolitan blights of urban sprawl, minority ghettos, and unimaginative "bedroom" suburbs. The new-town concept differs from the conventional suburban subdivision in that it contains all the ingredients for a full life (homes, jobs, stores, schools, churches, recreation, and other institutional facilities) in a convenient and rational relationship. One of the most powerful tools that the urban planner can use to achieve these new-town objectives is a well-planned, integrated transportation system around which the land-use plan is developed in a logical manner.

One example of such a new town is Columbia, Maryland, now under construction in the Baltimore-Washington corridor. By 1980, this new town will have a population of more than 100,000 and will occupy more than 25 sq miles, an area slightly larger than that of Manhattan.

Every effort has been made to ensure that the various attributes that many communities lack will be provided in Columbia. Columbia is being built according to a downtown-village-neighborhood hierarchical plan. Downtown will be surrounded by villages of 10,000 to 15,000 persons and various employment centers. Each village in turn will be made up of neighborhoods housing 1,500 to 2,000 people. Approximately 20 percent of the land will remain open land as pathways, parks, woods, common areas, and bodies of water.

Integrated into the land-use plan is a transportation system that includes three parts: (a) street network, (b) pathway network, and (c) transit network. The street network consists of freeways, parkways, village roads, neighborhood roads, and local cul-de-sac streets. The pathway network is designed to separate pedestrians from vehicular traffic. Each neighborhood will have a pathway system that connects it to the village center and in turn to downtown. The transit right-of-way is integrated into the land-use plan such that 40 percent of the ultimate population will be within a 3-min walk of the right-of-way.

Sponsored by Committee on New Transportation Systems and Technology and presented at the 50th Annual Meeting.

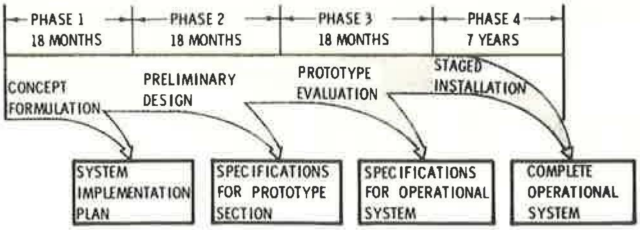

Figure 1. Columbia Transit Program.

This paper describes the approach and the results of a study to plan a transit system for Columbia. The study was conducted for Columbia under a U. S. Department of Transportation funded technical grant and was designated the Columbia Transit Program.

The Columbia Transit Program is divided into four phases as shown in Figure 1. Phase one, the concept formulation phase, used the systems approach that included the six tasks shown in Figure 2. The sections that follow describe each step of the process and the results.

PROBLEM DEFINITION

Problem definition included the following activities: (a) documentation of the broad urban objectives of the developer, (b) identification of the transportation implications of these objectives in terms of system development goals, (c) establishment of the constraints within which the transit system must be developed, and (d) development of the evaluation criteria for each system development goal.

The broad urban objectives for Columbia were sorted into transportation and non-transportation related areas. The transportation goals then led to the following two basic mobility goals: (a) provide mobility for those who are substantially dependent on public transportation and (b) provide a choice of travel mode for those in a position to choose between public and private transportation. The latter goal led to 11 detailed mobility goals. The mobility goals then led to the system goals, which were grouped in four areas: (a) technological, (b) aesthetic, (c) environmental, and (d) economics.

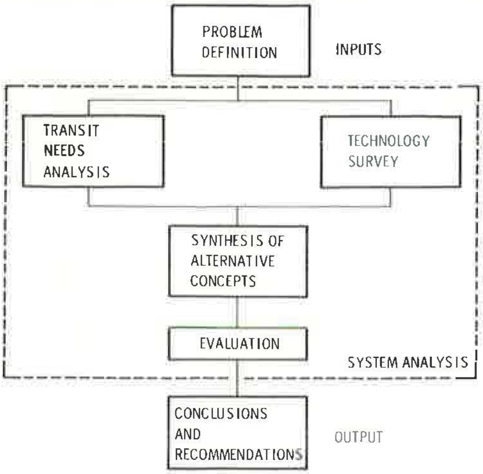

Figure 2. Systems-oriented approach to concept formulation.

The technological goals for the system, for example, included the following:

1. Eliminate or minimize potential interference among classes of movement, i. e., provide a separate transit right-of-way with grade separations at intersections with major roads;
2. Have a potential for growth, i. e., do not allow incremental or major extensions to the system either to give rise to disproportionate cost increases or to disrupt the operation of existing parts of the system;
3. Have a high level of safety and security where safety refers to the avoidance of collision or other events resulting in accidental damage to people or property and security refers to measures to avoid vandalism or malicious damage to people or property;
4. Provide a high level of service with respect to items such as routes, frequency of service, hours during which service is provided, and interfaces with external systems

at a modest user-perceived cost and at a reasonable capital cost; and
5. Be conveniently accessible to the population.

Problem definition also resulted in a statement of constraints or limits within which the Columbia transit system must be designed and operated. These are boundary conditions that cannot easily be relaxed or altered. The classification highlighted the cognizant agency for each constraint and the probable nature of the interaction. The constraints were identified in four categories: (a) legal, (b) economic, (c) right-of-way and land use, and (d) other. The "other" category included constraints such as a system implementation schedule that is consistent with Columbia's development plan and one that is of the right scale for Columbia.

Evaluation criteria were developed for each of the expanded objectives. Where feasible, these criteria were defined to permit quantitative evaluation using analytical techniques. For those criteria that did not lend themselves to analytical evaluation, arbitrary, but semiquantitative, evaluation techniques were developed. The latter included checklists and rankings on arbitrary numerical scales by a review board.

TRANSIT NEEDS ANALYSIS

The basic output of the transit needs analysis was a demand model. Because Columbia is a new town, it was not possible to follow the usual transportation planning approach of calibrating travel forecasting models based on existing travel patterns. For Columbia, travel demand had to be forecast for activities and people that did not exist.

Figure 3 shows the steps used to project passenger demand for Columbia. A classification rate analysis was used to estimate trip generation. Trip distribution was based on a gravity model, and K-factors were introduced to take into account an anticipated tendency of Columbia's residents to interact more frequently within Columbia than would normally be predicted by the gravity model. Because the pathway network would provide for walking in Columbia, walk trips were included in trip generation and trip distribution. The initial modal-preference model separated walk trips from vehicle trips. The person-vehicle trips were then factored to obtain peak-hour person-vehicle trips.

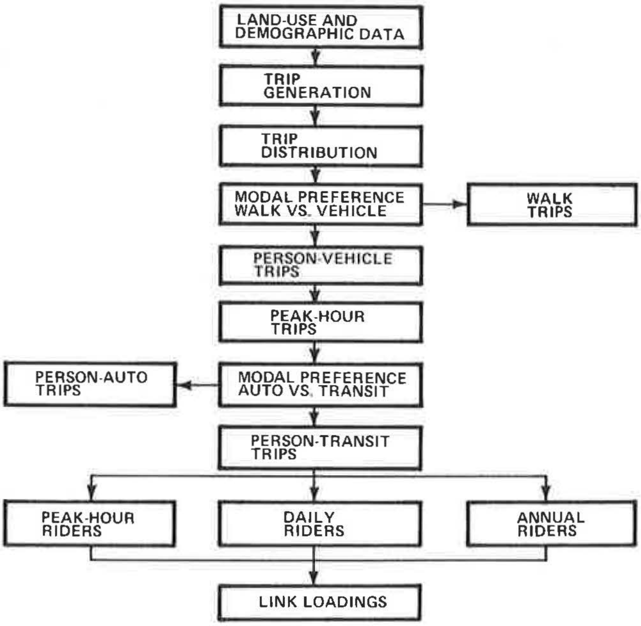

Figure 3. Projection of passenger demand.

The second modal-preference model was for automobile versus transit trips in the peak hour. This model took the form of diversion curves based on door-to-door travel-time ratios, cost ratios, and service or excess travel-time ratios for transit as compared to automobile. Person-transit trips could then be determined for the selected transit system configurations as a function of their characteristics. The number of peak-hour riders was converted to the number of daily and annual riders by applying appropriate factors. The daily factor was 90 percent of the peak-hour percentage, and the annual factor was based on Saturday and Sunday obtaining 50 and 25 percent respectively of the weekday riders.

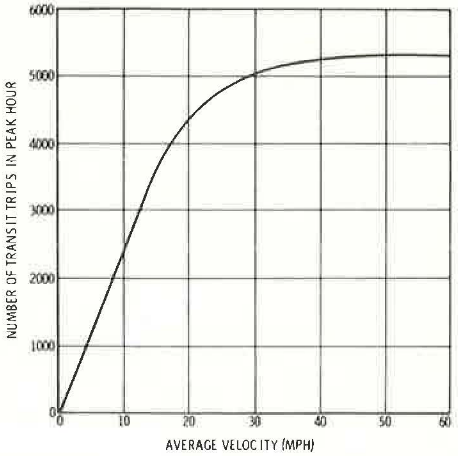

Figure 4. Primary system demand variation with velocity.

Generally the demand forecasts were obtained in parametric form for a range of system physical and operating characteristics. Sensitivity analyses were made for a range of fares, headways, and speeds. A typical demand curve for a personal, demand-responsive, automatic transit system on an exclusive right-of-way is shown in Figure 4. This curve is based on selected fare and headway levels and was used to assist in making a trade-off on vehicle speed versus number of vehicles.

TECHNOLOGY SURVEY

A survey was made to identify a complete spectrum of transportation systems. The resulting tabulations of physical characteristics, performance, availability, and cost were used in the synthesis task.

CONCEPTS SYNTHESIS

The concepts synthesis task identified two concepts and six systems. The two concepts were concept guideway and concept roadway. Concept guideway would provide completely automatic, nonstop, station-of-origin to station-of-destination service via six-passenger vehicles operating on a guideway built on 17 miles of exclusive right-of-way shown in Figure 5. All portions of the guideway are for two-way service. Forty-six stations are provided. Figure 6 shows a possible vehicle and guideway integrated into Columbia. The vehicle would offer privacy and comfort at least equivalent to that of an automobile. Concept roadway would provide transit service via buses on a paved, exclusive right-of-way shown in Figure 5.

Six transit-related systems were identified in concepts synthesis. These included the primary, feeder, operations and maintenance central facility, downtown distribution, transportation center, and regional bus systems.

TABLE 1

ALTERNATE CONFIGURATIONS

System	Guideway			Roadway				
	I	II	III	I	II	III	IV	V
Primary	X	X	X	X	X	X	X	X
Feeder	X		X	X		X	X	X
Operation and maintenance central facility	X	X	X	X	X	X	X	X
Downtown distribution	X	X		X	X	X		
Transportation center	X	X		X	X	X		
Regional bus	X	X		X	X	X		

Within the two concepts, eight alternate configurations were developed. The eight configurations were derived by combining the six systems previously listed in various combinations with various levels of service. The resulting eight configurations included three under concept guideway and five under concept roadway. Table 1 gives the systems included in each configuration, and Table 2 gives the service factors for the

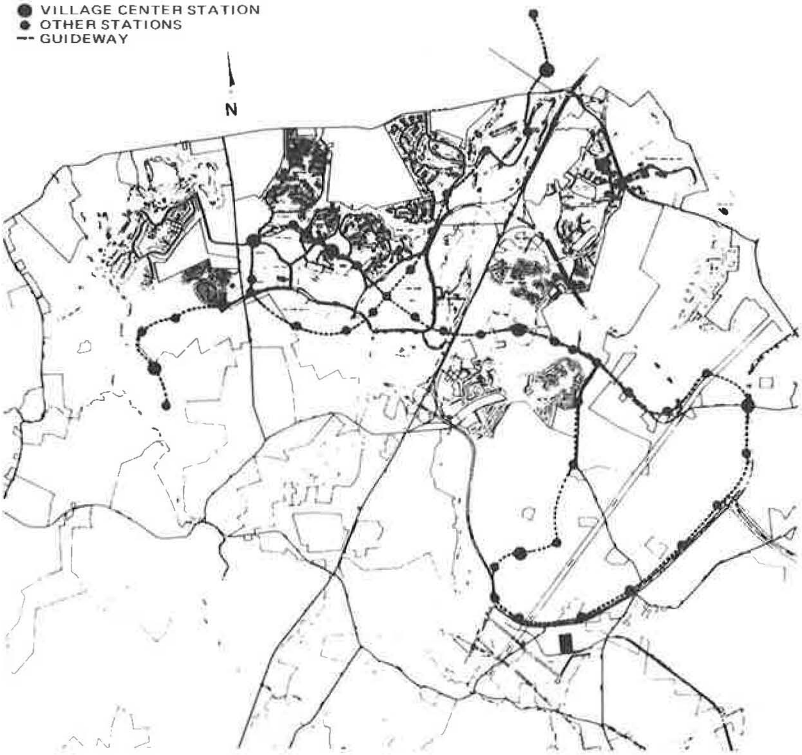

Figure 5. Location of transit right-of-way and stations.

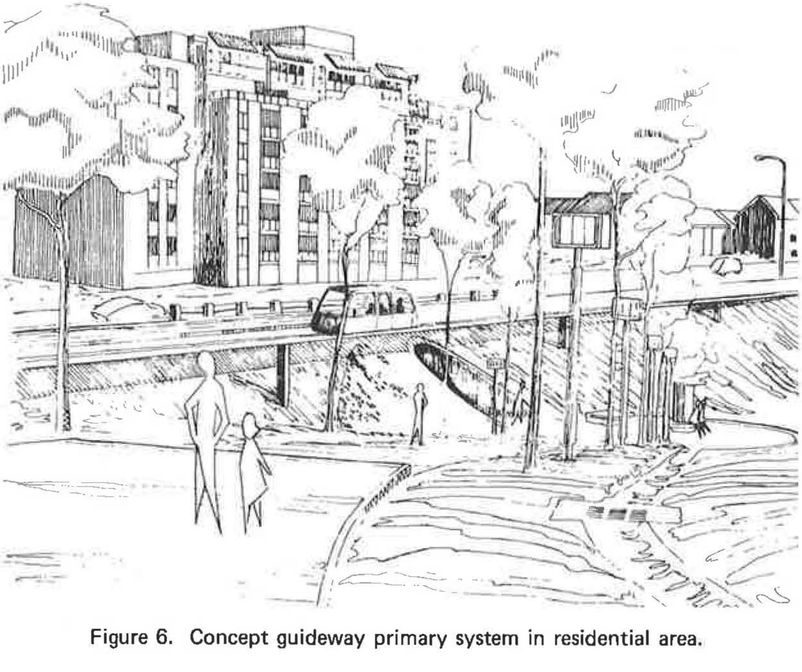

Figure 6. Concept guideway primary system in residential area.

TABLE 2

SUMMARY OF SYSTEM PARAMETERS

Configuration	System	Density of Area Served	Days per Week	Service (hr/day)	Peak-Hour Headway (min)	Average Vehicle Speed (mph)	Number of Vehicles	Vehicle Capacity (seated passengers)	1985 Riders per Day
Guideway I	Primary	High	7	24	2	35	470	6	40,370
	Comp. feeder	Low	7	18	18	15	21	15	11,220
	Total	All Columbia					491		40,370
Guideway II	Primary	High	7	24	2	35	310	6	29,150
Guideway III	Primary	High	7	24	2	35	320	6	30,100
	Nominal feeder	Low	6	12	90	15	10	25	950
	Total	All Columbia					330		30,100
Roadway I	Primary	High	7	24	9	15	19	50	17,870[a]
	Comp. feeder	Low	7	18	18	15	45	15	9,580[a]
	Total	All Columbia					64		27,450
Roadway II	Primary	High	7	24	9	15	19	50	17,870
Roadway III	Demand bus	All Columbia	7	22	10	15	78	15	30,170
Roadway IV	Primary	High	7	24	9	15	19	50	18,620
	Nominal feeder	Low	6	12	90	15	10	25	750
	Total	All Columbia					29		18,620
Roadway V	Nominal single	All Columbia	6	12	90	15	17	25/50	1,360

[a] This is the only case where riders on primary and feeder systems are additive.

primary and feeder systems of each configuration and also gives other system parameters including operational, equipment, and ridership characteristics.

EVALUATION

The objectives of the evaluation task were to rank the eight system configurations and to apply a financial filter to eliminate any configurations whose cost exceeded available resources. The ranking was accomplished by assessing each configuration in terms of each of the evaluation criteria developed in the problem definition task. By a process of weighted averages, ratings for each individual criterion were combined to establish a single overall figure of merit for each configuration.

To accomplish this assessment, it was necessary to describe each configuration in at least generic terms. To do this, various types of hardware were examined. By using the automatic system as an example, the proprietary candidates identified in the technology survey task were evaluated, and the number of candidates was reduced to 15. Each of these 15 surviving candidate systems would meet the established system requirements, although modifications would be required in some cases.

After defining the generic hardware, it was possible to perform a financial analysis for each configuration. Capital, operating, and maintenance costs were estimated for each configuration, and a 20-year financial analysis was made. Some results of the financial analysis are given in Table 3.

The financial analysis indicated that concept guideway has higher capital costs than concept roadway. It also has positive net cash flow versus negative net cash flow for concept roadway. Guideway, with its more extensive capital requirements primarily for automation, results in a system that requires a minimum number of operating personnel. Roadway, on the other hand, with its manually operated vehicles, has less capital investment but more operating personnel requirements. All three guideway configurations yield net cash flows for debt service. The roadway configurations do not. The most financially attractive guideway configuration is Guideway III. Guideway III, under conventional financing assumptions, requires support of 69 percent of the total capital and land costs and is estimated to cost $34.5 million.

As a result of applying the financial filter and completing the evaluation of the economic objectives, five configurations were eliminated as exceeding probable available

TABLE 3

SUMMARY OF FINANCIAL ANALYSIS

Configuration	Cost			Annual Revenue and Cost at Full Development		Capital Support Required, Including Land (percent)	Total Support Required During Development Period		Peak Cumulative Capital and Operating Cash Required	
	Capital	Land	Total	Revenue	Operation and Maintenance Costs		Operating	Capital	Year	Amount
Guideway I	36,827.6	4,295.0	41,122.6	2,542.0	2,439.3	88	5,742.4	41,832.0	1983	42,180.6
Guideway II	33,893.0	4,295.0	38,188.0	1,916.4	1,360.0	78	667.0	30,541.4	1979	32,947.8
Guideway III	30,221.0	4,295.0	34,516.0	1,476.7	622.1	69	33.8	23,993.9	1977	26,446.6
Roadway I	12,416.2	4,295.0	16,711.2	1,887.0	3,663.9	74	23,352.3	35,768.5	1985	35,768.5
Roadway II	9,852.7	4,295.0	14,147.7	1,397.7	1,708.9	70	6,852.1	16,704.8	1985	16,704.8
Roadway III	13,667.3	4,295.0	17,962.3	2,022.7	6,464.2	76	36,640.8	50,308.1	1985	50,308.1
Roadway IV	7,033.2	4,295.0	11,328.2	947.8	1,028.9	62	3,850.2	10,883.4	1985	10,863.4
Roadway V	2,228.6	–	2,228.6	66.2	244.4	100	2,183.4	4,414.0	1985	4,414.0

Note: Amounts are in thousands of 1970 dollars.

TABLE 4

SUMMARY OF ALTERNATE CONFIGURATIONS

Configuration	Vehicle Concept		Service Concept		Capital Cost (millions of dollars)	Capital Required (percent)	Net Revenue	Technical Risk	Ridership	
	Primary Right-of-Way	Low-Density Areas	Primary Right-of-Way	Low-Density Areas					Daily Trips	Relative (percent)
Guideway III	6-passenger automated	25-passenger bus	Nonstop, personal operation	90-min headway	34.5	53 to 69[a]	Sufficient to amortize 31 to 47 percent of capital cost	Significant	30,100	100
Roadway IV	50-passenger bus	25-passenger bus	90-min headway	90-min headway	11.3	62	Sustained annual deficit of $81,000	Minimal	18,620	62
Roadway V	50-passenger bus[b]	25-passenger bus	90-min headway	90-min headway	2.2	100	Sustained annual deficit of $178,200	Minimal	1,360	4.5

[a] Percentage of capital required depends on financing.

[b] Does not use right-of-way.

resources. The ranking of the remaining three configurations in order of goal satisfaction was Guideway III, Roadway IV, and Roadway V. Some of the characteristics of these three configurations are given in Table 4.

CONCLUSIONS

Of the three selected configurations, Guideway III is the top-rated candidate for further evaluation and consideration in the next phase of the program. Guideway III would be characterized by about 300 six-passenger vehicles operating automatically on demand on an exclusive right-of-way and ten 25-passenger buses operating as feeder service in the lower density areas. It would accommodate approximately 17 percent of the daily trips. Forty percent of the residential population, most of the retail, commercial, and institutional activities, and the entrances to the major industrial areas would be within a 3-min walk of the right-of-way.

Guideway III provides the highest level of service, attracts the highest number of riders, provides the only positive net cash flow, requires the lowest percentage of capital support, starts to pay for itself the earliest, requires the lowest operating support, and in general would provide a unique transit system for Columbia. However, Guideway III has the highest capital cost and the highest technical risk of the three selected configurations. It requires development of a relatively sophisticated control system. Additional development risks are involved because such an operational system has never been built.

By comparison, Roadway V provides the lowest level of service, attracts the lowest number of riders, operates at a deficit, and in general would provide a minimum level of service and a conventional type of transit system for Columbia. It is also the most economical roadway configuration and would offer low technical and development risk because of its conventional characteristics. Roadway V, however, does not satisfy the program goal of offering a realistic modal choice to noncaptive riders because of the low level of service provided. Therefore, it is not considered a viable alternative unless financing is unavailable for a more costly configuration.

Roadway IV, the next most economical roadway configuration, was selected as the preferred roadway configuration. Roadway IV would provide Columbia with a conventional bus transit system that satisfies the established program goals within the identified constraints. However, its merit rating as measured by the evaluation criteria established in problem definition was lower than that for Guideway III.

The concept formulation phase of the Columbia Transit Program demonstrated the technological and economic feasibility of providing public transportation in Columbia. Three configurations were identified, which, to varying degrees, meet the Columbia mobility objectives within a range of available resources. These three system configurations cover a spectrum of sophistication, service level, capital and operating costs, technical risk, and ridership.

The purpose of the next phase of the program is to investigate Guideway III in more detail including the preparation of preliminary engineering designs and precise cost estimates based on the engineering design. This information will permit a more informed decision to be made on which configuration should be taken into the acquisition phase.

REFERENCE

1. Columbia Transit Program Phase I. Bendix Corp., Ann Arbor, Mich., Pub. BSR 2814A, April 1970.

EVALUATION OF NEW URBAN TRANSPORTATION SYSTEMS

Robert U. Ayres, Richard McKenna, and M. Lucius Walker,
International Research and Technology Corporation

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:

$$C_v = 3{,}600/h_t \tag{1}$$

$$C_v = 5{,}280\,\overline{V}/h_d \tag{2}$$

for vehicles and

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

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

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

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

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

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

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

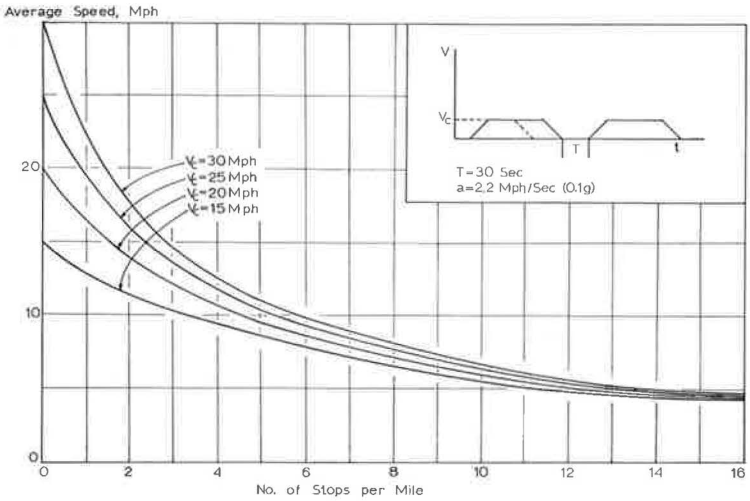

Figure 1. Influence of stop-and-go driving on average driving speed.

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-

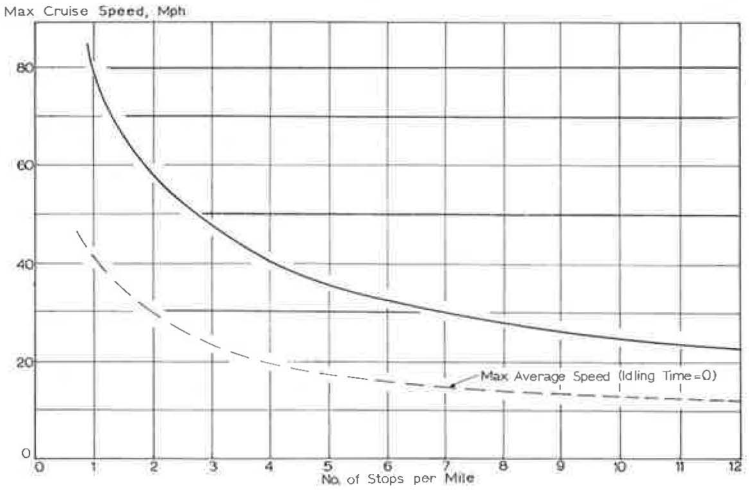

Figure 2. Limiting cruise and average speeds in stop-and-go driving.

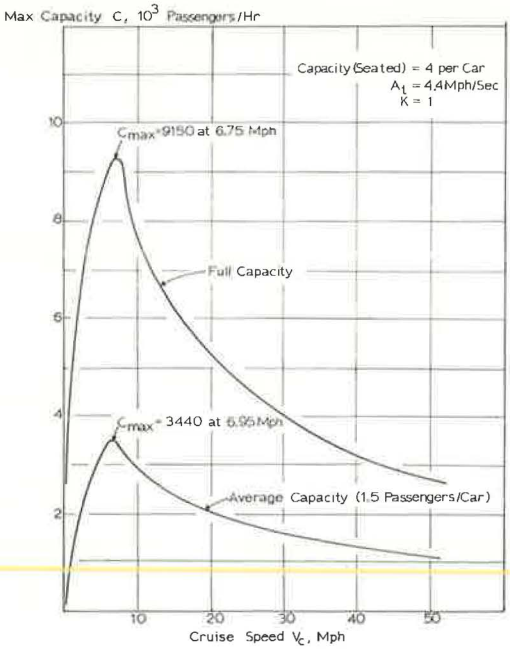

Figure 3. Maximum capacity versus speed for demand-activated transit vehicle, NSS-1.

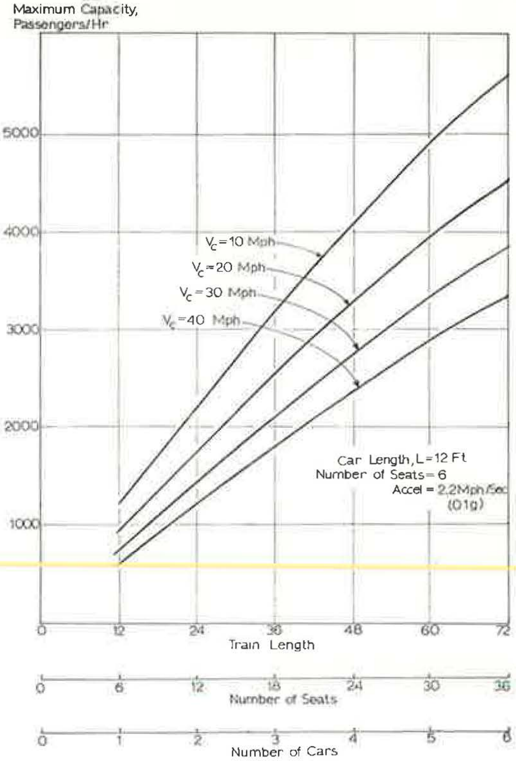

Figure 4. Maximum capacity of NSS-2.

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].

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

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.

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

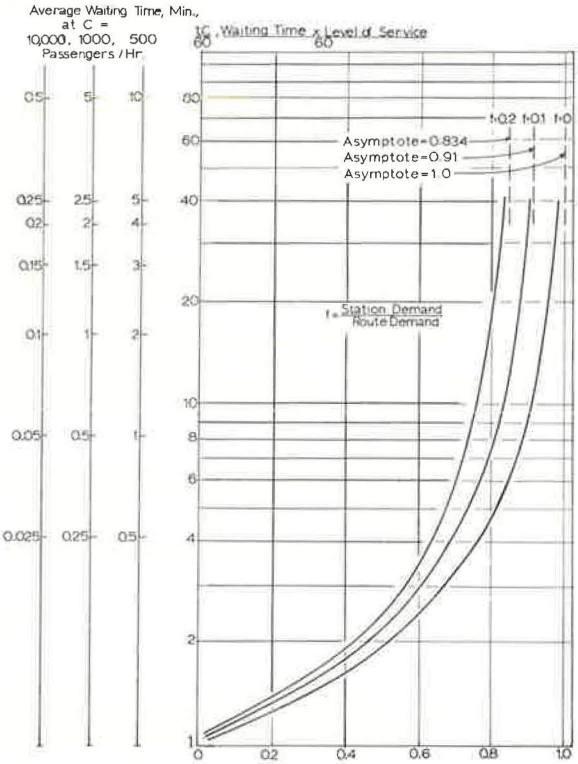

Figure 5. Congestion versus waiting time.

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, $\alpha = 1.5$, and $\beta = 0.5$ 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.

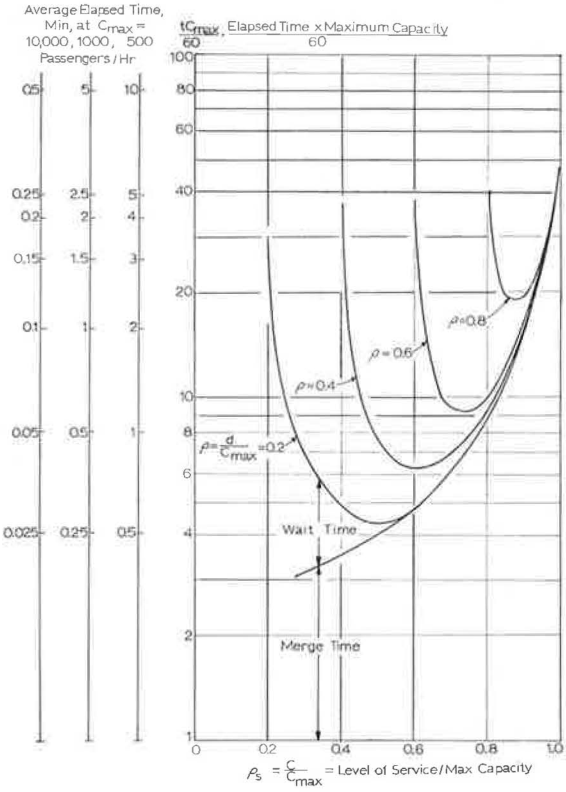

Figure 6. Average station time for NSS and personal transport.

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 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.

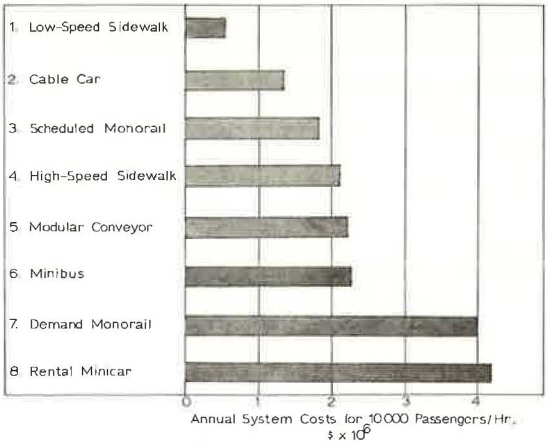

Figure 7. Rank ordering of annual system costs.

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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USER PREFERENCES FOR A DEMAND-RESPONSIVE TRANSPORTATION SYSTEM: A CASE STUDY REPORT

Richard L. Gustafson, Harriet N. Curd, and Thomas F. Golob,
General Motors Research Laboratories

If it is to help solve urban transportation problems, a demand-responsive transit system such as dial-a-bus, dial-a-ride, or demand-responsive jitney must be designed to provide service that is attractive and competitive in a consumer-oriented market and socially concerned society. Obtaining pertinent information concerning the potential users' preferences for the design of a transportation system of this type, as well as preferences for those not receiving direct benefits, is an important step in improving and making viable urban transportation and in providing increased benefits to the users of the system. This paper discusses the measurement of user preferences for a demand-responsive transportation system. The study was composed of three phases: survey design, which included the selection and grouping of system characteristics, the adaptation of psychological scaling techniques, and the design of an attitudinal survey; data collection, which involved the implementation of a home interview survey in a specific city; and data analysis, which included trade-offs between various design characteristics. The analysis was performed both on data for all respondents and also on data for particular market subgroup stratifications. Data from the application of the methodology in a case study community are provided, and interpretations of the analysis are discussed.

• THIS PAPER discusses the results of a research study to determine user preferences for a public transportation concept called the Demand-Responsive Jitney System (abbreviated D-J). The study has been conducted as one part of the Transportation Research Department's D-J systems study, which has analyzed the engineering, economic, and political feasibility of one type of demand-responsive transportation system in a chosen case study area.

The D-J system is intended to provide service for the user where he wants it and when he wants it. Because the system is demand responsive, it has some of the characteristics of a conventional taxicab system. However, to minimize costs of operation requires that passengers share the use of the vehicle; therefore, the D-J vehicle is somewhat characteristic of small buses, airport limousines, and shared taxis—the class of systems that may be called jitneys. As a hybrid between the taxicab and bus, the D-J system is generically similar to the demand-responsive systems previously described by General Motors and others under names such as dial-a-bus, Genie, and DART (1, 2, 4, 5, 6, 13, 14).

Within the overall framework of the D-J systems study, this research was aimed at the potential users of the D-J system. Of course, the design of any new transportation system involves more than satisfying the needs of those who are likely to use it. In a competitive, consumer-oriented market, however, user satisfaction is one of the most important considerations in achieving system success. In the past, public transportation system operators, designers, and planners have found it difficult to satisfy adequately consumer requirements when confronted with the competition of the private

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automobile. If new systems like the D-J and others are to be more successful, they must be designed to provide service that is attractive and competitive within the growing and changing consumer market for transportation.

The research study sought to achieve four specific objectives:

1. To gather information from potential users of the system about their relative preferences for specific system characteristics and specific design solutions being considered for incorporation into the design of the D-J system (these characteristics and solutions were classified into subsystems of vehicle design, levels of service, and convenience factors);
2. To analyze the differences in preferences found within and between each of these four categories for the total population sampled and for each of eight market subgroups identified within the total sample;
3. To identify by market subgroup and design subsystem the trade-offs that appear to be important; and
4. To permit conclusions to be drawn about the most desirable design of the D-J system from the users' points of view.

The research was conducted in five phases, as shown in Figure 1. The first phase—survey design—included a number of design and decision steps that led to the construction of an attitudinal survey composed of two separate questionnaires. The second phase—data collection—concerned the execution of a home interview survey in the case study community. The third phase included detailed analyses of the data collected for the total population. In phase four, the data were analyzed by market subgroups. The last phase involved the synthesis of preferred design. A detailed discussion of the methodology of this study is given in another report (3).

SURVEY DESIGN

The methods of paired comparison and semantic scaling were used to measure user preferences in the D-J attitudinal survey. These devices satisfied the criteria of validity, reliability, quantifiability, analysis potential, objectivity, and simplicity of administration (12).

The paired comparison technique was used to establish a scale of preferences for a set of system characteristics, and the semantic scaling technique was used to investigate design alternatives for a number of these characteristics. The survey there-

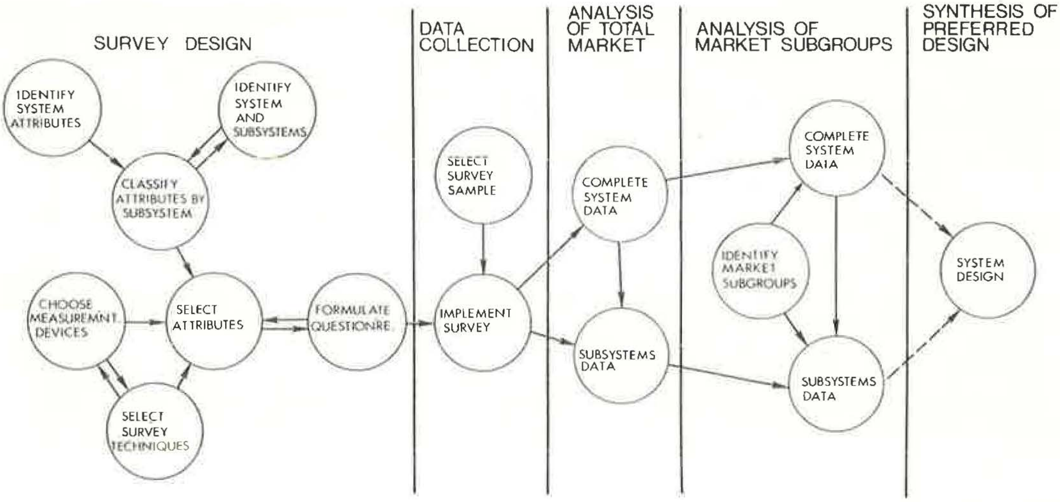


Figure 1. Research framework.

fore employed two separate but related questionnaires—a paired comparison questionnaire and a semantic scaling questionnaire.

The output of the paired comparison questionnaire is a preference scale of system characteristics as rated by the respondents. Both the rank order of the characteristics and an estimate of the preference intervals separating these characteristics were determined. The output of the semantic scaling questionnaire is an estimate of the mean acceptabilities of the design alternatives and estimates of the variances associated with the mean ratings. The methodology underlying these techniques is discussed elsewhere (7, 8, 9, 10, 11, 12).

An important first step in the preparation of the questionnaires was the determination of the set of characteristics to be measured. Over 100 characteristics were selected and grouped into three categories that determined how, or if, they would be used in the questionnaires. These categories are:

1. System characteristics for which the specific form would be based entirely on professional analysis and judgment and not subject to trade-off (these were not included in the questionnaire);
2. System characteristics for which relative user importances were desired (thirty-two of these formed the basis of the paired comparison questionnaire); and
3. System characteristics for which a user preference for alternative design solutions was desired (twenty-seven of these formed the basis of the semantic scaling questionnaire).

The 32 system characteristics selected for use in the paired comparison questionnaire are as follows:

1. Shorter time spent traveling in the vehicle;
2. Shorter time spent waiting to be picked up;
3. Arriving at your destination when you planned to;
4. Ability to adjust the amount of light, air, heat, and sound around you in the vehicle;
5. More space for storing your packages while traveling;
6. Stylish vehicle exterior;
7. Freedom to turn, tilt, or make other adjustments to your seat;
8. Availability of coffee, newspapers, and magazines in the vehicle;
9. Small variation in travel time from one day to the next;
10. More phones to use to call for service available in public places;
11. More protection from the weather at public pickup points;
12. More chance of riding in privacy;
13. More chance of meeting people in the vehicle;
14. More chance of being able to arrange ahead of time to meet and sit with someone you know;
15. More chance of rearranging the seats inside the vehicle to make talking with others easier;
16. Lower fare for passengers;
17. Making a trip without changing vehicles;
18. Less time spent walking to a pickup point;
19. Being able to select the time when you will be picked up;
20. Longer hours of available service;
21. Vehicle whose size and appearance do not detract from the character of the neighborhood through which it passes;
22. Calling for service without being delayed;
23. Being able to talk to, and ask questions of, systems representatives when desired;
24. Easier entry and exit from the vehicle;
25. Room for accommodating baby carriages, strollers, and wheel chairs in the vehicle;
26. Assurance of getting a seat;
27. Less chance of meeting with people who may make you feel insecure or uncomfortable;

28. More room between you and others in the vehicle;
29. Being able to take a direct route, with fewer turns and detours;
30. Being able to take rides that are pleasant or scenic;
31. More chance of riding with different kinds of people; and
32. Convenient method of paying your fare.

Comparing all 32 within a single matrix of paired choices would result in 496 paired choices, far too many to be included in a home interview survey. To reduce the number of paired choices while still retaining those choices that were important and logical, we developed nine smaller matrices, each related to a specific group of characteristics. As the matrices were formed, care was taken to group only those characteristics that the designer might actually trade off in making design decisions. To provide a common basis for measuring the relative importances of all of the characteristics even though separated into groups, we included several characteristics in more than one group. In the final questionnaire, 168 paired choices were presented. Part of a page of this questionnaire is shown in Figure 2.

The second aspect of the survey involved the determination of relative preferences for various design alternatives as means for achieving certain of the system characteristics. It was the purpose of the semantic scaling questionnaire to explore, over a selected range, the acceptability of various design alternatives for 27 of these characteristics. Questions were constructed describing the various design solutions for each, and the respondent indicated the importance, acceptability, or desirability to him of each of the design alternatives presented for a system characteristic by ranking the alternative on a 1 to 7 semantic differential scale. Part of a page of this questionnaire is shown in Figure 2.

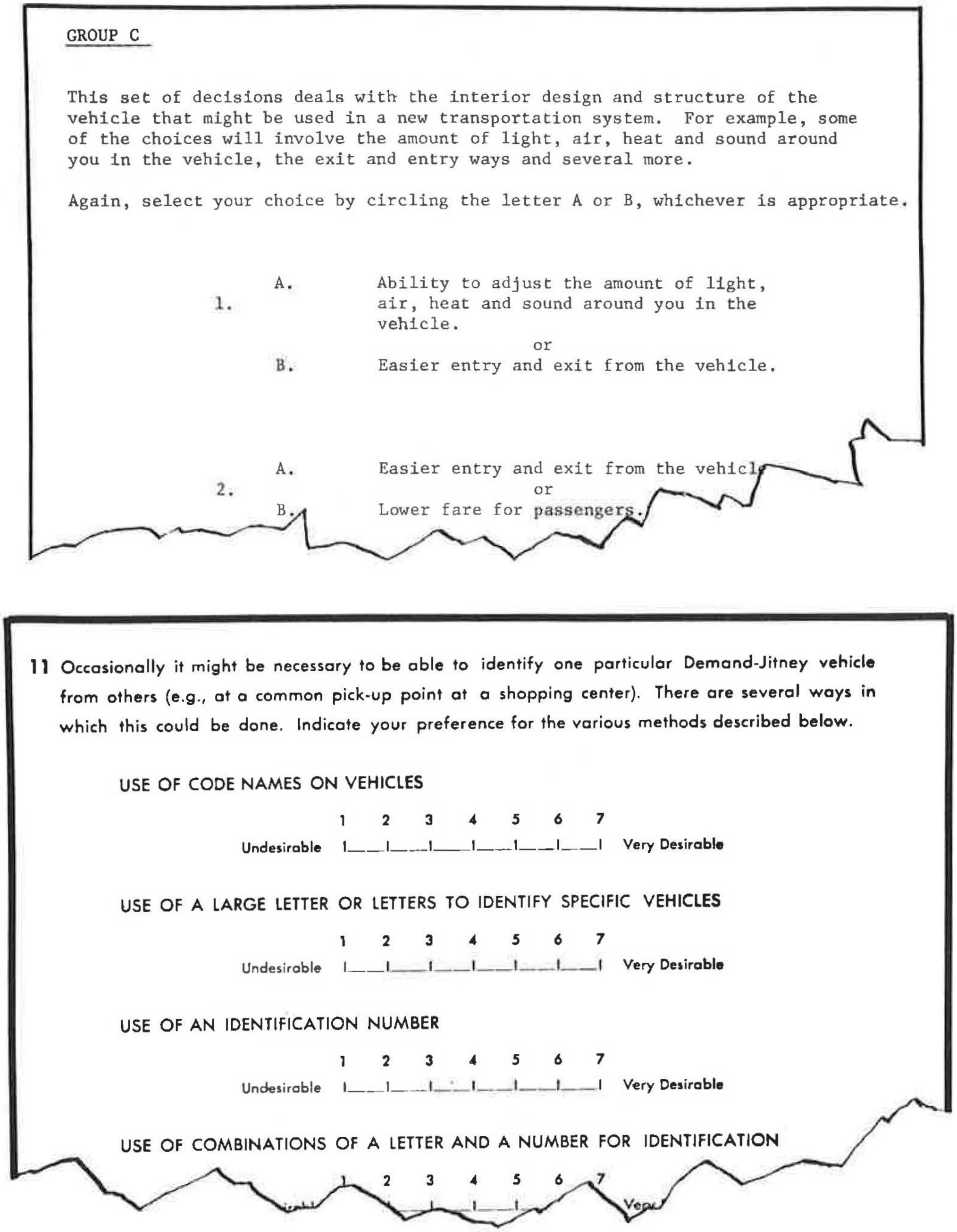
DATA COLLECTION

A home interview survey technique was used to implement the paired comparison and semantic scaling questionnaires. The survey was conducted by an independent market research firm to help ensure unbiased and objective results. The survey area selected was a suburb of a large metropolitan area. A cluster sampling technique was used to identify the sample of households within the case study community. The sample was composed of 210 clusters, and the starting point for each cluster was selected at random from the set of all households within the case study community. Within each cluster area, interviews were completed at six households according to a predesigned sampling plan. In this manner, interviews were completed at 1,260 households. If no one was at home at a selected household, a maximum of two-call-backs were made. If no one was at home during the second call-back, that households was replaced with another household selected according to a specific skip selection plan. Households for which interviews were refused were also replaced according to this particular plan.

Once an interviewer was allowed admittance to the household, she was to obtain as many interviews as possible from the adult members of that family. An adult was defined as anyone 14 years of age or older. The procedure for conduct of the interview was for the respondent to self-administer the questionnaire and for the interviewer to administer the introductory sections and help the respondent begin work on the self-administered part to ensure comprehension and establish rapport. The interviewer then monitored the remainder of the questionnaire and answered any questions of the respondent. Interviewers were able to obtain 1,631 interviews, or 1.3 interviews for every household in the sample. The number of questionnaires processed, after rejection of incomplete returns, was 1,603. Because approximately every other interviewed household received the paired comparison questionnaire whereas the remaining households received the semantic scaling questionnaire, there was a final total of 786 completed paired comparison questionnaires and 817 completed semantic scaling questionnaires.

DATA ANALYSIS FOR THE TOTAL MARKET

The nine matrices of comparisons produced nine preference scales, each of one group of system characteristics. (A tenth matrix, concerned with alternative methods



GROUP C

This set of decisions deals with the interior design and structure of the vehicle that might be used in a new transportation system. For example, some of the choices will involve the amount of light, air, heat and sound around you in the vehicle, the exit and entry ways and several more.

Again, select your choice by circling the letter A or B, whichever is appropriate.

1\. A. Ability to adjust the amount of light, air, heat and sound around you in the vehicle.
or
B. Easier entry and exit from the vehicle.

2\. A. Easier entry and exit from the vehicle
or
B. Lower fare for passengers.

11 Occasionally it might be necessary to be able to identify one particular Demand-Jitney vehicle from others (e.g., at a common pick-up point at a shopping center). There are several ways in which this could be done. Indicate your preference for the various methods described below.

USE OF CODE NAMES ON VEHICLES

1 2 3 4 5 6 7
Undesirable |___|___|___|___|___|___| Very Desirable

USE OF A LARGE LETTER OR LETTERS TO IDENTIFY SPECIFIC VEHICLES

1 2 3 4 5 6 7
Undesirable |___|___|___|___|___|___| Very Desirable

USE OF AN IDENTIFICATION NUMBER

1 2 3 4 5 6 7
Undesirable |___|___|___|___|___|___| Very Desirable

USE OF COMBINATIONS OF A LETTER AND A NUMBER FOR IDENTIFICATION

1 2 3 4 5 6 7

Figure 2. Sample from paired comparison questionnaire.

of fare collection, was included in this questionnaire as well as in the semantic scaling questionnaire to provide a comparison test between paired comparison and semantic scaling methods of preference rating. Results of this comparison test are discussed later in this report.) To formulate one integrated relative preference scale required that all nine scales contain the characteristic "lower fare." The value of lower fare in one comparison scale was then used as the standard value. The scale value for each characteristic was adjusted by the difference between the standard lower-fare scale value and the specific lower-fare scale value for the comparison scale in which the characteristic is contained. Because some characteristics were included in more than one comparison scale, there is more than one adjusted scale value for those characteristics. The adjusted scale values were compared to check the consistency of the data, and the largest deviation among the values was found to be within acceptable bounds. After all the scale values were adjusted to lower fare, the process of combining the scales was completed by plotting all the adjusted values on one scale (Fig. 3).

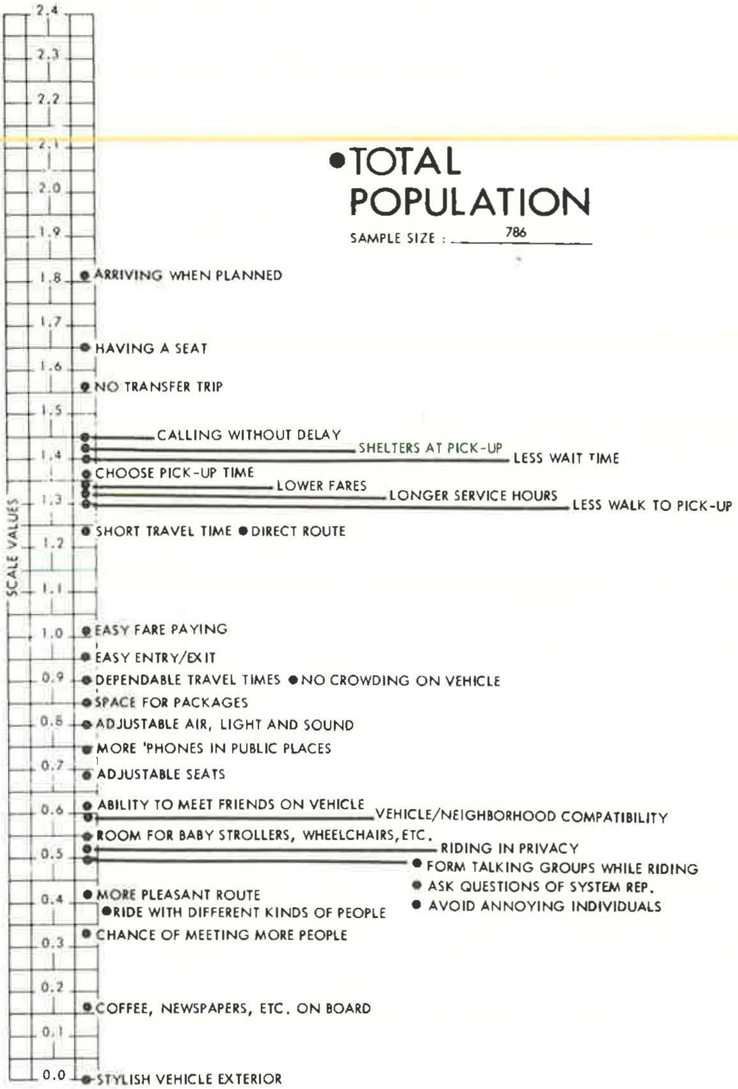


Figure 3. Scale of adjusted values.

The characteristic receiving the highest preference by the total market was "arriving at your destination when you had planned to," abbreviated in Figures 3, 4, and 6 as "arriving when planned." This was followed by "assurance of getting a seat," abbreviated as "having a seat," and "making a trip without changing vehicles," abbreviated as "no transfer trip." These three preferred characteristics are followed by a cluster of nine characteristics concerned mainly with the customers' time, fare, and shelters. Lower on the scale is a large cluster of 18 characteristics that are concerned primarily with interior design, aesthetic and social aspects of the actual trip, and passenger convenience. The two characteristics that are least preferred by the total market are "coffee, newspapers, and magazines on board the vehicle" and "stylish vehicle exterior."

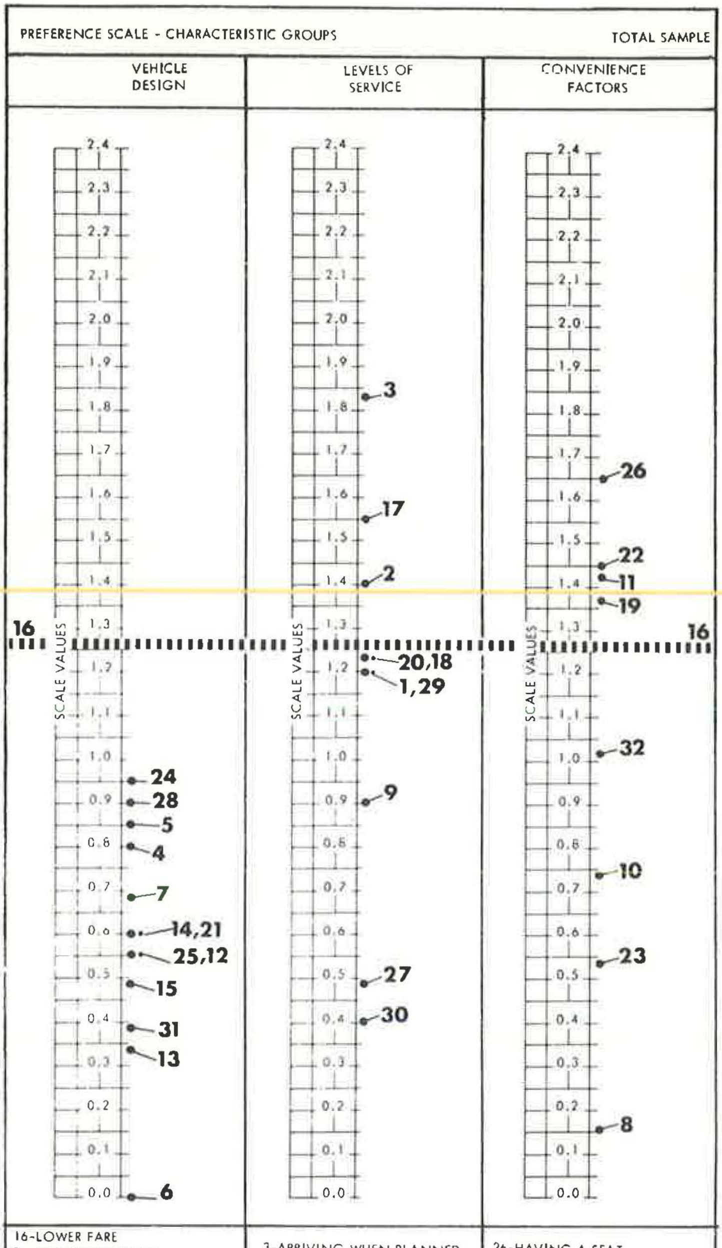
The 32 characteristics were classified into three subsystems: vehicle design, levels of service, and convenience factors. The universal preference scale is split into three separate scales, one for each of the subsystems (Fig. 4), and a black line indicates the position of the common characteristic lower fare. One can conclude by examining these scales that the vehicle design subsystem is the least important of the three because none of the relative differences from lower fare are less than 0.3. The level of service subsystem has three characteristics preferred to lower fare and four others clustered around lower fare. Only three characteristics of this subsystem are ranked significantly below lower fare. The convenience factors exhibit the widest dispersion; four characteristics are preferred to lower fare; "having a seat" is the most preferred. Four other characteristics have a significantly lower importance. The characteristics of most concern to the respondents involved levels of service and certain aspects of convenience, with the respondents especially concerned with time, dependability, and avoidance of physical inconveniences.

The universal preference scale is a very convenient way of establishing an order and preference ranking for the 32 characteristics, but the designer must keep in mind that this universal preference scale of the 32 characteristics is drawn from the nine scales where direct comparisons are made. Scale values of the 31 characteristics are implied through their relationship to lower fare. The implied scale value may be biased by the fact that a particular characteristic is not compared with all 31 remaining characteristics and may in fact be compared with only four or five. This does not mean that the scale values in the universal preference scale are not reliable; it only indicates that the system designer must keep in mind that some of the figures may be biased and that the analysis of the total preference scale should be limited to major differences in characteristics and should not attempt to draw fine lines between characteristics that are grouped closely together.

The semantic scaling questionnaire (with a semantic scale range of 1 to 7) was used to establish preferences for design alternatives for 27 of the system characteristics. For the vehicle design subsystems, a low two-step entry is preferred (mean = 6.0) over the standard three-step entry (mean = 3.8) as a solution to the entry-exit problem. The difference in preferences for the deluxe interior and the standard interior is not significant, as was determined by a statistical t-test (which measures the significance level of differences between statistical parameters of different distributions). Providing storage alongside the seat (mean = 5.0), under the seat (mean = 4.7), or on racks above the seat (mean = 4.6) are all preferred to storage near the door (mean = 2.6) or outside the passenger compartment (mean = 2.4).

Also important are items dealing with vehicle and passenger safety (all had mean acceptances of 5.5 or above), the identification of the vehicle (mean = 6.1), and the need for air-conditioning (mean = 5.6). Less preferred are various types of flexible or adaptable seating (interior grouped seats, rotatable seats, informal seat groupings, or tilt-back seats) intended to provide individual or group variations.

Some conclusions about vehicle design can be reached. The priorities for vehicle design include providing easier entry and exit, air-conditioning, more spacious seating, convenient storage areas close to the seats, and a more personally controlled microclimate. Less emphasis should be placed on providing for privacy or for a variety of social arrangements or on providing adjustable and movable seats. Styling, although still an integral component of vehicle design, would have to be considered as being shaped by, rather than shaping, these more important requirements. The designer



16-LOWER FARE
24-EASY ENTRY/EXIT
28-NO CROWDING ON VEHICLE
5-SPACE FOR PACKAGES
4-ADJUSTABLE AIR, LIGHT AND SOUND
7-ADJUSTABLE SEATS
14-ABILITY TO MEET FRIENDS ON VEHICLE
21-VEHICLE/NEIGHBORHOOD COMPATIBILITY
25-ROOM FOR BABY STROLLERS, WHEELCHAIRS
12-RIDING IN PRIVACY
15-GROUP SEATING
31-RIDE WITH DIFFERENT KINDS OF PEOPLE
13-CHANCE OF MEETING MORE PEOPLE
6-STYLISH VEHICLE EXTERIOR

3-ARRIVING WHEN PLANNED
17-NO TRANSFER TRIP
2-LESS WAIT TIME
16-LOWER FARE
20-LONGER SERVICE HOURS
18-LESS WALK TO PICK-UP
1-SHORT TRAVEL TIME
29-MORE DIRECT ROUTE
9-DEPENDABLE TRAVEL TIME
27-AVOID ANNOYING INDIVIDUALS
30-PLEASANT ROUTE

26-HAVING A SEAT
22-CALLING WITHOUT DELAY
11-SHELTERS AT PICK-UP
19-CHOOSE PICK-UP TIME
16-LOWER FARE
32-EASY FARE PAYMENT
10-'PHONES IN PUBLIC PLACES
23-ASK QUESTIONS OF SYSTEM REP.
8-COFFEE, NEWSPAPERS, ETC. ON BOARD

Figure 4. Universal preference scale of 32 characteristics.

should keep in mind, when evaluating various alternatives, that the user is not willing to pay a higher fare for improved design characteristics. Finally, attention should be paid to a method for vehicle identification.

For the levels of service subsystem the respondents ranked "waiting time-pickup" (mean = 5.9) and "travel time" (mean = 5.3) very high. Provision of service to areas outside the case study community was evaluated. The two (out of four) nearest shopping centers ranked the highest (mean = 4.9 and 4.8), while some interest was expressed in service to a transit line to the metropolitan area central city (mean = 3.5). Service to plants located in two nearby industrial areas ranked quite low (mean = 2.4 and 2.2). The most desirable times for operation were 9 a.m. to 7 p.m., whereas service from 5 a.m. to 9 a.m. was less desired.

The respondents ranked "pickup at place of call" (mean = 6.1) highly desirable, and the mean acceptability falls as the distance of the pickup point from the origin of the call increases ("nearest corner" = 5.5, "within neighborhood" = 4.9, and "nearest major street" = 4.0). Four possible information items that could be furnished the caller when he placed his call for service were evaluated (earliest and latest time of pickup and earliest and latest time of arrival), and all of the items were given high mean acceptance ratings (approximately 6.0). Specified time intervals for pickup and specified delivery time are most desirable. A 5-min waiting time is very acceptable (mean = 6.1) as is 10 min (mean = 5.8), but for 15 and 20 min the mean acceptability is much less (mean = 4.9 and 3.8). Early arrival experiences the same 10-min threshold because 5- and 10-min early arrivals rank high in acceptance (both 6.1), whereas a 20-min early arrival ranks much lower (mean = 4.3).

In evaluating the importance of travel time via the D-J relative to that via the private automobile, it is useful to know whether the potential customer is more interested in minimizing the difference between trip times or the ratio of trip times. The questionnaire was structured to resolve this by including questions on six travel situations involving three travel time ratios (1.5:1, 2:1, and 3:1) and two time differences for each ratio. The results of the survey indicate that the respondents are primarily concerned with the time difference in minutes rather than with the ratio of travel time.

The respondents are highly concerned with dependability of service. The characteristics receiving the highest rankings are "arriving when planned," "trip without changing vehicles," and "less wait time"—factors that could seriously inconvenience the user. The threshold for both waiting time for pickup and early arrival time is 10 min and every possible effort should be made by the system designer to provide service within these levels. A "lower fare" can be sacrificed, if need be, because this characteristic ranks below the service factors. Because the respondents are indifferent to "shorter travel time," a fast trip can also be sacrificed in order to meet the waiting time and arrival time criteria. The system should also be designed to pick up passengers as close as possible to the point from which they call for service.

Of minimal importance to the respondents are "avoid annoying individuals," "ride with different kinds of people," and "pleasant route." These characteristics should not be permitted to influence the fare. There is also little interest expressed in service to industrial areas bordering the area under consideration and service between 1 and 5 a.m.; thus a 24-hour operation of the system may not be warranted.

The semantic scaling responses indicate a more detailed measure of user preferences for various convenience factors. Both an overhead shelter with a phone (mean = 5.3) and an enclosed shelter (mean = 5.4) would be acceptable; however, the difference between the means for the two types of shelters is not significant. The median for both types of shelters is 6, which indicates that a majority of people find either shelter very acceptable. A mean of 4.7 for a curbside D-J stop indicates relatively high degree of acceptability; however, considering the importance given in the paired comparison analysis to protection from weather, it would seem that one could justify an expense for covered shelters in public areas.

Although recorded music (mean = 3.7) and broadcast of radio programs on board the vehicle (mean = 3.4) are rated higher than coffee and soft drinks on board (mean = 2.8), it would not appear that providing such equipment would have a significant effect on consumer acceptance of the system design.

In summary of the convenience factors subsystem, it should be noted that only protection at pickup points and factors concerning user delay are ranked above or very close to lower fare in importance. The other convenience factors should be considered only if they will not significantly affect the cost of the service.

Several methods of fare collection were evaluated by both the method of paired comparison and the semantic scaling technique. It has been presupposed by some that users of public transportation systems would prefer an easier method of payment such as a credit card. It is often argued that individuals think in terms of out-of-pocket costs and, if the method of payment for public transportation usage could be more aligned with the methods and frequency of purchases for the automobile, the demand for public transportation systems would increase. Figure 5 shows the preference scale values for the six methods of fare collection. The most preferred method of fare payment is cash with the ability to receive change. Exact fare and tokens are about the same and are next in line of priorities. A monthly pass and a 20-trip ticket maintain similar relative scale values. The respondents exhibit least desire to use a credit card to purchase usage of a public transportation system.

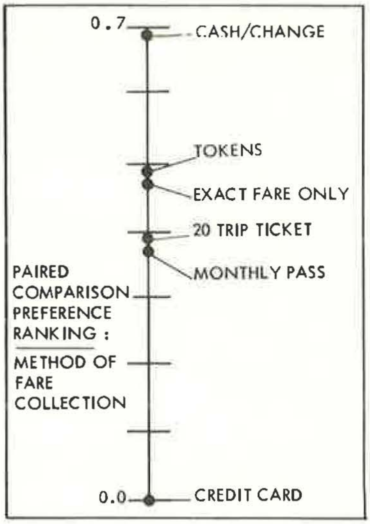


Figure 5. Preference scale values for six methods of fare collection.

This same trend is exhibited in the statistics from the semantic differential scaling responses. Paying "cash and receiving change" was ranked the highest (4.3). "Cash/exact fare only" and "twenty-trip ticket" were ranked second (both 4.2), followed by "tokens" (4.1), "monthly pass" (3.7), and "credit card" (3.3). The correlation between the results of the paired comparison method and the semantic scale method is thus observed to be good.

Some combination of fare payment methods seems to be desirable. A cash method must be provided for the occasional user, though requiring that exact change be deposited would not be unreasonable. From an operational viewpoint it would clearly be preferable for the driver of the vehicle not to be required to handle money. Twenty-trip tickets or tokens could also be sold by the system at a slightly discounted rate for the convenience of the regular user of the system. The cost to the system should be the determining factor in the selection of a convenient method of fare payment.

The attitudes of respondents toward giving fare discounts to certain classes of users were examined. These classes were students traveling at any time, students traveling to and from school, welfare recipients, children accompanied by an adult, retired persons, handicapped persons, persons purchasing a monthly pass, and persons purchasing a 20-trip ticket. The respondents strongly favor giving discounts to students traveling to and from school, retirees, the handicapped, and children accompanied by an adult (means of 6.0, 6.2, 6.2 and 5.7 respectively). Welfare recipients (mean = 5.2) and students (4.1) rate lower in acceptance toward a fare discount.

Four methods of determining the fare were examined. These were single fixed fare throughout the area, a basic fare plus an external trip charge (extra charge for trip outside city), a fare based on distance, and a zone based fare. The most desirable method of structuring the fare is a basic fare plus an external trip charge (mean = 5.4). A fare based on distance (mean = 5.2) is approximately equal to this method. The single fixed fare and a zonal fare are not too desirable (means of 3.5 and 3.9).

ANALYSIS OF THE MARKET SUBGROUPS

Attitudinal surveys can serve many important functions within a well-planned, broadly based marketing program. One of these functions is to provide information about preferences for selected market groups within the total population, thus helping to shape a more sensitive and strategic marketing plan.

User preferences were analyzed for the following market groups:

1. Low income (households with less than $5,000 annual income);
2. Elderly (respondents 60 years of age or older);
3. Young (respondents under 20 and single);
4. Nondrivers (respondents not holding a driver's license);
5. Housewives (female respondents not employed);
6. Both husband and wife employed;
7. Multicar households; and
8. One-car households.

In addition to these eight market groups, another classification was formed that analyzed the differences in relative preferences as a function of trip purpose. Three trip purposes were analyzed: work trips, shopping trips, and school trips.

Only three of the market groups, the elderly, the young, and the low-income group, demonstrated significantly different preferences from those expressed by the total market (Fig. 6).

There are four characteristics that the elderly definitely prefer. "Having a seat" and "no transfer trip" are ranked the highest and are followed by "lower fare" and "arriving when planned" (which is ranked the highest by the total population). The two clusters located at the center of the preference scale are close to the same. The exception is that "no crowding on the vehicle" and "easy entry and exit" rank in the first cluster for the elderly, whereas they rank in the lower cluster for the total market.

With respect to the subsystem groups of characteristics, vehicle design is still the least preferred; however, convenience factors are much less important to the elderly than they are to the total population. Level of service is definitely the primary concern of the elderly.

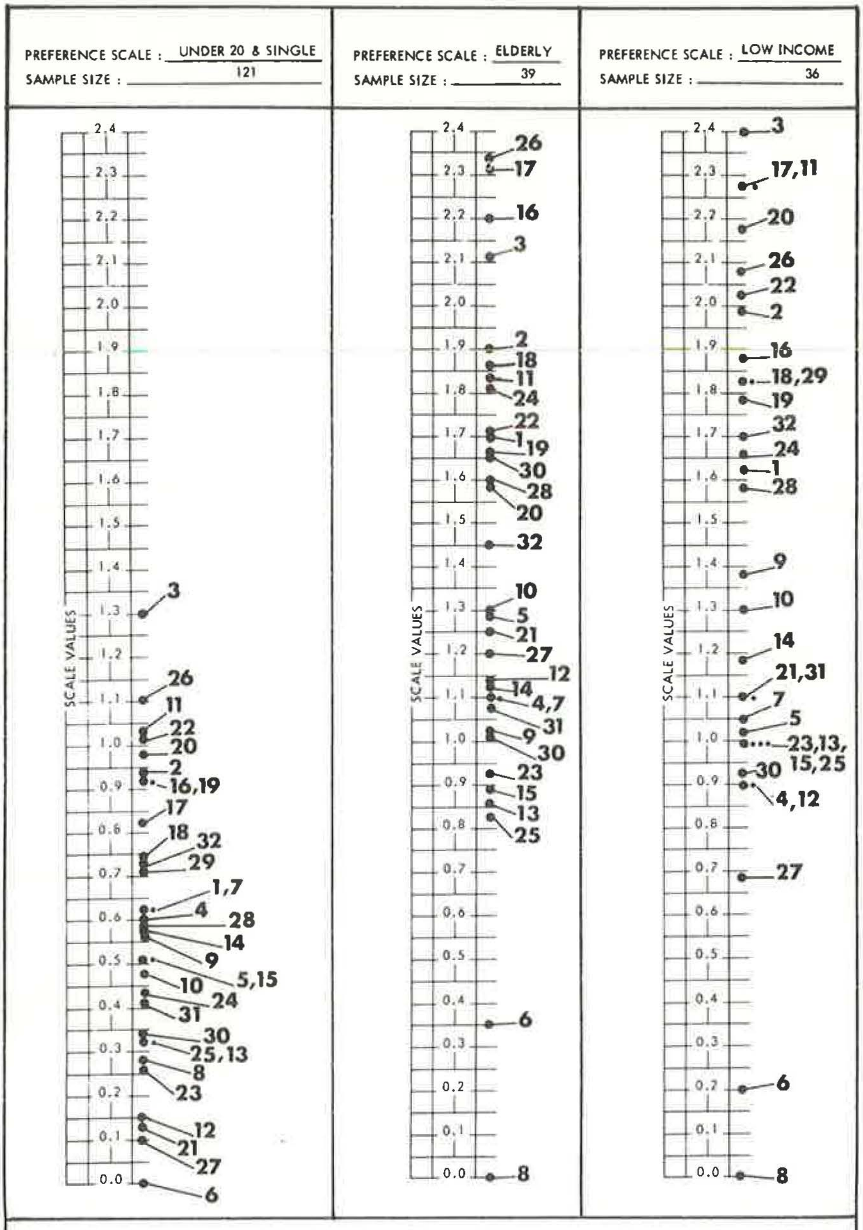
The elderly have focused attention on the special physical problem of riding public transportation—being able to get on and off the vehicle. They want to be able to sit down, not have to transfer, and pay a lower fare. They do not find most other conveniences worth extra fare, and they place a lower value on their time than does the total population. It should also be noticed that the preference scale is more dispersed for the elderly than for the total population, which indicates that a greater proportion of the respondents have extreme preferences.

The universal preference scale for the low-income group shows considerably more dispersion than the preference scale for the total market. The higher ranked characteristics do not cluster as closely as they did in the preference scale for the total population. The order of preferences is approximately the same as those expressed by the total market, except that "shelters at pickup" and "longer hours of service" are relatively more preferred by this group. There are seven characteristics of service and convenience that the low-income group prefers to lower fare.

The preferences suggest that members of this group are primarily concerned with their basic needs for public transportation. The system must be dependable. They want to be able to sit down on the bus and not have to change buses, and they have expressed a much higher preference for "shelters at pickup" and for "longer hours of service." The time that is important to them is waiting time, and they are concerned about "calling without delay." As was true for the elderly group, "easy entry and exit" and "no crowding on vehicle" are ranked much higher by this group than they are by the total sample. The lowest ranked characteristic is again "coffee, newspapers, and magazines on board."

The low-income group ranks "a convenient method of fare payment" higher than the total sample and expresses more definite preferences for methods of fare collection. In the semantic scaling questionnaire "cash/receive change" (mean = 5.4) is the most preferred form of fare payment; however, "cash/exact fare" (mean = 5.0) is almost as acceptable. The use of credit cards is even less acceptable to this group (mean = 2.7) than to the total market (mean = 3.3).

The low-income respondent's conception of the system may be different from that of a respondent from the other groups. For instance, it is likely that this person is a user of present transportation systems and perhaps conceives of waiting on a corner



1-SHORT TRAVEL TIME
2-LESS WAIT TIME
3-ARRIVING WHEN PLANNED
4-ADJUSTABLE AIR, LIGHT AND SOUND
5-SPACE FOR PACKAGES
6-STYLISH VEHICLE EXTERIOR
7-ADJUSTABLE SEATS
8-COFFEE, NEWSPAPERS, ETC., ON BOARD
9-DEPENDABLE TRAVEL TIME
10-'PHONES IN PUBLIC PLACES
11-SHELTERS AT PICK-UP
12-RIDING IN PRIVACY
13-CHANCE OF MEETING MORE PEOPLE
14-ABILITY TO MEET FRIENDS ON VEHICLE
15-GROUP SEATING
16-LOWER FARE
17-NO TRANSFER TRIP
18-LESS WALK TO PICK-UP
19-CHOOSE PICK-UP TIME
20-LONGER SERVICE HOURS
21-VEHICLE/NEIGHBORHOOD COMPATIBILITY
22-CALLING WITHOUT DELAY
23-ASK QUESTIONS OF SYSTEM REP.
24-EASY ENTRY/EXIT
25-ROOM FOR BABY STROLLERS, WHEELCHAIRS
26-HAVING A SEAT
27-AVOID ANNOYING INDIVIDUALS
28-NO CROWDING ON VEHICLE
29-MORE DIRECT ROUTE
30-PLEASANT ROUTE
31-RIDE WITH DIFFERENT KINDS OF PEOPLE
32-EASY FARE PAYMENT

Figure 6. Preference scales for 3 market subgroups.

for pickup, whereas a higher income respondent may be thinking in terms of pickup at his home. This would explain the higher importance of wait time, shelters, dependability, and longer hours of service.

The young are not as unanimous concerning their preferences as are the other subgroups. This is evidenced by smaller dispersion in the preference scale, which indicates a larger number of approximately equal proportional choices. The preferences of the young differ significantly from those of the elderly in that they are less concerned with the physical problem of riding public transportation. Such characteristics as "easy entry and exit," "no crowding on vehicle," and "no transfer trip" are given a much lower preference by the young, whereas "choosing pickup time," "calling without delay," and "longer hours of service" have higher relative importances. Because they are not constrained by the physical problem of riding a public transit vehicle, the young place more importance on items that would make the trip more enjoyable, such as "adjustable air, light and sound" and "coffee, newspapers, and magazines on board." "Riding in privacy," "avoid annoying individuals," and "vehicle/neighborhood compatibility" are of much less concern to the young than to any of the other groups or to the total market.

Convenience factors are ranked higher by the young than they are by the total population. The levels of service characteristics are ranked in about the same relative position as for the total population, with one or two characteristics interchanging positions. Vehicle design remains the least preferred subsystem, and "adjustable seats" and "adjustable air, light and sound" replace "no crowding on vehicle" and "easy entry and exit" as the most preferred of that group.

CONCLUSIONS

The study involved the application of a proven market research technique to achieve the objective of measuring user preferences for a demand-responsive transportation system. A statistically sound method of selection was used to choose a population of respondents from the case study community, and the home interview technique followed well-known guidelines in the field of marketing research.

The application of two complementary psychological scaling methods enabled a detailed analysis of the data obtained from the survey. These data were found to yield statistically significant estimates of perceived user preferences for the system characteristics investigated. The techniques yielded results that exhibited cross-validation, and the statistical estimates were found to be relatively stable across subsets of the total population.

The data enabled the analysis of user preferences and identification of trade-offs among design alternatives—two major objectives of the study. The results of the analysis are not contradictory to previous studies of user preferences and professional judgments concerning these preferences, but have, however, resulted in greater insight into design of a demand-responsive transportation system from the user's point of view. Moreover, the study has provided a source of detailed information that will be useful for future studies of related transportation systems.

The total population of respondents expressed preferences for high levels of service and certain convenience factors. These preference rankings suggest that the individuals prefer a mode that approximates the automobile with regard to level of service. The users indicate that they want to be able to depend on the system and wish to be inconvenienced as little as possible. The level of fare is important, but they are willing to trade off fare for a system that minimizes inconveniences. Dependability is much more important than extra travel time or fare level.

Social and aesthetic interests are not as important to the respondents; they appear to assess the practical aspects of a transportation mode. Special seating arrangements, coffee and music on board, or a smartly styled vehicle would be acceptable only if the inclusion of these extras did not increase the fare.

An analysis of market groups revealed that only three of the groups analyzed showed major variations from the preferences exhibited by the total sample. The elderly concerned themselves with the physical problems of riding the vehicle; they preferred not to stand, change vehicles, be crowded, or have trouble getting on the vehicle. A low fare was also important. They were willing to trade off their time conveniences and a better vehicle design for the solution of these physical problems. The low-income group expresses preferences that imply a greater dependence on the system. This group prefers a dependable system with long hours of service at a low fare, with the provision of protection from the weather at pickup points. The young express different preferences than the other groups. They rank convenience factors very high and, as a group, are not concerned with factors such as transferring vehicles or being crowded.

This detailed survey has yielded information of importance to the designer of a demand-responsive transportation system, but the analyst must be aware of the demographic and socioeconomic characteristics of the respondents. The individuals in the community surveyed make 93 percent of their trips via the automobile mode. There are 65 percent blue-collar workers in the community. The population of the community has not voiced a need for public transportation. Although this community was chosen to be representative of many suburban communities in the nation, significant demographic differences will be found in other communities.

This study is a step forward in the art of obtaining relevant information from the potential users of a public transportation system about their preferences and needs. It thus represents an improvement in the ability to design public transportation service that is attractive and competitive within a growing and changing consumer market.

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ANALYSIS OF DUAL-MODE TRANSPORT

Donn Fichter, New York State Department of Transportation

Dual-mode transport envisions compact conveyances that could be driven on roads and that could also travel on exclusive automated guideways. Performance characteristics assumed for this exploratory study reflect the technology proposed in the "Urbmobile" version of this innovative concept. This paper attempts to estimate the expected patronage and economics of a hypothetical dual-mode installation in a real city. Patronage is "synthesized" by selecting the most likely users from actual trip-making reported in the same real metropolis. The synthesis approach seeks to make relatively explicit the unavoidable guessing about how people would respond to an unprecedented mode. Results suggest that the total dollar economics of the dual-mode system and of private automobiles might be comparable. The limited road range of the battery-electric Urbmobile would preclude its being adopted as an alternative vehicle by most of the households owning only one vehicle. For persons lacking access to the stations by private vehicle or walking, extending the range of station coverage by frequent jitney or bus service would greatly enhance system usefulness. The scale of Urbmobile facilities might be a major consideration in the design of the route network and in the acceptability of the system.

•BECAUSE of its broad responsibilities for planning balanced metropolitan transport, the New York State Department of Transportation is naturally interested in the long-range potential of emerging transport technologies. The Department is interested in finding answers to questions such as: Do these technologies offer relief from pollution? Would they provide better mobility for more people? How would they bear on highway investments? Such questions can, to some degree, be answered by monitoring the literature on advanced transport, but that carries the risk of dependence on the assumptions and possible biases of others. We believe that there is special value in the experience gained by the first-hand pursuit of studies that try to predict the impact and applicability of new systems. Therefore, an investigation of the dual-mode concept was undertaken that resulted in a different approach to the use of this innovation. That method, the initial findings from it, and some additional observations on dual-mode transport are reported in this paper.

DUAL-MODE TRANSPORT

The dual-mode idea has been described as a class of hybrid systems in which the conveyance operates both on conventional roads under control of the driver and on an exclusive guideway with control of the conveyance completely automatic and independent of the driver. Thus, the dual-mode conveyance could be driven on streets like an automobile or travel on high-speed off-street tracks like a miniature rapid transit car. Conveyance change-over from the transit to the road-vehicle mode would be accomplished only at ramps in stations adjoining the guideways.

It is expected that dual-mode facilities could also be utilized for personal rapid transit. Because individually owned conveyances would be ill suited to this kind of service, a supplementary fleet of what may be termed public conveyances would be needed.

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A public dual-mode conveyance would be available to anybody while it was standing empty in a station. (The right to exclusive occupancy for the person boarding an empty conveyance would probably be accorded by statute.) Further, provision might be made for renting public conveyances to use as road vehicles. They would, of course, have a private status when not on the dual-mode facilities.

Urbmobile

Originally intended to be a generic descriptor of the dual-mode concept, "Urbmobile" is a name coined in 1964 by Cornell Aeronautical Laboratory, Inc. (CAL). In the course of their work, the CAL staff developed a specific version distinct from those of other innovators. This nonproprietary system was taken as the subject of our analysis.

CAL's dual-mode Urbmobile proposal appeared to be well-developed, as described in its report (1). From among the system possibilities discussed by CAL we came to view the basic Urbmobile system in terms of the following set of attributes that are likely to be significant to prospective patrons:

1. Has automated exclusive facilities;
2. Can be ridden as express transit (60 mph);
3. Can be driven on roads at moderate speed;
4. Is of compact size—seats 4 (with parcels);
5. Has road range of 40 miles (on battery);
6. Can be rented or owned like an automobile;
7. May not require downtown parking; and
8. Does not contribute to air pollution (at street).

The CAL precept of basing its design solely on established engineering practice gives the Urbmobile system a quality of relatively immediate practicability, although at a price in road performance. Exotic (and unproved) battery developments were spurned by CAL in favor of conventional lead-acid storage batteries—amounting to over 800 pounds in the basic Urbmobile. Thus, the Urbmobile would not be a lively vehicle and nominally could travel only 40 miles without a lengthy battery recharge. In most instances that would effectively impose a 20-mile "tether" on Urbmobile travel beyond the electrified guideways.

Yet the modest capabilities of the Urbmobile are appropriate for the system as described by CAL (1). In the CAL study, the Urbmobiles seemingly were regarded as being possessed by multivehicle households and used to commute between outlying homes and downtown. Tolerance toward Urbmobile deficiencies could be expected of a clientele that could secure convenient and nearly effortless commuting and, at the same time, retain a regular automobile for other journeys. CAL also envisioned a relatively small fleet of public Urbmobiles in the metropolitan installations considered, but in general CAL's view of the system may be characterized as focused on the Urbmobile-owning downtown commuter. This outlook on dual-mode transport was recognized as deficient with regard to nondrivers and persons not possessing a conveyance, and CAL candidly stated (1, Vol. 1, p. 87): "At this time we are unable to cite a means of use by which the Urbmobile can be claimed to have an unmistakably significant advantage over any other public transportation system or automobile rental service."

Availability

It was our view that dual-mode transport should serve as many people as possible, with the aim of winning a large constituency for the support of its development and implementation. Moreover, a transport innovation blending rapid-transit ease with doorstep convenience for many persons ought to be under some obligation to help with the comparative immobility of other persons. Thus, we were concerned with making the dual-mode system broadly useful.

What seemed a promising idea was the inclusion of a short-term rental capability based on public dual-mode conveyances being available and returnable at all stations. This rental capability would enable a suitable licensed subscriber to use a public conveyance as his own until it was returned. System operations would benefit because empty public conveyances could be recirculated and stored indiscriminately (unlike private ones that must be retrievable by a specific person at a specific place). Yet this on-and-off kind of Urbmobile possession, despite its convenience for some subscribers, does not appreciably enhance mobility or gain efficient use of the public fleet.

The home is the key to the limited impact of the short-term rental concept. On the average, only two out of ten urban person trips are not made to or from home. For the large majority of trips, then, what is the situation at the home end? For rented public Urbmobiles to be available in the morning, they must (with few exceptions) have been driven home the previous evening and kept there overnight—just like a family automobile. CAL in its own investigation, however, indicated that possession of an Urbmobile would be financially comparable with owning an automobile (1, Vol. 1, pp. 81, 82, and 113; Vol. 2, p. 275). Therefore, the overnight "family style" possession of Urbmobiles would merely be a substitute for private automobiles, one for one. It is difficult to see how this practice would create a mobility gain for nondrivers and persons not having a vehicle in Urbmobile households. Vehicle availability could be improved greatly if off-line rental depots for public Urbmobiles were nearly as widespread as mail boxes, as in the PAS concept (2); however, that idea quite transcends the intent of dual-mode transport as generally conceived.

If we must reject the widespread use of rental depots, what about access to and from Urbmobile stations via nondriving modes? Walking is naturally the basic station access mode for those few trip-makers within range. The schedules of bus transit in middle-sized cities (our context here) have a way of seldom seeming convenient, and that experience would tend to affect the entire dual-mode trip. CAL proposed to combine access with line haul via the dual-mode Urbmobus. It is supposed to collect passengers along a street route and then take them along the guideway without any transferring—except by the driver, who would get off to board and operate an incoming Urbmobus. (On the guideway no one aboard would have authority to cope with an unruly rider. Also, the efficient scheduling of the drivers could become woefully complex.) Demand-jitneys appeared attractive for station access, but the feasibility of the basic concept had not been established.

An appealing means for extending station coverage would be by so-called "minibus loops." Each would be a short one-way route, traversed by a single small bus on a dependable 10-min headway from early morning until late evening. Figure 1 shows

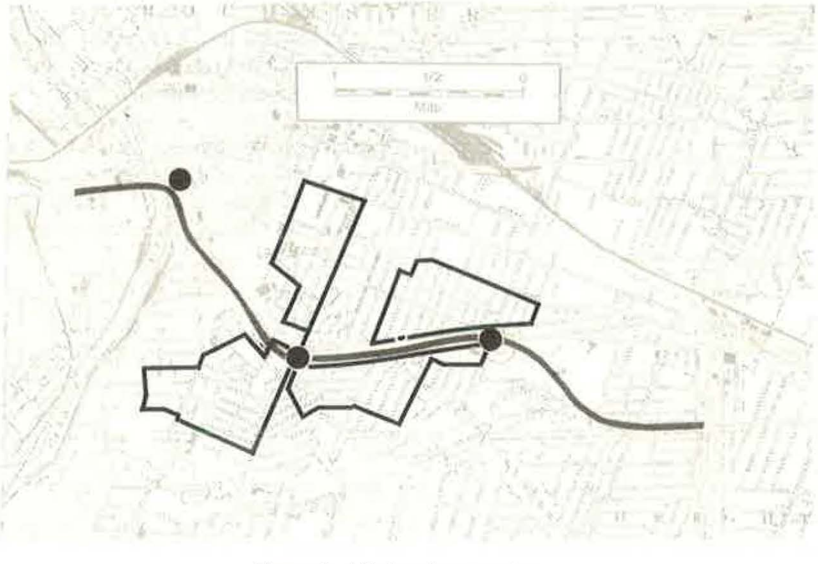

Figure 1. Minibus loop routes.

several loops warped to fit an existing street pattern. The service would be better than is usually available on typical bus routes in middle-sized cities. The simplicity of the operation facilitates estimating its expense, which is believed to be roughly in balance with the revenue likely to be generated.

Extent and Scale

The kind of Urbmobile installation primarily studied by CAL consisted of a few radial routes converging in downtown. Figure 2 shows how this kind of "basic" network might appear in a real metropolis. Obviously for many residents the facilities would be inaccessible or seldom useful. Enlarging the scope of a dual-mode installation seemed to require a more comprehensive network, augmented by minibus loops providing service to many of its stations. Figure 3 is an example of a so-called "metro" network, which encompasses most of the populous part of an actual metropolis. Urbmobile routes were laid out with an eye to effective coverage by minibus loops (which implies a route spacing of somewhat under 2 miles).

These contrasting types of Urbmobile networks could involve significant differences in the location and general bulk of their facilities. Much of the mileage of a basic network might advantageously follow existing railroads and freeways, thus facilitating economical construction of guideways alongside or above. Guideways could be sized to accommodate Urbmobuses while also allowing for the emergency service trucks that CAL tentatively proposed for removing disabled Urbmobiles (Fig. 4).

The comparatively fine mesh of the metro network would restrict locational options for many of its routes and would confine guideway alignments to narrow corridors, which would

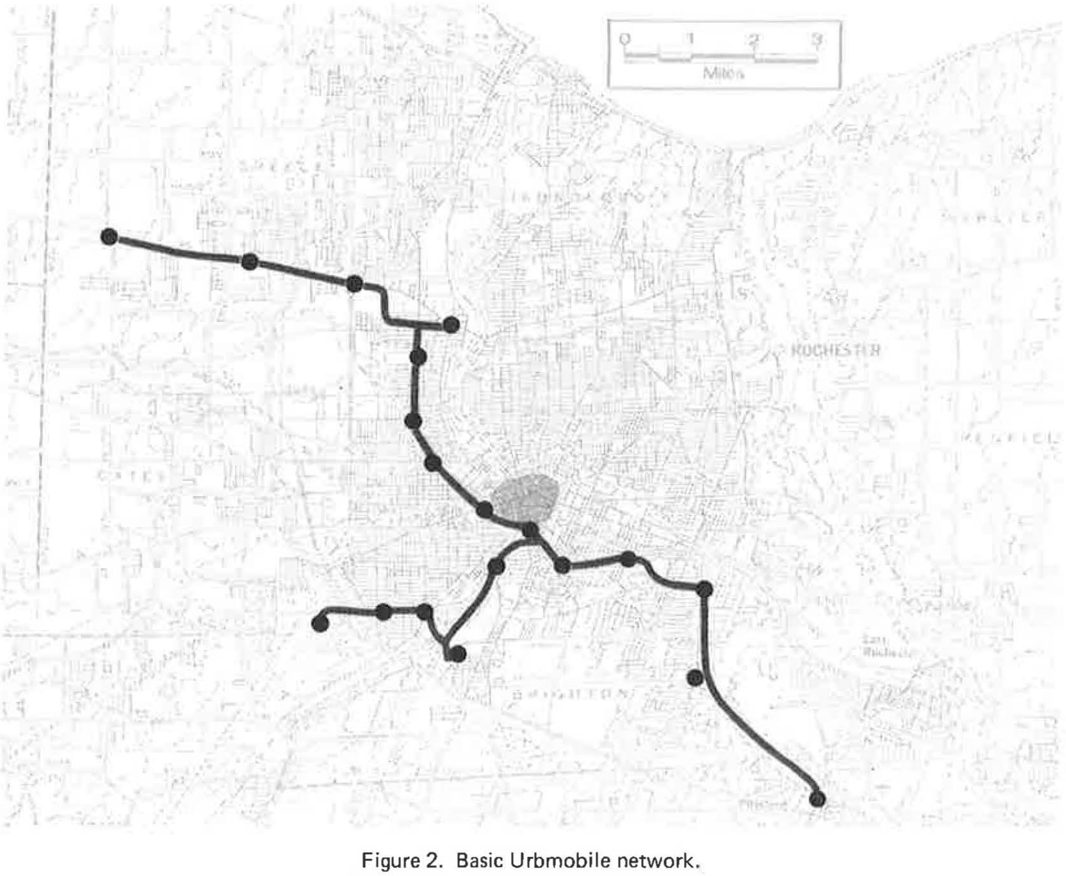

Figure 2. Basic Urbmobile network.

virtually compel fitting the facilities into all manner of urban settings. Hence a scaling down of Urbmobile facilities could become critical. Rejection of Urbmobuses and of the precautionary service trucks seems justified. Their omission (Fig. 5) might make possible a subway for Urbmobiles only, which would be shallow enough to avoid costly sewer relocation. Conceivably, too, the smaller elevated guideways (open or enclosed) would be tolerated where larger ones would not be. A metro network contains so many stations and junctions that their massive size, as conceived by CAL, would have to be curtailed sharply to prevent serious displacements (1, Vol. 1, p. 63).

It appears that dual-mode transport might be furthered by expanding the route network and contracting the scale of the fixed facilities. That would entail some modifications in Urbmobile technology, of course, but that might be the price to be paid for gaining a larger constituency.

UTILIZATION

Assumptions and Background

Any serious appraisal of a proposed innovative mode, and of the role it is apt to attain among other modes, depends heavily on how much it is expected to be used. Because Urbmobile would be so unlike existing modes, we were skeptical of applying current prediction techniques. We decided to place a hypothetical Urbmobile installation into a real-world trip-making environment and then to judge which trips might have found use of the facilities to be worthwhile.

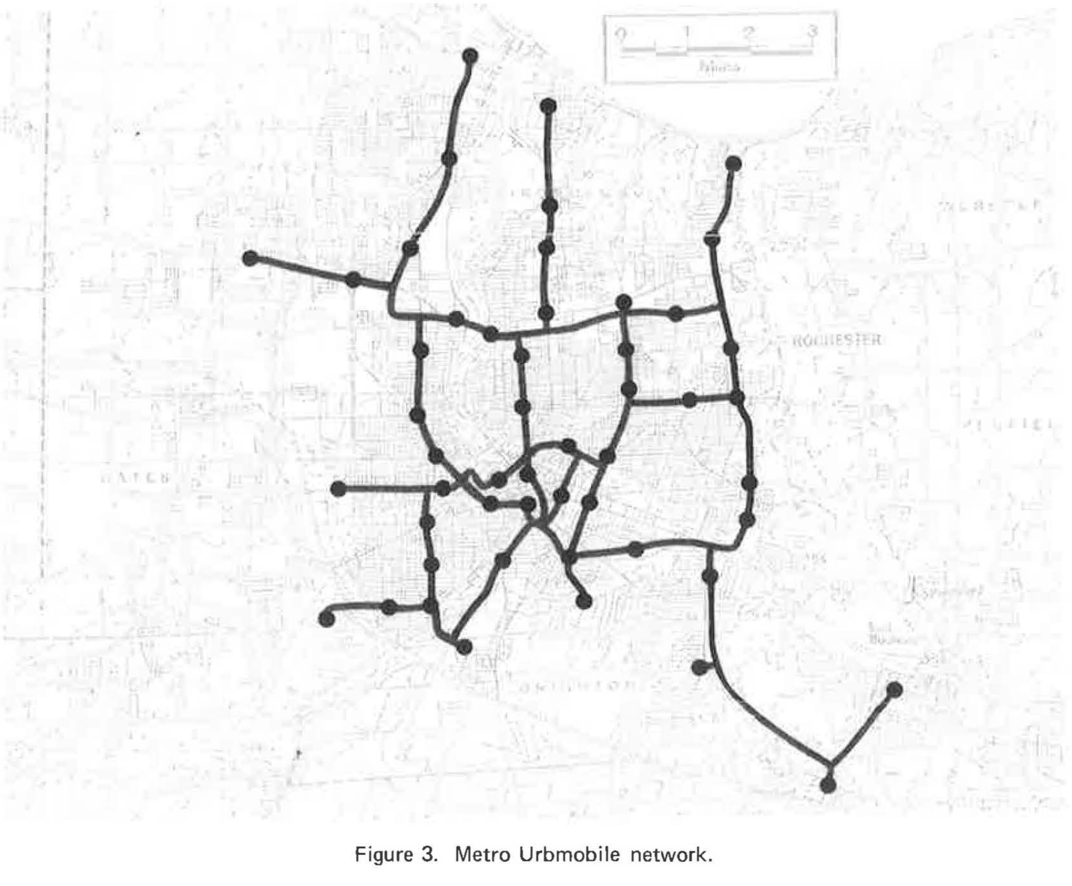

Figure 3. Metro Urbmobile network.

The trip-making environment was supplied by a large sample of person trips, as reported in the 1963 home interview survey of the Rochester Metropolitan Transportation Study (RMTS). Because the vast majority of such trips were by private automobile, the most productive initial course was to forecast Urbmobile patronage only from the actual trips of automobile drivers and their passengers. In relation to total vehicular activity in the survey area, the forecast patronage gives an indication of the local impact of the installation.

We refer to this type of forecasting as "synthesis." It is essentially just a reasoned selection of trips from the travel survey file. By computer, the trips were screened individually through a sequence of criteria. The criteria are supposed to reflect the forces on the trip-maker (and household) that would shape his response to the new system on each one of the survey trips. It is the resulting trip-maker responses—considered together, for one vehicle at a time—that finally determine which households might advantageously have possessed an Urbmobile.

The hypothetical Urbmobile installation to be tested was the basic network shown in Figure 2, less its spur to the southwest. As shown in Figure 6, the test facility is a single 17-mile suburbs-to-CBD route having 14 stations. To save computer processing, we excluded from consideration whole households and all their trip-making if they lived where an Urbmobile probably would not be useful. Only residents of the arbitrary "domain" (414,000 persons out of an RMTS total population of 610,000) were, by definition, even eligible to possess an Urbmobile.

Only the reported trips of private automobiles, and their "conversion" into Urbmobile trip-making, are dealt with in the synthesis. When considering its output, one should bear in mind the rudimentary nature of the procedure. Here are some assumptions and other factors in the synthesis:

1. Because the possession of an Urbmobile would be financially comparable to owning an automobile, households could only rent, lease, or own an Urbmobile to replace an automobile—not to supplement it.

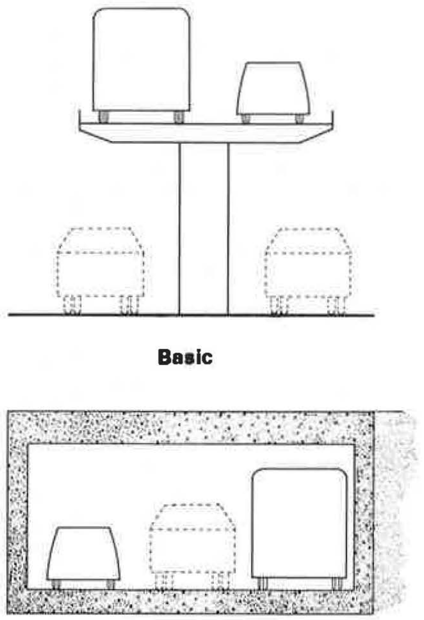

Figure 4. View of basic type of Urbmobile facility.

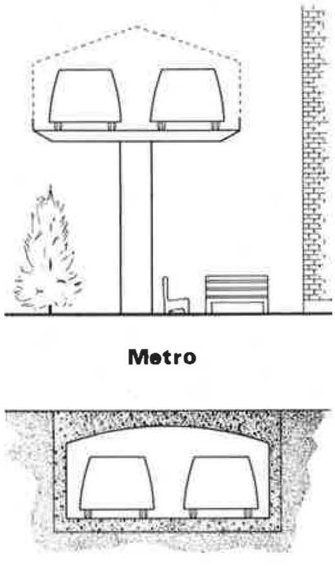

Figure 5. View of metro type of Urbmobile facility.

2. The patronage on the hypothetical high-speed route is drawn from traffic that occurred in the absence of such a facility, and it thus had no real-world opportunity to rearrange traffic patterns to its advantage.

3. Processing was expedited by using simple differences and aggregations of travel time, which was chosen as a major factor in determining Urbmobile possession.

4. Our survey data are a window on the trip-making activity of any particular household for a single workday—how the weekend performance of the new mode would affect its overall attractiveness is not known.

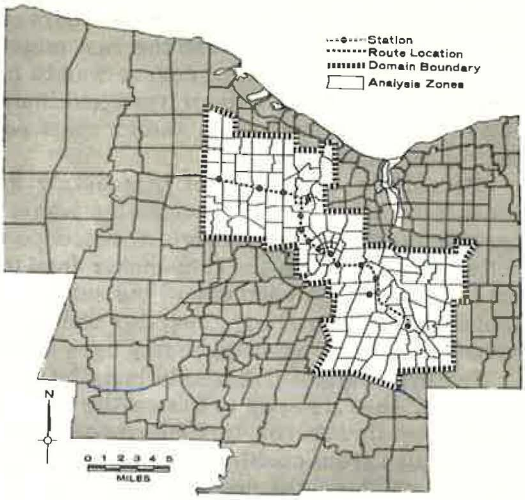

Figure 6. Urbmobile domain and hypothetical route.

Synthesis of Patronage From Automobile Trips

1. Screen out unsuitable trip records—The trip file, which includes thousands of detailed records, is first trimmed to facilitate later processing. The computer confronts each trip record with a battery of questions. Those records that do not deserve further consideration are ignored while the surviving records are duplicated on magnetic tape. As this abbreviated file progresses through later steps, any record that passes a major test is so marked, which allows analysis by category at the conclusion of the synthesis.

For the initial screening, households located outside of the domain are screened out as most unlikely candidates for possessing an Urbmobile. All trips made by persons not driving a private automobile and trips made by all households not having automobiles are also discarded. Urbmobile capacity and range limitations are taken into account in two ways. Any one-automobile household is excluded if it had more than four members, or if its automobile carried more than four occupants. Also, the computer is programmed to test whether the successive trips reportedly made by an automobile would have outrun the battery "tether" of an Urbmobile; if so, all travel by that automobile is disregarded.

2. Identify trips that might have utilized the guideways—Each record that was copied on the duplicate tape then faces the next challenge: Would the Urbmobile system have sufficiently improved the journey for the driver such that it might "qualify" as a possible dual-mode trip? Travel time can be conveniently used as the basis for deciding whether avoidance of city driving outweighs the delays in changing-over the Urbmobile between street and guideway travel.

(Existing tree-building programs permit calculation of average-speed travel time between every pair of traffic analysis zones. One set of zone-to-zone average-speed path values is calculated for automobile travel on the actual arterial network. A second set of path values is calculated for possible dual-mode travel on the same arterial network, to which the hypothetical high-speed guideways are added in the form of infinite-capacity freeways connecting directly with the arterials at each Urbmobile station.)

A look-up table is used by the computer to find the two-path values for whatever trip is being screened. If the paths are equal, the guideways were not useful; in that case the trip is of no more interest. If the paths are unequal, the guideways seemingly provided a faster route than did arterial streets. The apparent saving in time could not fully be realized in practice, however, because of Urbmobile mode-changing delays. Therefore a realistic penalty is charged—about 1 min to enter the facilities and 1 min to leave—and a "net time saved" is calculated for the trip. (Should this turn out to have a negative value, the dual-mode trip would have taken longer than driving the whole way on the streets.)

Metropolitan travel is probably perceived by the traveler in terms of both time and effort. We assume that drivers in Urbmobiles would prefer the ease of traveling on the automated guideways even if that slightly lengthened the trip duration. Therefore each trip is subjected to the tentative (and arbitrary) criterion shown in Figure 7 in order to decide whether there is enough net time saved relative to automobile driving time. For example, a ½-hour automobile drive could take as much as 3 min longer when made partly via guideway and yet still qualify.

Figure 7. A criterion for deciding whether an automobile trip would save enough time to qualify for further synthesis processing.

3. Select households warranting an Urbmobile—The trip records of each household are processed individually, and the computer identifies those trips qualified to become dual-mode trips. These trips are the input for answering the question, If the advantages of the dual-mode system for this household today are considered, would an Urbmobile have been warranted in view of system disadvantages? The warrants shown in Figure 8 offer explicit criteria for deciding whether a household automobile should be converted to an Urbmobile. These arbitrary warrants are readily altered. They match the total net time an Urbmobile would save against the total amount of time for driving an automobile over the same 1-day aggregation of trips. For any household these two totals define a point on Figure 8. If the point lies on the convex side of the criterion line, an Urbmobile is not warranted.

Because of the assumed role for the Urbmobile as an automobile replacement, one-automobile households would be most sensitive to system deficiencies. Therefore, a relatively stringent warrant (Fig. 8, left) is appropriate for such households. As an example of the present criterion, if a one-automobile household would not save time by using an Urbmobile, none would be warranted unless the single automobile had been driven for at least 45 min on "qualified" trips. In the case of multivehicle households, the more lenient warrant is applied to each driver individually, as a subhousehold, though no more than one Urbmobile is ever assigned to an entire household.

When an Urbmobile is found to be warranted by a household (or by a driver or subhousehold), all of its trip records are so marked on the duplicated magnetic tape. This amounts to conversion of the automobile and its trips into an Urbmobile that made Urb-

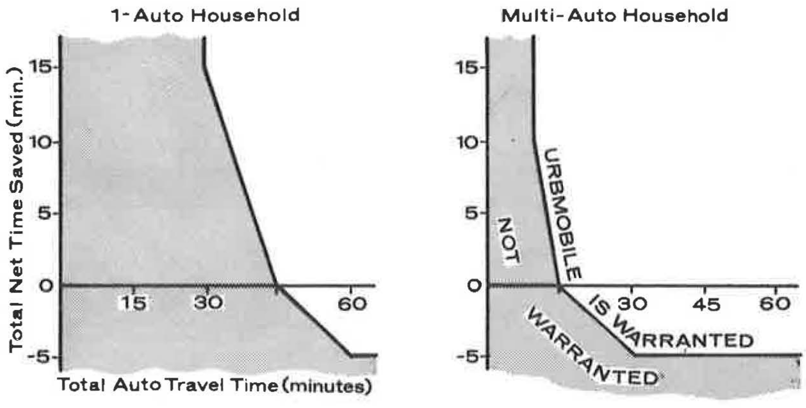

Figure 8. Tentative criteria for deciding whether an automobile would warrant being converted to an Urbmobile.

mobile trips. Trips that traversed only the streets are Urbmobile "street" trips; the so-called qualified trips finally become dual-mode Urbmobile trips, which implies some use of the guideways.

Synthesis Results

Preliminary results from the synthesis procedure are given in Table 1. These results are shown in Figure 9 in relation to the domain. Perhaps the most striking feature is the seemingly minor share of vehicle possession and use attributable to household Urbmobiles. In fairness, though, the arbitrarily defined domain may be disproportionately large as the basis for judging the single Urbmobile facility.

More significant is the evidence of the important contribution that converted one-automobile households would make to system utilization. Although under present criteria fewer than 10 percent of the one-automobile households switched to possessing an Urbmobile, these households would produce over 40 percent of the revenue from

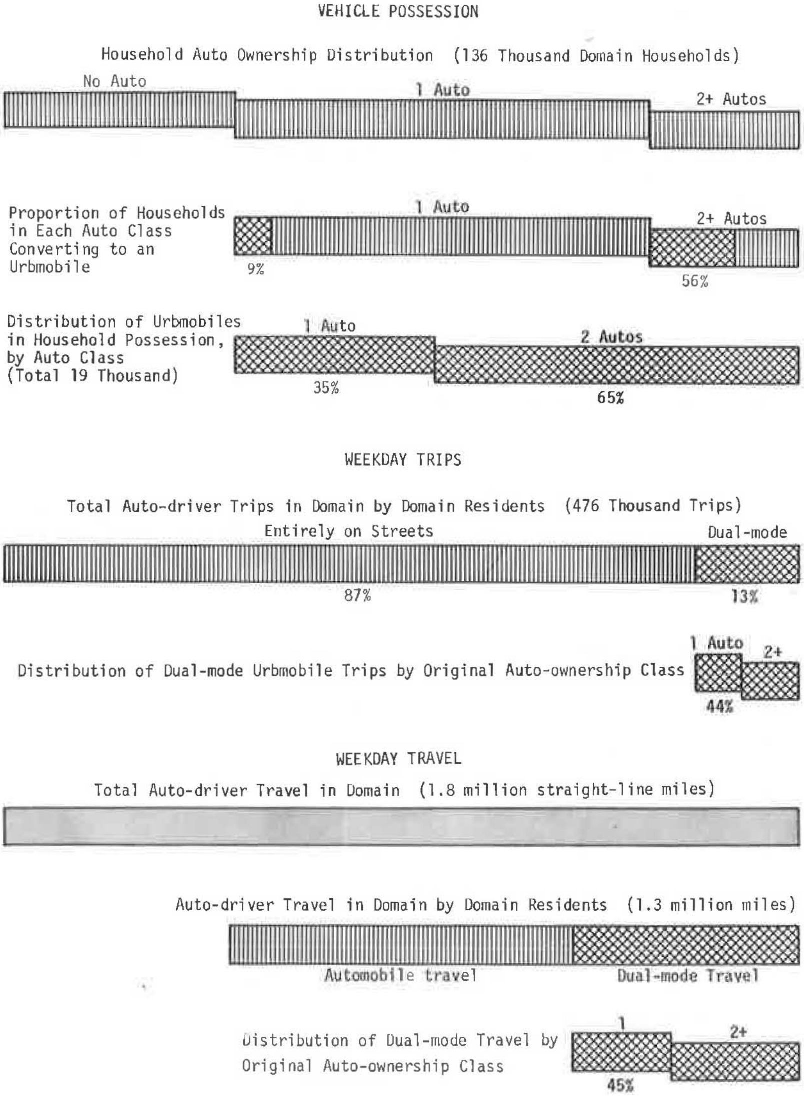

Figure 9. Results of a trial synthesis: role of Urbmobiles in relation to domain.

TABLE 1

RESULTS FROM AN INITIAL SYNTHESIS

Household Use and Possession of Urbmobiles	Household Automobile Ownership			
	1 Car	2 Cars	3 Cars	Total
Urbmobiles (one per household)	6,773	10,967	1,588	19,328
Urbmobile trips				
Dual-mode	26,177	29,208	4,478	59,863
Street only	20,159	26,624	4,482	51,265
Person trips via urbmobile				
Dual-mode	39,680	40,264	6,172	86,116
Street only	30,775	39,558	7,309	77,642
Urbmobile travel (straight-line miles)				
Dual-mode	135,473	143,944	24,415	303,932
Street only	37,361	50,799	9,567	97,727

converted automobile travel. The obvious inference is that an Urbmobile installation—needing all the utilization it can gainfully obtain—must be designed as a complete system that serves the needs of present-day one-automobile households. A valuable auxiliary might be an automobile rental service that could dispel any inconvenience caused by not keeping an automobile all of the time.

It must be emphasized that present criteria represent an initial venture. Further work is expected to give insights on the sensitivity and, perhaps, reasonableness of the criteria governing patronage. In any case, sensitivity analysis can in principle be carried out simply by altering criteria in the computer program in an easily understood and explicit fashion.

This first test indicates that Urbmobiles possessed by households in the domain would, on a typical weekday, generate about 300,000 (straight-line) miles of dual-mode travel plus about 100,000 additional miles of travel on street-only trips. Although the net environmental gain in electrifying that much travel has not been established, it is estimated to represent the avoidance of street fumes from the incomplete combustion of perhaps 100 tons of gasoline a day. Another environmental benefit would be the shifting of travel from road facilities to the high-speed guideways. For the average dual-mode trip a net reduction of about 2.75 road-miles could be expected. (This is based on having "driven" eight so-called qualified trips over a map of the Urbmobile route and city streets. Each trip was made as an automobile would travel and repeated as an Urbmobile taking advantage of the high-speed facility for part of the way.) The Urbmobile guideway is thus estimated to lift roughly 165,000 vehicle-miles of travel daily from domain streets. That is about one-eighth of the automobile travel made within the domain by its residents.

The synthesis indicated that Urbmobiles would replace only 1 out of every 6 automobiles among the 125,000 owned by domain residents. Still, a requirement for some 20,000 Urbmobiles is implied. A production lot of that size, even in the absence of a wider national market, should be large enough to benefit significantly from economies of scale.

Preliminary Urbmobile Economics

A rough economic check can hint at the financial realities of the kind of Urbmobile installation tested here. First, consider the fixed facilities. The investment in them is reduced to an annual expense and then combined with an assumed total operating expense (Table 2). (The capital recovery factors given in Tables 2 and 3 approximate a 5 percent interest rate on a quarter-century term for fixed facilities and a one-decade term for the fleet. Considered historically, the designated interest rate is not unreasonable. The service life assigned the facilities is comparable with that often given highways, and the Urbmobiles, necessarily kept in excellent repair, presumably outlast the average automobile but not the average transit bus.)

TABLE 2

ESTIMATE OF FIXED EXPENSE FOR HYPOTHETICAL URBMOBILE FACILITY

Item	Cost (millions of dollars)	Annual Expense (millions of dollars)
Line		
New subway, 4.1 mi at $8 million/mi	33	
Elevated and surface, 13.3 mi at $2 million/mi	27	
Stations		
Outer, 13 at $2 million	26	
Central, 1 at $4 million	4	
Subtotal	90[a]	6.3
Operations (assumed)		
100 station attendants and 200 other employees		3.0
Power, supplies, upkeep, and revenue handling		3.7
Total		13.0

[a] $90 million at 0.07 capital recovery factor = $6.3 million.

TABLE 3

ESTIMATE OF EXPENSES RELATING TO AVERAGE HOUSEHOLD URBMOBILE

Item	Annual (dollars)	Daily (dollars)	Per Mile (cents)
Depreciation, $3,000 at 0.13 capital recovery factor	390	1.07	4.6
Insurance	50	0.14	0.6
Maintenance		0.12	0.5
Road-use tax[a]		0.12	0.5
Total		1.45	6.2

[a] 50 percent of travel is estimated to be on roads.

The final $13 million annually (Table 2) is essentially a fixed expense, notwithstanding some variable components. This sum translates to an average $40,000 expense per weekday, assuming 325 equivalent weekdays per year. To illustrate its scale, this burden may be charged entirely to the dual-mode travel of the 19,300 Urbmobiles. Their synthesized 300,000 straight-line miles are equivalent (at a 1.25 network/straight-line ratio) to 375,000 miles of travel on roads and guideway. Thus, the expense of the installation—exclusive of the fleet and of patronage from sources other than household Urbmobiles—could be covered by a rate of fare approaching 8 cents per dual-mode Urbmobile mile.

Next, the economic component relating more directly to the fleet may be estimated. The average household Urbmobile travels a total of about 21 (straight-line) miles per weekday, or some 23 miles of guideway and road travel every day (allowing for equivalent weekdays and network/straight-line conversion). Because it is less exposed to street traffic than most automobiles, such an Urbmobile might incur an insurance premium of about $50 annually. The average expense for possessing and using one of these conveyances (estimated by CAL to cost $3,000) is given in Table 3.

The total economics of the typical "family" Urbmobile, assembled from these components, are summarized as about 15 cents a mile, or roughly $1,200 per year. Because these estimates are derived from crude inputs, for a specific installation, they should be considered merely as tending to confirm that a family Urbmobile would be as expensive a possession as a family automobile. The highly conjectural nature of nearly all cost items in this brief economic check cannot be overemphasized.

CONCLUSION

The synthesis technique described here appears to be a reasonably straightforward approach to estimating the expected use of an entirely novel transport system. In the context of the middle-sized metropolis, the results suggest that dual-mode transport may border on financial feasibility, in spite of the heavy capital expense of the automated guideways and related facilities.

Underlying that tentative conclusion are the merits and flaws of a particular dual-mode system, Urbmobile, proposed and described by Cornell Aeronautical Laboratory, Inc. Although Urbmobile technology should achieve commendably simple automation of the guideways and stations, there are some deficiencies in the Urbmobile system as a whole. These deficiencies primarily stem from the inadequate performance of the Urbmobile when driven on streets; the typical household that owned only one automobile would be disinclined to give it up for an Urbmobile limited in road range and speed. If the Urbmobile could be modified in this regard to perform as well as an ordinary automobile, numerous one-vehicle households might be induced to convert, thus increasing guideway travel and system revenue. Alternatively, instead of the automotive refinement of Urbmobiles, a convenient and favorably priced automobile rental service for regular Urbmobile possessors might be incorporated into the system.

It is evident that the existence of a metropolitan dual-mode guideway network would not, by itself, overcome limitations on personal mobility caused by the lack of a vehicle or the inability to drive. If a costly dual-mode installation is to be used fully and make its maximum social contribution, access to the facilities by everyone cannot be ignored. Thus, adequate transit service to and from the dual-mode stations should be considered an important system element.

There may be a significant environmental role for the Urbmobile system. Although its clean-air superiority has been diminished with the advent of legislation on vehicular emissions, the small size of the guideways could prove to be highly advantageous. Potentially, these channels might move travelers rapidly and individually with little disruption to the urban environment. If Urbmobile technology and operations could be adjusted to minimize the scale of all the automated facilities, the system might be feasible to install in urban corridors where the construction of conventional high-capacity facilities is becoming unacceptable.

It appears that dual-mode transport may be furthered in a variety of ways, some technological and others commercial or institutional. The parties interested in this innovative transport concept ought to consider seriously the purposes for which the dual-mode capability is desired and how it most effectively may be employed.

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A NOVEL SYSTEM FOR IMPROVING URBAN TRANSPORTATION

T. Z. Harmathy, National Research Council of Canada

With the conventional "stop-go" type of traffic the overall speeds achievable in urban dimensions are discouragingly low. Because the limitation in the attainable maximum overall speeds is due to physiological reasons, namely, to the limited ability of people to endure the discomfort of acceleration and deceleration, it cannot be eliminated by the application of technological improvements. A novel "semiconventional" transportation system is suggested, by which the overall speeds achievable with conventional systems can be doubled. The concept of "at-speed" passenger transfer is used. With the aid of mobile people-platforms carried on board, any passenger can be transported nonstop from any station to any other station of the transit line without the need for additional trackage. The traffic remains unfragmented and the rules of travel are simple. The system has to operate automatically. The applicable control systems, some technical solutions, and the question of passenger safety are briefly discussed. Under a particular set of conditions, it is possible to build a cable-operated version of the system, which offers the additional advantages of very simple operation and very high degree of safety.

•URBAN development experts are greatly concerned about the problems posed by the transportation of people in certain rapidly growing urban areas. The unrivaled popularity of the private automobile is undoubtedly the main source of the difficulties. In this free society, however, any new system designed to improve urban transportation must offer not only superior performance but also some additional advantages by which people can be enticed away from the convenience of using their private cars.

SHORTCOMINGS OF CONVENTIONAL TRANSPORTATION SYSTEMS

Unfortunately, it seems unlikely that the pressing problems of urban transportation can be solved by the use of conventional rapid transit facilities. Some recent developments, such as computerized controls, will undoubtedly improve some safety aspects of the operation. The plain truth is, however, that an upper limit exists beyond which the overall speed of conventional transportation cannot be increased, and this limit is discouragingly low under normal urban conditions.

The thick curve shown in Figure 1 is a typical speed-time curve for an underground train at 1-mile station-to-station distances. The time allowed for the boarding and disembarking of the passengers was taken as 25 sec, and the initial acceleration and braking deceleration as 0.000833 mile/sec^2 (3 mph/sec), which is probably close to the maximum value permissible from the point of view of tolerable passenger discomforts. With the given speed-time curve the overall speed of transportation is only 30 mph.

It is obvious that under the given conditions the overall speed of transportation cannot be higher than it would be if the train kept accelerating at the maximum permissible rate up to the point when the braking retardation begins (also at the maximum permissible rate), as shown by the thin speed-time curve in Figure 1. The overall speed in

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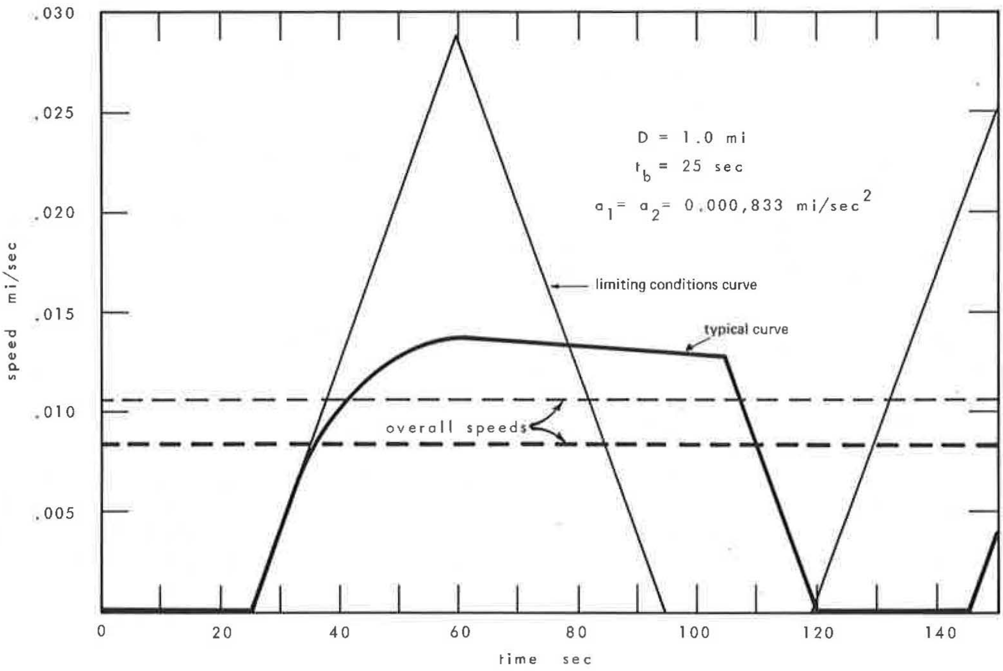

Figure 1. Speed-time curves for conventional system.

this limiting case is 38.2 mph, only 27 percent higher than in the previous realistic case. Yet to achieve even this modest gain the available power has to be increased by at least a factor of 4.

The limiting overall speed can be calculated by the following equation:

$$(v_o)_{lim} = \frac{D}{t_b + \sqrt{[2D/(a_1 + a_2)]}\left[\sqrt{(a_1/a_2)} + \sqrt{(a_2/a_1)}\right]} \tag{1}$$

where

$(v_o)_{lim}$ = limiting overall speed achievable with a conventional system, miles/sec;
D = distance between stations, miles;
t_b = time of boarding and alighting, sec;
a_1 = permissible acceleration, miles/sec^2; and
a_2 = permissible deceleration, miles/sec^2.

The following values were calculated by Eq. 1 for t_b = 25 sec and $a_1 = a_2 = 0.000833$ mile/sec^2:

D (miles)	v (mph)
0.5	24.3
0.75	31.8
1.0	38.2
1.25	43.9
1.5	49.2
1.75	54.0
2.0	58.6

Whether the value 0.000833 mile/sec^2 actually represents the upper limit of tolerable passenger discomforts may be questioned by some physiologists. Nevertheless, it is believed that realistic comparisons can be made with the consistent use of this value.

Two important conclusions can be drawn from the data given in this table.

1. With the conventional stop-and-go type of systems, it is impossible to achieve overall speeds comparable with the average speed of freeway traffic unless the station-to-station distances are selected at several miles; and
2. The speed barrier is based on physiological constraints and cannot be exceeded by the application of technological improvements such as by the use of more powerful motors or computerization of the operation.

Because of these difficulties, the Stanford Research Institute (1, 2) recommended the conventional mode of operation only for extended area travel, preferably for station-to-station distances greater than 4 miles. For travel at major activity centers and in local areas the reports visualized the use of more continuous types of transportation facilities such as low-speed conveyors and man-controlled or automatic point-to-point transportation systems.

There are, however, considerable difficulties in providing point-to-point public transportation systems. Relatively few people can be expected to contemplate identical trips. For example, 45 different nonstop trips are conceivable in each direction along a line comprising 10 stations. Thus the time gained by completing the trip nonstop may be overshadowed by the time lost due to long waiting periods at the stations. In addition, a complete fragmentation of the traffic—similar to present automobile traffic—would result.

A SEMICONVENTIONAL SYSTEM

By using the system to be described here, the limiting overall speeds achievable in urban dimensions, even by the most modern transportation facilities, can be doubled. This system has been devised to solve the fundamental problem of urban passenger transportation: how to make large numbers of nonstop trips possible without the complete fragmentation of the traffic and without adding substantially to the cost of transportation.

The system utilizes the principle of at-speed passenger transfer between vehicles temporarily joined together. Generically similar systems have been suggested earlier by Fogel (3), M.I.T. (4, 5), and Larson (6). The M.I.T. system was specifically developed for providing nonstop passenger transfer between intercity and intracity trains. The other two systems are easily adaptable to both long-distance conditions and urban conditions. They both require some additional trackage, the relative length of which increases with a decrease in the distance between the stations, and thus may not be ideal under certain typical urban conditions.

The basic concept of the present system was suggested by Brown (7) almost 70 years ago. With his system the at-speed transfer of passengers could be achieved without the need for extra trackage. Because the utilization of his idea required a much more thorough knowledge of automation than was available at the turn of the century, it is not surprising that his suggestion received hardly any attention. Much later, Barry (8) described some automatic control equipment applicable to Brown's system.

By using the semiconventional system, the nonstop transportation of passengers takes place along a single track by the repeated application of the following operations:

1. The overtaking of a transport unit that carries passengers boarded recently at a station along the transportation line by a second unit that runs behind nonstop through this station;
2. The temporary joining of the two units;
3. The automatic advancing of the through-passengers from the second unit into the first and the transferring of the passengers to be discharged at the next station from the first unit into the second; and
4. The leaving behind of the second unit with the passengers to be discharged at the next station and the nonstop running of the first unit through this station.

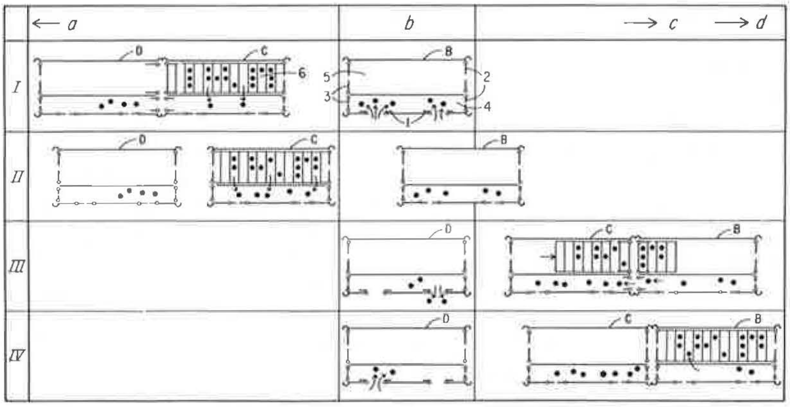

Figure 2. Operation of semiconventional system.

Figure 2 shows phases I through IV of the operation, involving vehicles B, C, and D, in the vicinity of a station b. All vehicles are of identical design. They have side doors (door 1) on the side of boarding and end doors at the front and rear (doors 2 and 3) respectively. The interior of each vehicle is divided into two areas. Area 4 is a strip area adjoining the side doors. This area is for interim stay and one- and two-station travelers; therefore, it is not furnished with seats. Area 5 will be referred to here as the "operational" area. It is accessible from the strip area only when covered by a mobile "people-platform," which in phase I is located over the operational area of vehicle C and is shown as a lined area. There may be seats provided on this platform. Because the average travel time with the use of this system is, in urban dimensions, usually less than 10 min, it is believed that a few seats should be provided for disabled persons only.

In phase I, vehicle B stands still in station b, and its side doors are open allowing passengers to board. (The passengers are shown as dots. Their movements and the movement of the people-platform are indicated by arrows.) Those passengers who wish to travel farther than station c can stay anywhere along the strip area, but the one-station travelers must remain in the vicinity of the rear-end door.

A combined unit, consisting of vehicles C and D, are approaching from the direction of station a. Before reaching station b, unit C-D will separate into its components, as shown in phase II. Vehicle D slows down and later stops in station b, while vehicle C continues its travel at its cruising speed through the station.

Meanwhile the process of boarding in station b has ended. The side doors of vehicle B have closed and the vehicle has left the station. It is now accelerating. The time of its departure is programmed, and its speed is controlled in such a way that, by the time vehicle B attains its cruising speed, it is overtaken by vehicle C. The two vehicles join and for a while continue their travels as a temporarily combined unit.

In phase III, unit B-C is shown a few seconds after the joining of the vehicles. Their adjacent end doors are open and the people-platform, with passengers on it, is in the process of advancing from vehicle C to vehicle B. During this time two of the recently boarded passengers of vehicle B, who want to alight at station c, walk over to the strip area of vehicle C.

Vehicle D is already standing still in station b, and its side doors are open allowing passengers to alight. In phase IV the discharge is completed and new passengers are boarding. Phase IV also shows the last moments of the existence of combined unit B-C. The advance of the people-platform has been completed and the adjoining end doors of the two vehicles are already closed. The passengers who wanted to alight at station c are by now all in the strip area of vehicle C. Those passengers of vehicle B who intend to disembark at station d remain standing in the strip area. All others start to move onto the people-platform. In a moment unit B-C will separate into its components.

Vehicle C will stop at station c, while Vehicle B will run through the station for a rendezvous with vehicle A (not shown).

The speed-time curves for the four vehicles are shown in Figure 3. When the time allowed for embarkation and disembarkation expires, vehicle B (the speed-time curve of which is shown in thicker line) leaves station b. As mentioned, its time of departure and speed during the period of acceleration are programmed in such a way that, at the time when vehicle B attains its cruising speed, it becomes overtaken by vehicle C, which has been approaching from the direction of station a. The two units join, and in this temporarily combined unit the people-platform advances. (The period of advance is shown in Figure 3.) After the completion of the platform movement, unit B-C divides into its original constituents. Vehicle B, with the through-passengers (and the people-platform) on board, continues its travel at the cruising speed and passes nonstop through station c to join with vehicle A, while vehicle C, with the passengers to be discharged on board, slows down and stops at station c.

The initial acceleration and the deceleration of 0.000833 mile/sec^2 were also selected here so that comparison can be made with the conventional system. The cruising speed (i.e., the overall traveling speed over a large number of stations) is 73.4 mph, which compares with an overall speed of 30 mph under similar conditions with the use of the conventional system (Fig. 1).

It is clear from data shown in Figure 3 that the time required for the advance of the people-platform is one of the main factors that limits the achievable cruising speed. If we assume that the first third of the travel of platform takes place at constant acceleration, the second third at constant velocity, and the final third at constant deceleration, and that the acceleration and deceleration are of equal value, the time of advance of the platform can be written as

$$t_p = 2.5\sqrt{2L/3a_p} \tag{2}$$

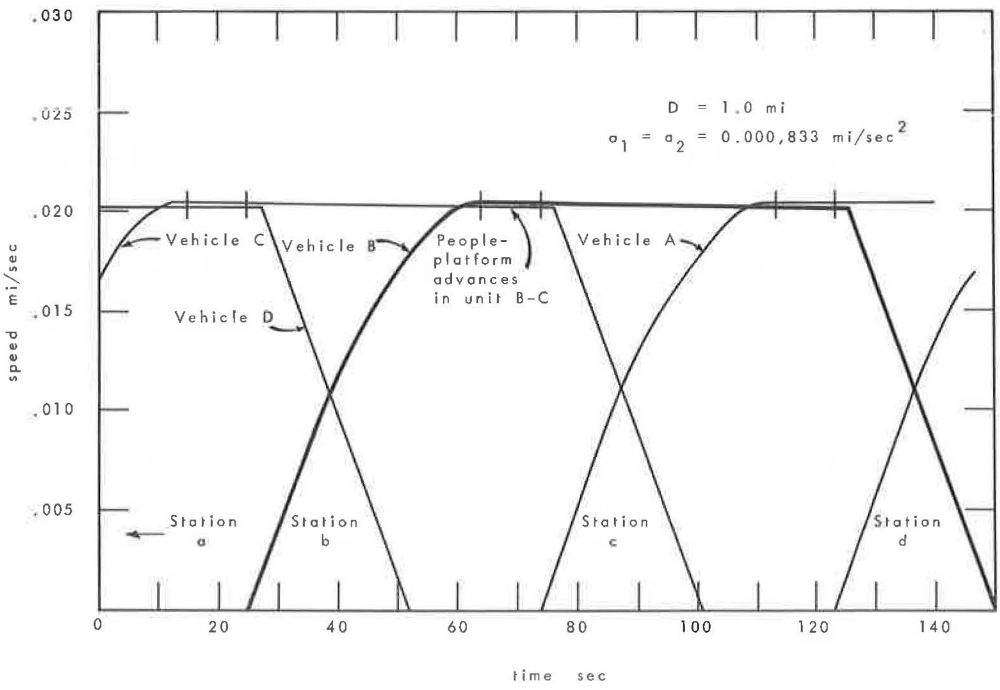

Figure 3. Typical speed-time curves for semiconventional system.

by virtue of the fact that the total travel of the platform is equal to the vehicle length. In this equation t_p = time of advance of platform, sec; L = length of vehicles, miles; and a_p = acceleration and deceleration of people-platform, miles/sec^2.

The following expressions can be further utilized in estimating the achievable cruising speed: The distance run by the first vehicle during its period of acceleration (by the end of which the cruising speed is reached) can be taken roughly as

$$s_1 = v^2/a_1 \tag{3}$$

i.e., as twice the distance that the vehicle would run if the initial acceleration (taken as the maximum permissible acceleration) could be maintained throughout the entire period. The distance covered by the second vehicle during its period of deceleration (with the deceleration taken as constant and equal to the maximum permissible deceleration) can be written as

$$s_2 = v^2/2a_2 \tag{4}$$

Finally, the distance run by the two-vehicle unit at the cruising speed is

$$s_c = v(t_p + t_m) \tag{5}$$

In Eqs. 3, 4, and 5

s_1 = distance covered by the first vehicle during the period of acceleration, miles;
s_2 = distance covered by the second vehicle during the period of deceleration, miles;
s_c = distance covered by the two-vehicle unit at the cruising speed, miles;
v = cruising speed, miles/sec; and
t_m = time required for miscellaneous operations, such as the joining and separation of vehicles and the opening and closing of the end doors.

Because the sum of s_1, s_2, and s_c must be equal to the station-to-station distance, D, an equation is obtained from which the cruising speed can be expressed. The result is

$$v = \frac{\sqrt{\left[2.5\sqrt{(2nL/3a_p)} + t_m\right]^2 - 4D\left[(1/a_1) + (1/2a_2)\right]} - \left[2.5\sqrt{(2nL/3a_p)} + t_m\right]}{(2/a_1) + (1/a_2)} \tag{6}$$

In this equation nL has been used instead of L to allow for the possibility that each transport unit may be made up of n number of vehicles.

Another important aspect of the system is the maximum passenger throughput, which is limited by the fact that the movement of each unit is programmed. Therefore, to avoid interference and to allow sufficient times for boarding and alighting, there must be a minimum time left between the departure of two subsequent units from the same station. From an examination of the conditions the following equation can be derived:

$$T \approx t_b + t_1 + t_c + t_2 - (D/v) \tag{7}$$

where

T = minimum time-spacing between two units departing from the same station, sec;
t_1 = period of acceleration, sec;
t_2 = period of deceleration, sec; and
t_c = time of run between two stations by a combined unit at the cruising speed, sec.

By expressing these variables in terms of some already introduced variables one obtains

$$T \approx t_b + (v/2)\left[(1.4/a_1) + (1/a_2)\right] \tag{8}$$

Consequently

$$V \approx (3{,}600\ nC)/\left\{t_b + (v/2)\left[(1.4/a_1) + (1/a_2)\right]\right\} \qquad (9)$$

where

V = maximum achievable throughput, passengers/hr, and
C = passenger capacity of one vehicle.

Equations 6 and 9 are only approximately valid. The exact expressions for v and V depend on the actual speed-time program during the period of acceleration.

In the design of the system it is usually necessary to check whether the throughput of the system is sufficient both for one-station and for multistation travels. The first can be expressed as some fraction of the capacity of the strip area, and the second is determined by the capacity of the people-platform. Of course, such a sophisticated calculation can be performed only if a reasonably good estimate of the passenger flow model is available.

Figure 4 shows some calculations based on Eq. 1 concerning the limiting speed for conventional systems and on Eqs. 6 and 9 concerning the cruising speed and maximum throughput for the described semiconventional system. The following numerical values have been used: $a_1 = a_2 = a_p = 0.000833$ mile/sec^2; $t_b = 25$ sec; $t_m \approx 0$; $L = 0.009470$ mile; $n = 1$ to 5; $D = 0.5$ to 1.5 miles; and $C = 250$ passengers.

The multistation transportation speeds that can be achieved with the present semiconventional system are, in urban dimensions, twice as high as the limiting overall speeds that can be attained with the conventional system and are comparable to or higher than the average speed of freeway traffic. This finding clearly indicates that the described system is potentially capable of competing with automobile transportation in popularity.

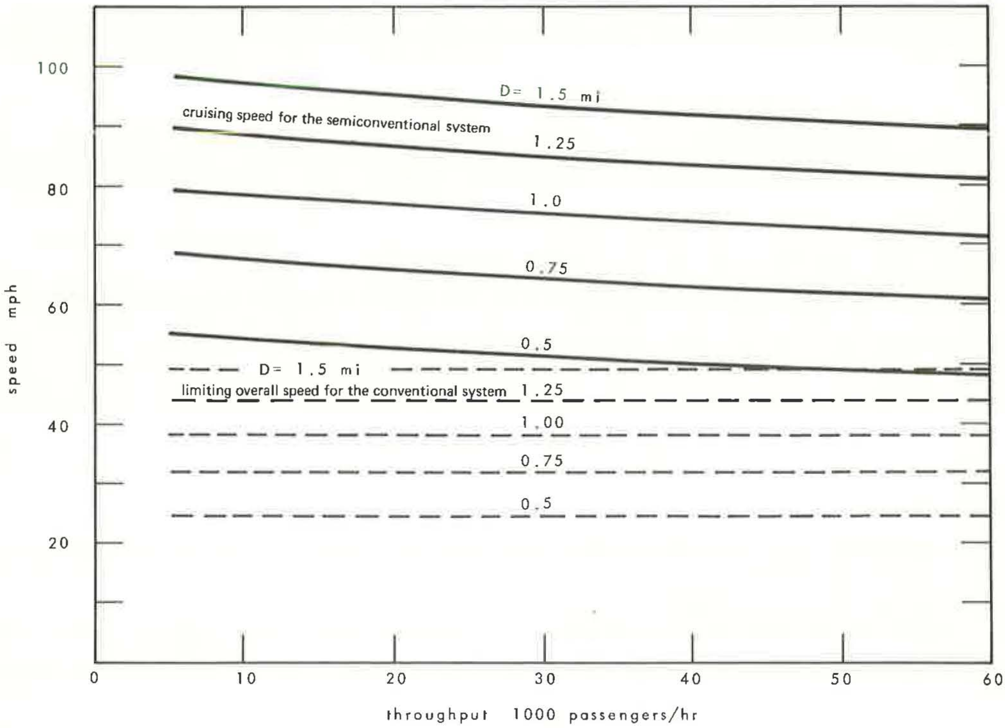

Figure 4. Comparison of performances of semiconventional system and conventional system.

It is obvious from data shown in Figure 2 that the number of vehicles needed for the operation of this semiconventional system is larger than that for a conventional system. The rolling stock requirement is roughly three times as high as in the case of stop-and-go type of traffic and even higher for lower throughput levels if the system is designed for a passenger throughput close to the maximum achievable value (Eq. 9). Clearly, the need for a greater number of vehicles is the price that has to be paid for faster transportation. It is well known, however, that modern rapid transit facilities have at least 80 percent of their investment in immobile assets, such as acquisition, track, structures, stations, and power supply facilities, so that the extra costs associated with the larger number of vehicles do not alter the overall expenditures significantly. (In general, more than 100 transit vehicles can be purchased for the price of a 1-mile section of a subway line.)

Control

It is clear that the smooth and safe operation of the suggested transportation system is inconceivable without automatic controls. An extremely simple control system can be devised in that particular case if the following two conditions are met:

1. The transportation line can be made a closed curve without sharp curvatures (half of the curve may take care of the reverse traffic or the reverse traffic can be carried on a parallel loop), and
2. The stations can be spaced at equal distances.

Under these conditions the system can be operated from (k + 2) cables or chains (k = 1, 2, 3, . . .) with every (k + 2)th vehicle firmly attached to the same cable at kD distances. The movements of the cables can be effected from (k + 2) sets of stationary motors, brakes, and control equipment programmed to yield the prescribed periodic movements, differing only in phase for the various cables.

Fortunately, the least expensive solution is one that gives maximum passenger throughput. In this case three cables are needed, and every third vehicle is attached to the same cable at distances equal to the station spacing.

With careful planning of the transit lines the preceding two conditions can always be met. Figure 5 shows an example of the arrangement of the transit lines in a metropolitan area in such a way as to fulfill those conditions. In this example the rapid transit system consists of seven closed loops. Three of these (loops 1, 2, and 3) are simple loops (i.e., each loop takes care of the traffic in both directions). Loops 4-5 and 6-7 are double loops (i.e., the reverse traffic is carried by a separate closed loop). Mileages and speeds are as follows:

Loop	D (miles)	v (mph)
1	0.5	53
2	0.5	53
3	0.625	60
4-5	0.75	67
6-7	1.5	96

Because of the great advantages offered, such schemes would deserve consideration at every new planning, even if they would require the installation of a few stations that are not fully used. These "extra" stations would not affect the speed of transportation. Because people tend to go where transportation is, it is very likely that these extra stations would quickly attract housing development in the area. (In Toronto, two-thirds of all new construction over a 5-year period was along the route of the Yonge Street subway.)

If the preceding schemes are not feasible, or if the task is to modernize an already existing rapid transit system, each transport unit must be propelled and controlled individually. Although the problem of automatic vehicle control is regarded as a controversial topic, there is nothing basically new about the techniques used. The automatic control of the proposed system creates few problems that have not already been

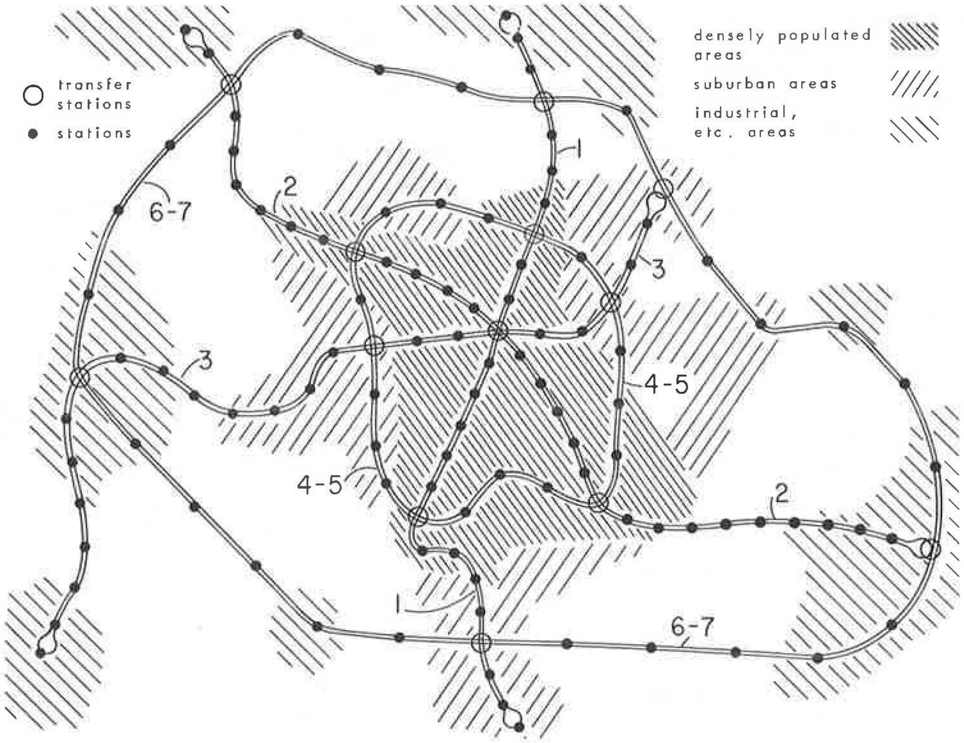

Figure 5. Arrangement of transit lines for cable operation.

studied by the companies participating in the design of the control system for the San Francisco Bay Area Rapid Transit District (9) or by M.I.T. in connection with Project METRAN (10).

Only the main features of the control system will be discussed here. For details the reader may refer to the previously mentioned reports or to handbooks dealing with modern information feedback control methods (11, 12, 13).

Two kinds of control systems are conceivable. One may be termed "on-board" control, the other "centralized" (or computerized) control. As its name implies, with the on-board control system each individual transport unit is equipped with facilities for (a) gathering information on its own velocity, the distance between itself and the unit ahead, and the velocity difference between itself and the unit ahead; (b) comparing this information with the information prescribed for the given situation; and (c) taking corrective actions (acceleration or braking) to minimize the difference between the two sets of information.

With a centralized control system each transport unit carries equipment only for (a) determining its own position and velocity and (b) taking corrective actions. The information concerning the position and velocity of each unit is continuously transmitted to a central computer that makes the decisions concerning the corrective measures. The computer commands are then transmitted back to the individual units for execution.

For networks consisting of simple loops with no branching, the on-board control system would probably prove more advantageous. On the other hand, for a complex network containing many nodal points, especially when the variable routing of the transport units is a requirement, the use of the centralized control system is unavoidable. By using the centralized control system it is also possible to increase the cruising speed along those sections of the line where the stations are located at longer distances, which increases further the overall speed of transportation.

People-Platform, Doors

The use of the mobile people-platform offers two advantages. First, it greatly simplifies the rules of travel because only the newly boarded passengers and those who wish to alight have to act. The through-passengers who are standing or seated on the platform are automatically transferred forward from one vehicle to another and thus continue their travels as long as they stay on the platform. Second, the people-platform makes it possible for the transfer of the passengers always to take place in a prescribed time. This factor is extremely important in a completely automated process.

Some problems may arise in the design of the platform because of the fact that it must be capable of absorbing certain length changes that occur when it is advancing between two units while the vehicles are running along a curved section of the track. A possible solution is shown in Figure 6. The main components of the assembly shown are a rubber sheet reinforced with obliquely placed steel wires, a substructure consisting of rib-like elements, and a flexible spine, possibly also made from rubber, reinforced longitudinally. When the platform moves, the spine is guided along the centerline of the vehicles by a multitude of rollers. The lower section of the spine is formed into a flexible rack with metal pegs. The pegs mesh with the teeth of pinions driven by driving mechanisms fastened to the operational areas of the vehicles.

Figure 7 shows the interior of two joined vehicles at a time when the platform advances. For simplicity, only three through-passengers and a one-station traveler are shown. The latter walks along the strip area in a direction opposite to the platform movement.

All doors are automatically operated, and the side doors are sliding doors. In order to ensure that the opening and closing of the doors is accomplished in minimum time and to keep the whole cross-sectional area of the vehicles unobstructed while these doors are open, the use of sectional "fold-up" or "roll-up" doors are recommended for end doors.

Safety Aspects

Some railway people may receive the idea of the described transportation system with mixed feelings. People think that safe operation along a single track is inconceivable without maintaining a certain minimum headway between the trains or vehicles.

The fears of the increased possibility of rear-end collision with the suggested transportation system are, of course, unfounded. In fact, the normal vehicle control equipment is capable of taking care of most emergency situations. With the use of additional control features, it is possible to design the system to any specified degree of safety.

At first sight one may think that during the period preceding the joining of two vehicles there is an increased danger of collision if, for some reason, the front vehicle

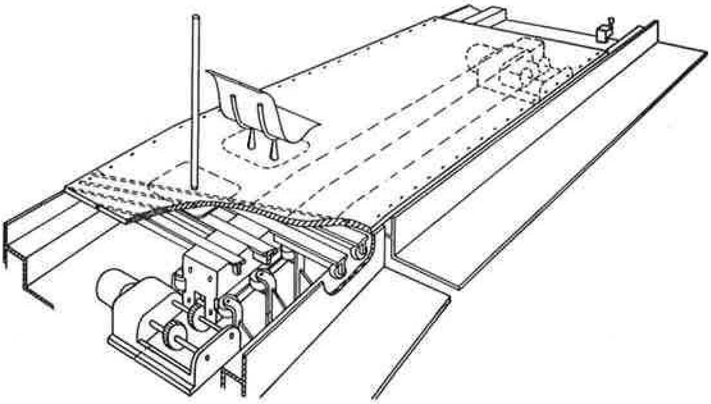

Figure 6. Possible design of people-platform.

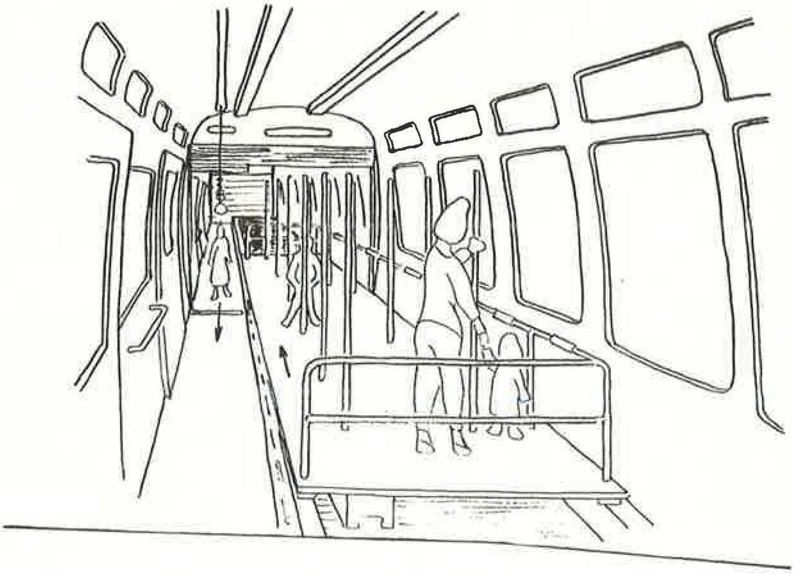

Figure 7. Interior view of two joined vehicles while people-platform advances.

is forced to stop suddenly. However, the following facts should be remembered:

1. Because of the automatic operation the system must have exclusive right-of-way, and interference in its operation by people or foreign vehicles is most unlikely;
2. Short of some rare disaster (for example, tunnel collapse) the front vehicle cannot stop instantly but will slow down at a deceleration that is not likely to be higher than 0.000833 mile/sec^2, the value regarded in this paper as representing the limit of permissible discomforts;
3. With the use of an on-board control system, the vehicle running behind continuously obtains information on the distance and velocity difference between itself and the vehicle ahead, compares this information with the theoretically correct information, and takes immediate corrective measures; and
4. With the use of centralized control system, the position and velocity of all vehicles in the transport system are continuously checked by the computer.

In case of any irregularity the appropriate corrective action comes immediately. Thus, if the distance between the two vehicles begins to drop unexpectedly, the vehicle running behind will at once apply its brakes in an effort to maintain the theoretically correct distance.

There is a relatively narrow range of distances between two vehicles during the joining period at which, in case of emergency, the vehicle running behind may be forced to slow down at decelerations within the discomfort zone in order to prevent rear-end collision. To achieve such decelerations the use of rubber-tired wheels may be necessary.

Naturally, if the previously described cable-operated version of the transportation system is used, there is practically no possibility for collision.

SUMMARY

A transportation system has been described by which the overall speeds achievable with modern rapid transit facilities in urban dimensions can be doubled. With this system any passenger can be transported nonstop from any station to any other station along the transit line without the need for additional trackage. The initial costs of this system are only slightly higher than those of a comparable conventional system.

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THE CASE FOR PERSONAL RAPID TRANSIT

A. J. Sobey and J. W. Cone, Transportation Technology, Inc., Denver

Present systems of urban transportation, private (primarily the automobile) and public (conventional buses or rail transit), have not satisfied the need for transportation. The automobile is expensive and cumbersome for many urban transportation needs. It cannot be used by those who for reasons of health, age, or wealth cannot drive. The conventional transit systems have had declining patronage for many years due to the increased cost of these systems and their inability to provide service competitive with the automobile. It is, therefore, necessary to consider the possible development of new forms of public transportation that can meet the established needs. This paper considers the requirements for, and possible development of, personal transit systems that combine some of the characteristics of the automobile and public transportation. These systems are designed to provide transportation for an individual or a group in an exclusive vehicle, routed directly from the origin to destination by automatic controls. This paper describes the advantages and application of such systems. It includes a preliminary evaluation of the relative areas of application of such systems, as well as more conventional transit systems, and a discussion of possible technical approaches to such systems.

•THE declining acceptance of urban transit, coupled with an increasing demand for transportation, makes it desirable to take a new look at public transportation in order to establish whether more attractive systems can be devised by using existing or advanced technologies, for example, personal transit systems that would provide direct origin-to-destination service for the passenger on a demand basis.

Most public transportation systems transport groups of unassociated people to common destinations on pre-established schedules with frequent intermediate stops. The only personal transit system in significant use today is the taxi, which is routed directly to the passenger's selected destination. This service is provided at a significantly higher cost than an equivalent trip by bus; however, it provides sufficient value such that almost every city, even a very small one, has a viable taxicab service. The same cannot be said of urban transit systems, which are poorly used and rapidly becoming economic liabilities.

A personal transit system would consist of small vehicles (4 to 10 passengers) operating under automatic control on a network of guideways in an urban area. Such a system would provide direct service from origin to destination without intermediate stops. The potential advantages of this type of system would include the following:

1. Lower cost due to light simple vehicles, smaller guideways, and reduced right-of-way requirements;
2. Faster trips due to direct service without intermediate stops and without waiting for vehicles;
3. A more extensive area of service due to the larger network that could be built for the same cost; and
4. A more attractive service due to privacy and direct service provided by the personal transit vehicle.

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The objectives of this paper are to review each of the major advantages of the personal transit system and provide evidence, where available, that suggests the order of improvements possible. It is the authors' hope that adequate supporting information has been included in this paper to encourage transportation authorities to make additional comparative studies of personal and conventional transit for major transportation applications and to conduct actual tests and demonstrations of this concept.

STATUS OF PUBLIC TRANSPORTATION

The declining public acceptance of urban transit has been pronounced since the end of World War II and has accompanied the change in the form of the city. It is, in part, a result of the increased discretionary wealth of the private citizen who can choose to purchase amenities (or luxuries) such as a private automobile for his personal transportation.

Usually the transportation planner has only three choices that he can make in planning for the future transportation needs of a city or town:

1. Continued expansion of automobile systems;
2. Introduction (or expansion) of a rail transit system; and
3. Expansion of bus transit, possibly coupled with the use of express lanes or private rights-of-way.

Many cities are looking for improved public transportation, and detailed studies and major plans have been made by a number of cities. For historical reasons that can be readily justified by the transportation authorities and planning groups, these studies have concentrated on conventional steel rail transportation systems (moderately upgraded) that can carry large passenger volumes.

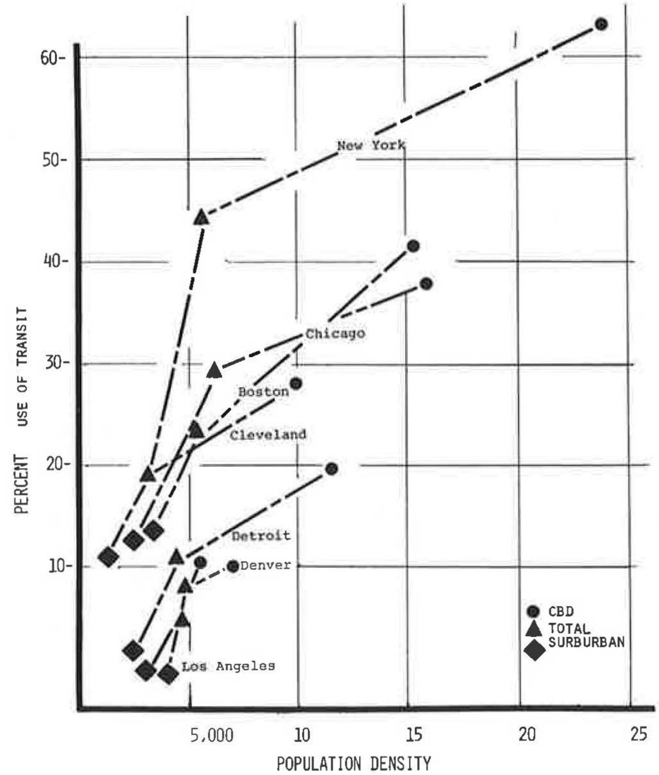

Figure 1. Percentage of CBD-oriented trips by transit system.

The high costs of a rail system can be justified only by service to a high-rate traffic generator. Commonly the CBD is the only such generator in a city. In cities where rail transit has been installed, the transit system does provide a high percentage of the CBD-oriented trips, as Figure 1 shows. However, as cities expand, they tend to become less centrally oriented and less dense. Newer cities may have many centers of activity. For example, in a recent study, Los Angeles was shown to have nearly 30 activity centers of relatively similar importance as traffic generators.

Data on some recent transit proposals and subsequent action are given in Table 1. The percentage of trips is based on the total daily trips in the area. Rail transit systems are usually designed to operate for peak loads rather than to handle the entire traffic demand. Considered on this basis, the Los Angeles rail system should handle about 11 percent of the a.m. or p.m. peak trips equiv-

TABLE 1

RECENT TRANSIT SYSTEM PROPOSALS

City	Length (miles)	Number of Stations	Cost ($ billion)	Trips (percent)		Results
				Total	CBD	
Los Angeles	87	66	2.5	2	6	Voted down (11)
Atlanta	10	—	0.475	5	10	Voted down (10)
Seattle	47	—	1.1	7.5		Voted down (14)
Washington	98	—	2.5	5	10	In planning (17)

alent to 30 or 40 percent of the automobile trips in these hours (23), a very worthwhile reduction in freeway traffic.

Some extensions of existing systems are making notable records. The Lindenwold line in Philadelphia attracts more ridership than predicted, and the airport line in Cleveland attracts a significantly larger ridership than estimated.

Although the reasons for the failure of the proposed systems to obtain the support of the electorate are not fully understood, there are two basic reasons that appear to have an influence in all cases.

1. The rail systems have an image of the 1919 streetcars or the elevated loop and, therefore, appear to many people to be a step backward; and
2. In the best systems, rail transit provides service for only a small portion of the total trips in the urban area.

The preference of trip-makers for the automobile appears to be based on a number of factors. In contrast to public transportation, the automobile can

1. Travel directly from origin to destination (less the requirements for parking at each end of the trip);
2. Be immediately available to its user (who does not have to worry about time schedules or availability of seats);
3. Provide convenient transportation and storage of personal articles (invalids and the infirm can be accommodated with relative ease as passengers);
4. Provide security and privacy (it is not necessary to share the trip with strangers);
5. Almost always provide lower trip time; and
6. Offer pride of individual and private ownership.

Conventional transit systems (rail or bus) have not competed effectively with the automobile for a number of reasons.

1. Trips generally are possible only along major corridors (some method of access is usually necessary at one or both ends of the trip, and transfers are frequently necessary thereby reducing speed and convenience);
2. Public transit systems operate on a schedule (the service frequency is seldom shorter than every 2 min, may be 15 min to an hour during the day, and may not exist during certain time periods);
3. Vehicles are frequently difficult or inconvenient for the aged or infirm to use (buses have high steps, and rail systems have long difficult stairs);
4. Increasing labor and material costs make even relatively popular runs unprofitable;
5. Inadequate amenities exist for the passenger (seats are hard and crowded, and all classes of passengers must mix in the same compartment); and
6. Low average speeds are typically less than one-half the actual en route speed (a transit system trip may be several times as long as an equivalent trip by automobile).

Limitations of the Automobile

Although the automobile is a very effective means of transportation in general, its major advantages are outstanding in moderate- or low-density areas where other forms of transportation are uneconomic or nonexistent. In large urban areas, the advantages of an automobile used for commuting to the center of the city are diminished by excessive distances, inadequate and crowed roads, and expensive parking facilities. The cost of building additional facilities is often significantly more expensive than the cost of providing equivalent transportation capabilities by use of public transit systems. Although we do not expect new forms of transportation systems to replace the automobile or existing conventional transportation modes, we have emphasized the comparison of the transit systems and the automobile because the car is the standard by which most Americans judge their transportation service.

PUBLIC TRANSPORTATION REQUIREMENTS

In evaluating future transportation needs, one must understand the factors that influence the magnitude and nature of the transportation required. An evaluation of future transportation systems must consider (a) changes in population and urban density, (b) changes in rate of travel and travel requirements, and (c) availability and attractiveness of alternative modes of transportation

The requirements for transportation of people and goods are based on both social and economic factors, the locations of centers of population and industry, the areas of residence and recreation, the location of service activities, and the geographic constraints of the area in which transportation is to be provided.

Changes in the number of people and the form of community organization will bring changes in the requirements for transportation. The increased time available for recreation and sports will increase the need for transportation. Larger cities with lower population densities will make the movement of people by conventional transit systems less competitive with the private automobile.

The design of transportation systems and vehicles (whether public or private) is related to the movement of people and how their needs may change in the future. The extreme transportation need of this country is demonstrated by the 1966 figure for the movement of people—almost 1 trillion passenger-miles (approximately 80 percent in automobiles). On this basis the per capita average was nearly 5,000 miles.

A primary factor in establishing whether a specific trip will be taken is travel time. With increasingly effective transportation modes, the distance between residence and place of employment increases. The 1-day trip across the continent for a business meeting is not uncommon today.

The rate of travel is anticipated to increase even more rapidly than the population; for example, in one eastern town where a new rapid transit system is being considered, the number of trips per capita is expected to increase 25 percent between 1960 and 1980. The total mileage per capita is expected to more than double, and the number of automobiles is expected to increase by 50 percent (7).

Availability of a Car

Urban mobility requires a dependable, available transportation system. The modern passenger car has satisfactorily provided this for a large number of people. However, to use a car, one must have

1. A license,
2. Adequate funds to buy or rent a car,
3. Adequate physical health and skill, and
4. An adequate and available road system.

There are large groups of people who cannot meet all of these conditions. In 1967, 22 percent of United States families did not own a car, and in a substantial majority of families only one car was available. Car ownership in urban areas varies from 71 percent of the family groups in the Northeast to 84 percent in the West. Many who need transportation are not qualified to drive because of age, health, or legal restrictions.

The percentage of those who are unable to drive because of lack of licenses is shown in Figure 2. Over half of the eligible men under 17 and above 70 are not licensed to drive; at best, between the ages of 25 and 40, barely 50 percent of the women are licensed to drive.

Studies have shown that most users of public transportation systems are captive riders and have not made a free choice between public transit and an automobile. The typical reasons for using public systems are (a) car is not available; (b) user is unqualified to drive; (c) user is aged, infirm, or too young; and (d) there is no other way practical to reach destination, for example, commuting to Manhattan and, to a lesser extent, Chicago.

The captive nature of public transit users is borne out by the relationship of transit use and automobile ownership as shown in Figure 3 for 15 major United States cities (12). The relationship for work trips is almost directly proportional to automobile ownership. What is not clear is whether the presence of a transit system led to low automobile ownership, as the cities with the largest transit usage are the older, denser cities.

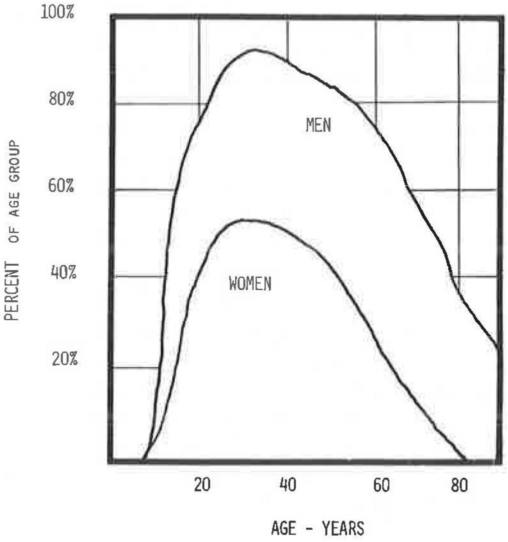

Figure 2. Percentage of population licensed to drive by age.

Many authorities, in particular the environmentalists, expect urban transit to make a significant inroad into the use of the private automobile. However, the demand for transportation is increasing so rapidly that even the most optimistic assumptions of the use of public transportation do not indicate a decrease in the use of the automobile. Table 2 gives the range of prediction of the use of public transportation based on a number of logical projections (12). The most significant is an increase of about 33 percent in the use of public transportation. This would result in only a slight decrease in the use of the automobile.

Although we cannot fully substantiate these assumptions (and reductions in automobile purchases would be anticipated by some authorities), they do indicate that expanded use of conventional transit will have little influence on the use of the automobile.

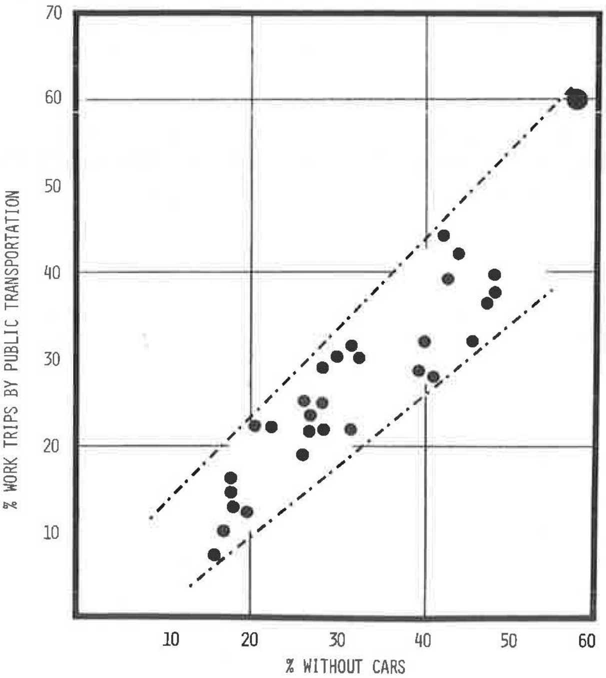

Figure 3. Relationship of automobile ownership and transit trips.

CRITERIA FOR IMPROVED PUBLIC TRANSPORTATION

A superior public transportation system should provide (a) short trip times, (b) extensive coverage of urban area served, (c) adequate system capacity and expansion capability, (d) privacy and safety, and (e) minimum impact on the urban environment.

TABLE 2

ESTIMATED FUTURE CHANGES IN TRANSIT USE IN THE UNITED STATES FROM 1960 TO 1980

Method of Projection	Percentage of Change
1. Extrapolation of existing transit riding trends	-21
2. Projection based on extension of composite trends reported in origin-destination studies for selected urban areas	+4
3. Extrapolation of existing trends increased 33 percent for service improvements[a]	+5
4. Projection based on stratification of nation's urban residents according to urban population, and estimated transit riding in each grouping	+14
5. Extrapolation based on general relationship between automobiles per capita and transit rides per capita	+30

[a] This value is based on reported gains in patronage resulting from selected service improvements.

A successful urban transportation system must meet many needs. It must, at the least, provide transportation for those who are unable to afford automobiles or unable to drive from their residences to work, recreation, or shopping. However, in our affluent society, a system designed for only the indigent and infirm will not have sufficient patronage to be economically successful. The system must also attract those who can afford to pay for the services and therefore must provide more extensive, better service than could otherwise be obtained.

Studies of rubber-tired transportation systems indicate that a significant number of people are willing to pay a higher fee for a system that will provide rapid, personalized service. For example, in New York, nearly 20 percent more passenger trips are made by taxicabs than by subway and commuter rail.

Personal Rapid Transit Systems

It has been proposed that a tracked system can be devised that bears the same relationship to a rail system as the taxi bears to the bus. This type of system would provide direct service for a traveling group and improved and possibly more economical service.

Such systems must be greater in extent than conventional rail systems and provide more frequent terminal locations. It must be possible to install them with a minimum disturbance to existing buildings or to the appearance of the city.

Although taxi and bus data indicate that many people would be willing to pay a premium price for individual or personal rapid transit (PRT) type of service, there are to date very few data to indicate the importance of service in attracting additional patronage.

Trip Times

For many trips, personal transit systems operating at moderate speeds (i. e., less than 60 mph) will provide shorter trip times than other modes of transportation, including the driver-operated car. The personal transit system will provide an average speed approaching the line speed of the system when operated to a significant distance. There are no intermediate stops for stations, no stoplights, and no slowing of speed for traffic. Vehicles would be immediately available in the stations.

Other modes of transportation are inherently slower than their running speeds. For example, Table 3 gives the average trip speed for the more commonly used modes of transportation for five major cities (12). Only the automobile exceeds an average speed of 10 mph. The automobile speed is influenced significantly by the length of the trip and the availability of a suitable road system.

Comparable trip speeds for PRT systems, assuming a 5-min walk to the station, a 30-sec station delay, and 0.3 g acceleration, would be as given in Table 4 (12). Even including the 5-min walk ($^1/_4$ mile), the average trip time for an 8-mile trip by PRT would

TABLE 3

RELATIVE PORTAL-TO-PORTAL SPEEDS (MPH) FOR VARIOUS MODES OF TRANSPORTATION

Mode	Chicago	Philadelphia	Detroit	Pittsburgh	Philadelphia Center City
Automobile driver	11.1	11.4	8.9	13.6	10.0
Automobile passenger	10.4	11.3	8.9	13.6	10.1
Bus	6.2	5.4	6.0	7.4	5.7
Rapid transit	8.9	7.4	—	—	7.5
Commuter railroad	14.4	13.4	—	—	13.1
All	—	10.0	8.1	—	8.5

Note: Based on comprehensive origin-destination studies in each urban area.

range from 12 to 18 min. The equivalent trip would require 18 to 22 min, not including station waiting times; by automobile this trip would require 20 to 35 min depending on the available roads. Thus, the average time to complete a trip can be significantly lower by PRT than by other modes of transportation.

Line Capacity

Personal transit vehicles operating at typical automobile load factors (i. e., 1. 6 passengers per vehicle) can satisfy most of the real demands of passenger service. Typical peak-hour passenger requirements, actual or predicted, on rail transit systems in New York, Los Angeles (11), and Seattle (14) are as follows

City	Passengers per Peak Hour
New York	12,000 to 72,000
Los Angeles	12,000 to 24,000
Seattle	2,000 to 7,000

In many cases, these peaks exist only because the passenger load has been forced into channels to permit the economic operation of the rail system. PRT systems that are economic at a lower capacity would provide for alternate or parallel routes that would reduce the capacity required significantly while improving service.

The line capacity of a personal transit system depends on the control and braking technologies assumed and the conditions against which the system is to be protected. The technology exists today for a vehicle line capacity of 250 to 600 vehicles per hour (1,500 to 3,600 passenger-seats per hour for a six-passenger vehicle). A conventional rail transit system by contrast provides for 40 trains per hour (90-sec headways).

It is logical to assume that the technology will be developed to permit much higher capacities that approach the theoretical limits. For example, at 40 mph with 0.5-g (11 mph/sec) braking capability by the vehicle, the theoretical peak capacity of the line flow would be more than 2,000 vehicles per hour. This capacity assumes that there is a continuously monitoring control system and protection for the trailing vehicle against the improbable condition of an instantaneous stop of the lead vehicle. A 0.5-g stop is slightly lower than the maximum braking rate of a typical passenger car on dry pavement. The line capacity would increase with increased braking capability. For example, at 1.0-g braking the theoretical line capacity would exceed 4,000 vehicles per hour as shown in Figure 4.

TABLE 4

AVERAGE TRIP SPEED OF PERSONAL TRANSIT SYSTEM

Distance (miles)	Line Speed		
	40 mph	60 mph	80 mph
1	10	10.6	11.1
2	15.5	17.6	18.6
4	21.0	26.6	30.0
8	28.4	36.8	44.0
16	33.7	45.5	56.5

Note: Times include 5-min walk and 30-sec station access time.

Several possible approaches could be used to increase significantly the actual capacity after experience is obtained and safety ensured. For example, if it is found that the worst condition requiring protection is a 1.0-g stop by the lead vehicle, the capacity with a 0.5-g vehicle braking capability would again be more than 4,000 vehicles per hour. At higher deceleration rates (i. e., 0.8 g), which may be tolerable for emergency conditions, the capacity could theoretically be as high as 14,000 vehicles per hour.

Such capacities will probably never be obtained or required in practice. Practical control considerations will significantly reduce the actual vehicle capacity. Figure 5 shows the effect of various block lengths on the vehicle capacity that provides protection against a 1.0-g stop by the leading vehicle. A 30-ft block reduces the line capacity by more than 30 percent. Note that the effect of speed is such that with small blocks or continuous monitoring the capacity drops off exponentially with speed. At 80 mph the line capacity is half of the capacity that exists at 40 mph.

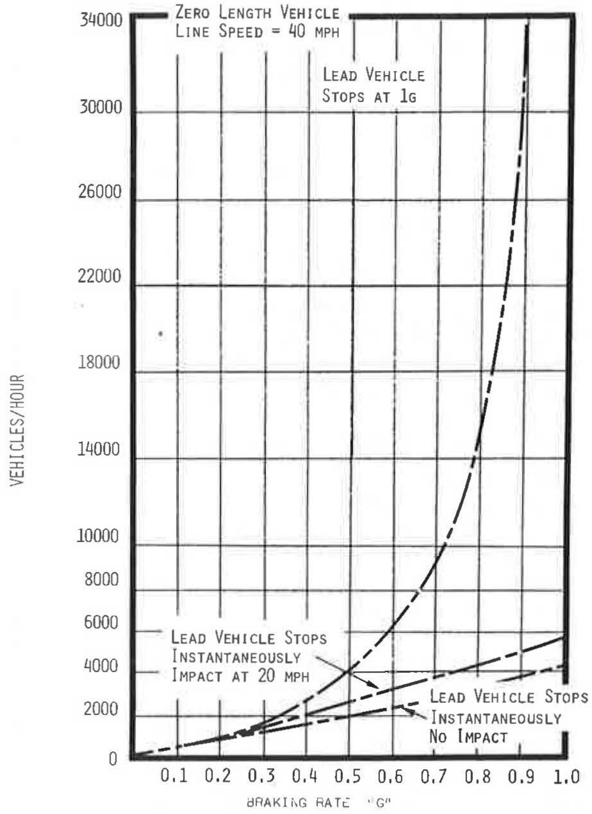

Figure 4. Line capacity and braking rate relationship.

Station Capacity

The limiting capacity of most systems, however, is established by the terminals. The random access or docking terminal provides unique advantages in this aspect, as follows:

1. The dock provides for loading the vehicle "off line" and thus permits vehicles to bypass the station;
2. Capacities equivalent to large vehicle systems can be provided with small personal transit vehicles; and
3. By having some docks occupied by empty vehicles, the passenger is assured of immediate service on entering the station, and holding up a single vehicle need not impair total system performance.

If six-passenger vehicles are used, a single gate can handle approximately 70 passengers per hour. On this basis, an eight-gate station (approximately 90 ft long) would be capable of handling 5,600 departures per hour if the vehicles were fully loaded. However, it may be expected that there would be an average passenger occupancy of 1.5 to 2.0 passengers per vehicle during most times of service, resulting in a flow of 1,800 passengers per hour—adequate for most urban needs. In places where lower passenger requirements are anticipated, fewer docks would be used; for example, two docks (24 ft total length) could handle over 1,000 passengers per hour.

A conventional transit system requires a loading platform equal in length to the vehicle; a 90-passenger vehicle, for example, requires approximately a 140-ft platform.

If a 90-sec headway exists, such a vehicle could handle the same volume as the eight-dock terminal.

Vehicle Management

The regulation of the vehicles in a personal transit system can be accomplished by using several modes. The choice of mode depends on the size of the system and specific requirements. The examples of possible modes of vehicle management include individual single-vehicle demand, transit or batch and scheduled sequential demand.

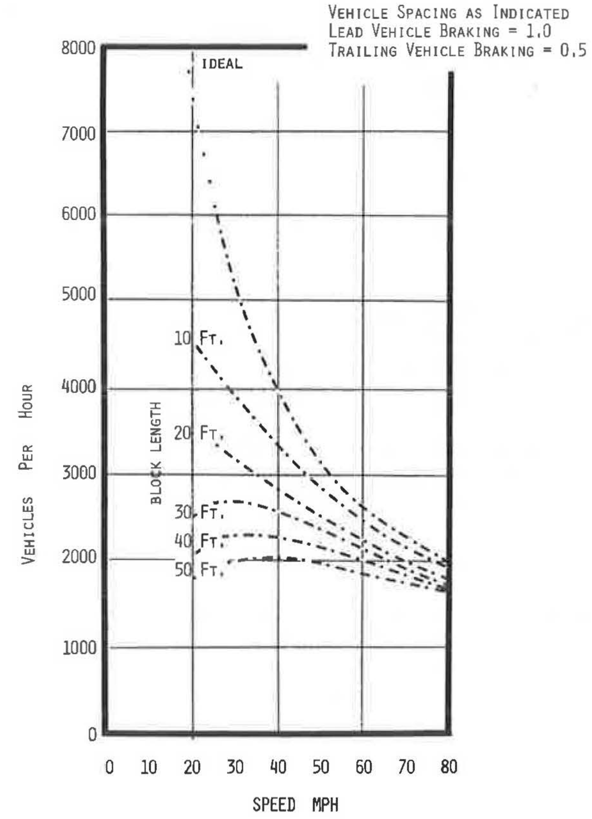

Figure 5. Line capacity and vehicle speed relationship.

The single-vehicle demand mode would provide a vehicle for each traveling individual or traveling group. The vehicle would be dispatched for the specific trip only. Vehicle management would provide control of the path of the vehicle through the system network in a manner producing the minimum time for the system and existing demand. A secondary requirement of the vehicle-management system would be the supply of vehicles to the stations in response to the actual or anticipated demand. Where inadequate return service exists, empty vehicles would be scheduled to the stations. Such systems have an upper capacity limit per line due to the constraints discussed previously. However, in a large network system there will usually be adequate alternate routes to permit the vehicles to be scheduled to their destinations even where the peaks exceed the capacity of the most direct route.

Where higher capacities than can be provided on a single line are required, a batch mode of operation can be used on the same system. This could be provided by the incorporation of larger vehicles, each scheduled to specific destinations. In a terminal, a given dock could be identified for specific destination or route of destinations to provide efficient grouping of passengers. An alternate method of providing the same type of capacity would be to group vehicles in small trains with each directed to the same destination, or sequential destinations, such that the vehicles could be disconnected from the train at appropriate stops.

A simple circulation system may involve two to ten stations and several miles of track with few alternative paths between destinations. These systems are compatible with a number of basic vehicle management logic concepts and could be implemented in a relatively short period of time. More complex networks, as in a large city where there may be hundreds of stations and several alternate paths for almost every origin-destination pair, require more complex vehicle-management concepts. A number of approaches to these problems have been evaluated. The most attractive at this time are based on the use of a central computer that has full control of the velocity and position of each vehicle in the system. It is reasonable to assume that the problem of design of such a complex network can be resolved. Studies indicate that with proper vehicle management the peak-hour waiting times should still be less than the delays due to schedule frequency for conventional systems (13).

Passenger Service

The personal transit concept provides a class of service that cannot be provided by conventional transit systems. The small (4- to 6-passenger) vehicle will transport a single individual, a family, or a business group directly to the selected destination. The passenger can read, listen to music, work, or converse during the trip. It provides an environment equivalent to the private car but does not require attention and skill of the passenger. Children, the aged and the infirm, and those not qualified to drive can use this system.

Although there are few data on the actual use of personal transit vehicles, or the rider preferences, some studies have been conducted (28) to survey the preferences of possible rider groups for various typical system characteristics. The reference study indicated that the 5 most important characteristics out of more than 30 considered were as follows:

Characteristic	Rating
Arriving when planned	1.8
Having a seat	1.65
No transfer	1.56
Calling without delay	1.45
Shelters at pickup	1.42

It is very possible that the relative privacy of the personal transit system will attract a significant portion of the riding public who now use their private cars. V. B. Hammett, of the Psychiatry Department of the Hahnemann Medical College in Philadelphia, points out that there are many people who have an intolerance to being lumped in a group and who have a great need for privacy. He observes that, even in a traffic jam, these people have real privacy when driving their cars. They do not have to rub elbows with anyone. The independency and privacy are worth it to those who are willing and able to pay extra for it.

The significance of the degree of privacy on ridership is difficult to evaluate. One experiment that could be conducted with a demonstration PRT system would be to compare large transit vehicles with small personal transit vehicles (perhaps with a fare differential). This could be done in parallel with both classes of vehicles in the system or sequentially with the entire system dedicated to one or the other class of transit for a significant period of time.

The personal transit system provides a higher level of personal security than do conventional transit systems. Because each trip is made to a selected destination, the passenger can select his traveling companions. The station will be under continuous manual or TV monitoring, and a problem can be identified with appropriate corrective action taken. In most cases the vehicle would be held in the dock until authorities could investigate. This is in contrast to the situation in large transit vehicles where it is frequently necessary to maintain security guards.

Urban Development and Land Use

The PRT systems will have a somewhat different influence on the land-use pattern of a community than would a rail or all-automobile approach. The rail systems tend to force transportation into narrow channels and place a high premium on the value of the land most accessible to the individual stations. The decision as to the route, and particularly the station locations, is a significant one in determining how the community will develop and what form it will take.

The automobile provides relatively similar access to all locations in the community, thus tending to level land values. In part, as a consequence of this ease of access, the community will tend to grow in a scattered, disorganized pattern with industrial, commercial, and residential facilities intermixed.

The personal transit system, much as the rail system does, will tend to enhance the value of areas adjacent to the stations. However, because of the much greater number of stations, the effect will be less pronounced. The PRT system does provide many of the same advantages in urban development as does the rail system. Some stations will be placed in commercial areas and others will be placed in industrial, educational, and recreational areas. Stations located primarily in residential areas will tend to become the centers of small local communities and for that reason should be located in or adjacent to schools and other community facilities.

System Cost

Personal transit systems (using small, light, low-cost vehicles) should cost significantly less per route-mile and per station than conventional transit systems. PRT networks can be installed through places where the use of conventional transit systems would be impractical. The light weight and low noise of the vehicles should permit the systems to be routed through buildings and installed in locations that would be unacceptable for other forms of transportation.

In dense central business districts, for example, the system can be routed through existing buildings, and stations can be provided in the buildings much in the manner of an elevator. Surveys in several major cities have indicated that merchants and building owners would be willing to consider such installations in their buildings in exchange for the direct access it would provide.

The small vehicle guideways can be fabricated of conventional materials and erected with normal construction tolerances. They are small in cross section (4 to 6 ft wide total) and, because of the light weight of the vehicle, can be designed to be aesthetically pleasing.

The personal transit system concept can be implemented with a number of different technological approaches. Small individual-rail, rubber-tired, or air-supported vehicles can be designed, and a number of variants have been proposed. Although the actual cost figures for these systems are for the most part proprietary, some comparative cost data have become available in the literature. For the purpose of the study, the costs given in Table 5 were used. Individual differences in the cost per mile of elevated rail systems have varied significantly, and it may be anticipated that the ratio of cost for PRT systems may be even greater as they are more significantly influenced by line density and use of existing building structures.

A number of studies have been made to establish the relative economics of various forms of transit systems, and, although each application is a specific and unique case such that generalizations are suspect, it is convenient to consider the costs of competitive transit systems for the same type of service.

A previously published study by Transportation Technology, Inc., was based on a 10-mile route of uniform density. Bus, rail, and personal transit costs were compared directly with the operating costs of a conventional transit bus on the city streets. The

TABLE 5

REPRESENTATIVE TRANSIT SYSTEM COSTS

Item	Bus	PRT	Rail
System design, dollars	250,000	500,000	500,000
Engineering services, percent	15	20	20
Vehicle			
Capacity, passengers	52	8	80
Unit cost, dollars	50,000	10,000	250,000
Average right-of-way costs per lane-mile, dollars	400,000	200,000	400,000
Cost of guideway			
On-grade, dollars	25,000	300,000	300,000
Elevated, dollars	2,000,000	900,000	2,500,000
Average cost of stations, dollars	250,000	300,000	2,000,000
Cost of controls and electrification per mile, dollars		300,000	250,000
Cost of service facility, percent		5	10

study considered only the costs of moving a number of passengers, not the speed, attractiveness, or other considerations of importance to the passenger. In this study, the effect of peak-line requirements was evaluated, and each system was evaluated at a number of demand levels. To provide a basis for generalization and to minimize local effects, we normalized all costs to the cost of operating a city bus on city streets. The results of this evaluation are shown in Figure 6. The capital recovery cost was computed on the basis of 6 percent annual interest. In addition, operating costs were considered.

These results indicated that the PRT concept selected was competitive with the conventional bus on city streets down to an average line capacity of 1,000 seats per hour depending on the specific system. This is approximately one-half of the seat-mile cost of a bus operating on a route with a separate right-of-way, the next lowest cost of the systems evaluated.

Although the PRT system is capacity limited (approximately 7,000 seats per hour assumed in this case), it was shown that by the use of parallel lanes (perhaps a block apart) the total system capacity would be increased to the equivalent of the transit system at a lower total cost.

Network Size

The ratio of cost per mile between a conventional rail transit system and a personal transit system is of the order of 3:1 to 10:1 depending on the technology used, frequency of service, and similar factors. For an equivalent initial cost, the personal transit system may have three times or more route mileage and several times the number of stations per route-mile. This will provide easier access to the system, particularly by those walking. People ½ mile from a transit system will use the system less than half

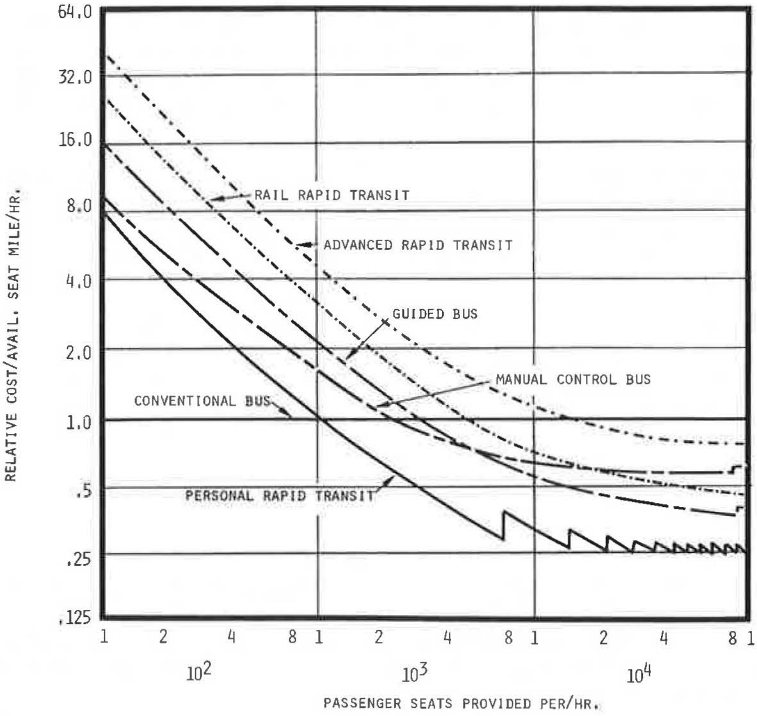

Figure 6. Transit cost comparison.

as often as those ¼ mile or less. A recent study (22) showed that the average walking trip was 0.20 mile in both Dallas and Chicago and that there were only a negligible number of walking trips longer than 0.60 mile.

An evaluation of the influence of the increased number of stations available to a passenger in a stated distance or period of time indicates that the number of trips should increase exponentially with the probability that a suitable destination will exist.

Balanced Transportation

The PRT transportation systems, as envisioned by the authors, will probably never provide all or even a majority of the transportation in an urban area. Other forms of transportation will be required to meet the specific needs of the area or the traveling public. The automobile will probably continue to provide for the majority of the transportation needs of the community. It can serve low-density areas where no other form of transportation is practical. The taxi, as the rubber-tired version of the PRT, will continue to have broad application for special nonrepetitive trips. The conventional bus (upgraded in appearance, technology, and operation) will provide service to areas where the cost of a fixed-route system cannot be justified because of low demand or infrequent needs for service. It is very probable that the rubber-tired bus will continue to be the largest supplier of public transportation. Large conventional rail (or rail-like) vehicle systems will continue to be used in high-density corridors where there are existing facilities or where high demands exist.

In addition, there will be need for special systems, multimodel devices combining one or more of the characteristics of other vehicle systems, and moving sidewalks, or an equivalent, for relatively short trips.

COMPARATIVE SYSTEM EVALUATIONS

An accurate evaluation of the relative usefulness and advantages of a personal transit system in a specific urban area will require a comprehensive study in which at least four system alternatives are considered (automobile only, bus including exclusive express lanes, conventional rail, and personal transit). Such a detailed study would require consideration of the actual needs of the area, established trip patterns, and the influence of changes in transportation service on future transportation patterns. To make a direct comparison, the evaluator would have to quantify at least the following:

1. Relative costs of the competitive systems;
2. Effect of system parameters on attraction, e.g., trip time, en route delays (i.e., transfers and parking), user perceived cost, user actual cost, access provisions, distance to parking lots, and convenience and privacy; and
3. Effect of network size and configuration on actual ridership (i.e., riders per dollar investment).

Existing modal-split and passenger-assignment models cannot accurately make such studies for new and unconventional transit concepts. For example, there is no information to quantify the effect of convenience and privacy on the actual ridership. A comprehensive study of this nature is beyond the scope of this paper; however, the authors did consider a number of possible applications of personal transit and have made qualitative evaluations of representative systems.

PRT Applications

One significant advantage of the personal transit systems is the fact that they can be developed on an evolutionary basis. Relatively small activity center systems can be built where there is adequate demand; these can be extended to serve larger areas as demand increases. Several isolated activity center systems can then be linked by relatively high-speed (60 to 100 mph) routes, and the overall systems can be expanded as the need and finances permit.

PRT systems can be applied to a number of specific transportation needs, such as for access from remote parking to activity centers; for access to, and circulation through, large airports; for distribution of trips in a central business district; and for urban transportation throughout an urban area.

Remote Parking

Small versions of personal transit systems can be used to connect parking facilities with commercial buildings, campus areas, recreation facilities, or industrial plants. Studies have indicated that in many cases the savings in cost of land or construction by providing remote parking facilities will more than offset the cost of the transportation system required to provide access between the parking area and the facility being served.

Cost studies indicate that systems of this general class can be built to operate profitably at a fare that is acceptable to the using public, i. e., 10 to 50 cents. In many developments it may be possible to pay for the system by a slight increase in the rental cost of the facilities being served.

Airports

The application of modified versions of the PRT system to airports may greatly improve passenger circulation from the parking lot, or other point of access, to the terminal activities and on to the aircraft. Not only does this permit location of major parking facilities in low-value land areas (approach zones, for example) some distance from the terminal, but it also provides a basis for improvements in the utilization of the airport facilities themselves.

Central Business Districts

Small individual vehicle systems are particularly applicable to the transportation needs of central business districts. The CBDs in most of our major cities are in serious trouble because of the difficulties associated with travel to and through them. Parking is difficult to find and is expensive, distances walked are long and undesirable in inclement weather, and personal safety is uncertain in the evening and off-hour times.

Personal transit systems provide an opportunity for overcoming some of these problems. Parking can be remotely located at the fringes of the central business district and thus more easily reached. More area can be made available for parking facilities. Passengers in personal transit vehicles are protected from weather and from the more serious crime problems. Access stations can be monitored by television from a central location to spot potential problems. As a result, the passengers will be safer than in their own cars.

The lightweight, small guideways can be installed in existing urban areas and can penetrate buildings if required. The installation of stations in existing commercial buildings may be attractive to building owners; the improved access to an upper floor can make the building more valuable to tenants; and higher rentals can be charged.

A study by General Motors (23) described such a system for a large, eastern town. The system provided distribution service between the commuter rail terminals and peripheral parking areas to the major buildings in the 2-sq-mile CBD. It had an anticipated 1980 ridership of 100,000 passengers per day (approximately 50 percent of the local trips within the CBD). The system incorporated 11.7 miles of track and 138 stations. It had 3,000 four-passenger (adult) vehicles.

The analysis indicated that the cost per passenger trip (including operating and capital recovery costs) would be in the order of 4 cents per trip. The average trip time was only 2 min for a trip of 0.6 mile.

Area-Wide Systems

The PRT systems can, of course, be expanded from such bases as described to cover an entire city. The vehicles would operate at speeds appropriate to the length of the trip (up to 60 to 80 mph in most cities) and would provide a degree of service not possible with conventional rail transit. Although such diverse systems may not be built for a number of years because of technical, economic, and political factors, the fact that they can evolve from smaller systems should result in the near-term development of smaller activity center systems or the equivalent.

A brief comparison was made for selected city A of a proposed rail transit system and the possible rail applications of a personal rapid transit system for the same relative cost. The proposed rail transit system is shown in Figure 7. It consists of 160 miles of two-way rail track and 87 stations. The system would cost $1.5 billion and would provide 450,000 daily trips or 3 percent of the total transportation demand of the area.

The city is a relatively low-density urban area of 3,500,000 population plus major suburbs. It is largely dependent on the automobile for transportation, although bus systems currently provide 5.2 percent of the total daily trips. The proposed rail system will serve six major corridors and will be oriented to the CBD (Fig. 7). The average distance between stations will be 1.3 miles; thus, each station serves an isolated area approximately 1 mile in diameter as shown in Figure 8. These ½-mile radius areas cover 14 percent of the urban area.

This system will not provide adequate capacity to reduce the use of the automobile in this area. Between 1970 and 1990 the use of the automobile is expected to increase 230 percent, and the relative use of public transit is expected to decrease from 5.2 percent (all bus) to 3.0 percent, approximately half of which is rail. The performance characteristics and estimated costs of the system are given in Table 6, where the planning agency estimated a cost of $1½ billion for the system, approximately 4 percent higher than that estimated by the authors using Table 5.

A PRT system was postulated for the same area at the same price (note that a contingency of 25 percent was used for the PRT versus 10 percent for the rail transit). This system provides a grid network of one-way lines across the city. The total length is 382 miles and there are 410 stations. The system route network is shown in Figure 9. All of the routes are single track, which minimizes the impact on the environment in each area. The one-lane guideways can be easily incorporated into marquees, pedestrian shelters, or freeway medians, and can penetrate buildings. The cost is, of course, greater for two single-lane routes than for a two-lane route. However, the area served is greatly increased, which attracts additional patronage and offsets the

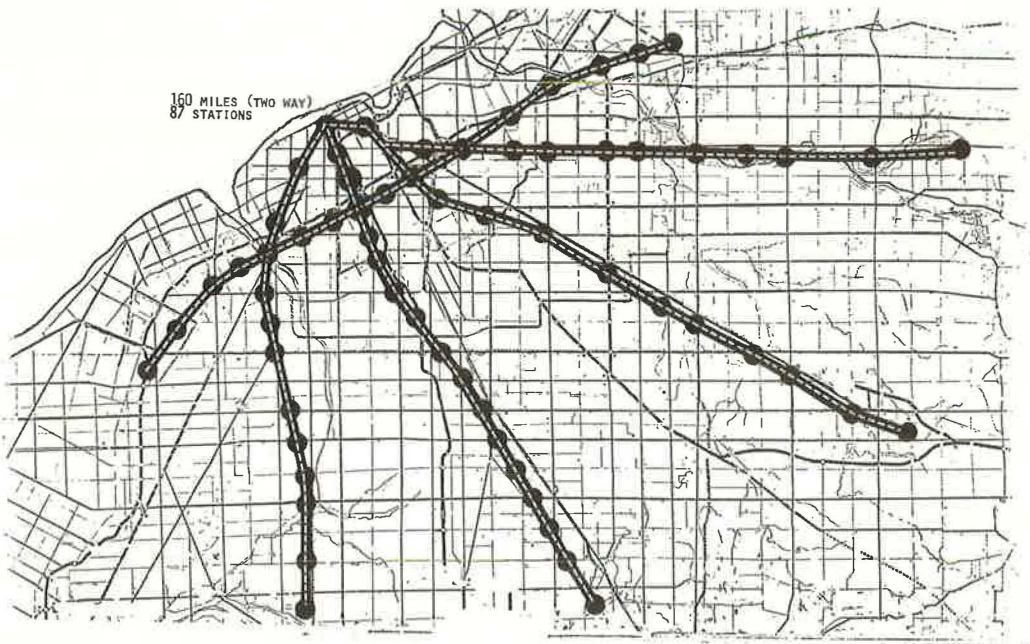

Figure 7. Proposed rail transit system.

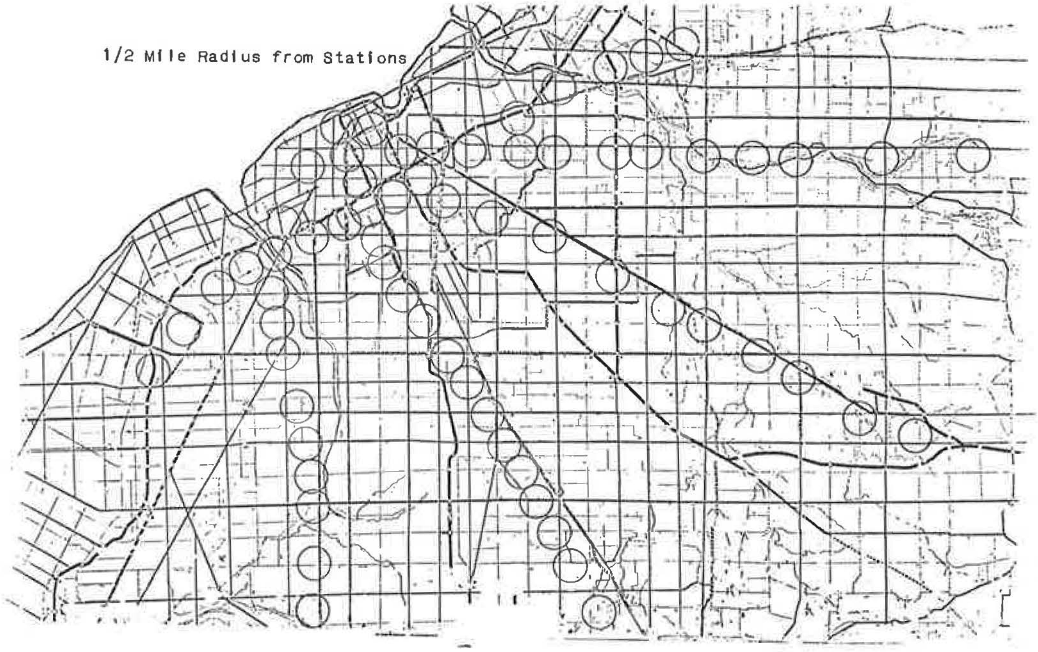

Figure 8. Rail transit service areas.

Figure 9. Personal rapid transit system.

TABLE 6

ESTIMATED COSTS OF RAIL RAPID TRANSIT SYSTEM

Element	Amount	Unit Cost ($)	Total Element Cost ($)	Percentage of Total System Cost
Track	226 mi	2,500,000	580,000,000	44
Stations	87	2,000,000	174,000,000	13
System design	1	500,000	500,000	
Right-of-way	226 mi	400,000	90,000,000	7
Control and electrical	226 mi	250,000	59,000,000	4
Subtotal			903,500,000	
Engineering and service facilities, 30 percent of facilities			274,050,000	21
Vehicles	565	250,000	140,000,000	11
Subtotal			1,317,550,000	
Contingencies, 10 percent			132,855,000	
Total			1,450,405,000	

small increment in cost. The direction of vehicle flow is represented by the position of the triangles, which indicate the location of the stations. In some cases, where there is a very high demand, parallel reversible guideways are installed to accommodate peaking requirements. These are shown by the dotted lines near the CBD (Fig. 9). Table 7 gives a summary of the cost estimates for this system. Note that the share of the cost for the control and electrical systems and for the vehicles is higher than for conventional systems.

Figure 10 shows the significant improvement in accessibility made possible by the PRT class of system. Approximately 65 percent of the urban area is within ½ mile (walking distance) of a station. Because many of the stations are less than 1 mile apart, the maximum walking distance in many activity centers (such as the CBD) is less than ¼ mile.

The conduct of a demand analysis for this system was beyond the scope of this paper; however, there are certain improvements in service and performance that can be shown to have a significant effect on the probable use of the system.

1. The increased number of stations significantly increases the areas of the city within walking distance to transit service (65 versus 14 percent);
2. The trip time for an average length trip (4.5 miles) is reduced significantly (from 9 to 6 min); and
3. The convenience of the vehicles is significantly improved.

TABLE 7

ESTIMATED COSTS OF PERSONAL TRANSIT SYSTEM

Element	Amount	Unit Cost (dollars)	Total Element Cost ($)	Percentage of Total System Cost
Track	390 mi	900,000	351,000,000	31
Stations	410	300,000	123,000,000	11
System design	1	500,000	500,000	
Right-of-way	390	200,000	78,000,000	7
Control and electrical	390 mi	300,000	117,500,000	10
Subtotal			670,000,000	
Engineering and service facilities, 25 percent of facilities			167,000,000	15
Vehicles	30,000	10,000	300,000,000	26
Subtotal			1,137,000,000	
Contingencies, 25 percent			284,250,000	
Total			1,421,250,000	

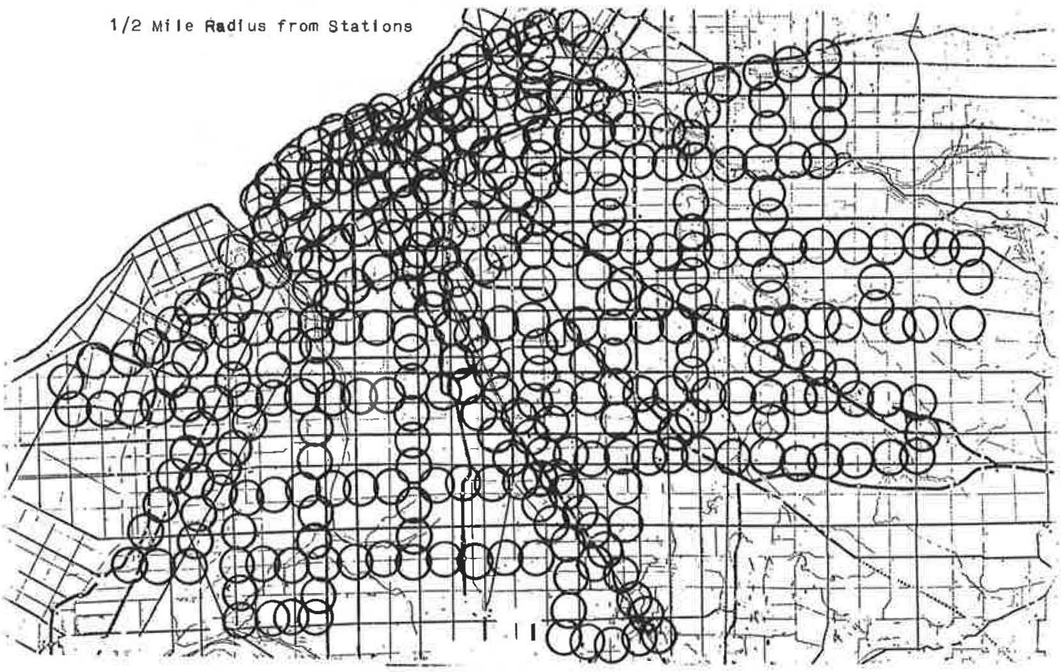

Figure 10. Personal transit service areas.

The actual increase in use of the PRT system as compared to the rail rapid transit system would require a definitive study; however, by inspection we would expect the ridership on the PRT system to be 5 to 10 times greater.

A common criticism of small vehicle systems is that they do not have adequate capacity to meet the demands of the system. It is true that the single-line capacity is less, but there are a sufficient number of alternate paths so that the total daily trip capacity (even assuming low load factors for the vehicle) is more than 10 times the predicted peak ridership of the rail transit system.

It should be noted that a greater effective use of PRT than of rail vehicles can be anticipated. Because of the diffuse nature of the trips in this area, it is probable that during the peak hour there will be fewer "deadheads" or low-load factor vehicles being returned for additional passengers on the PRT than on the rail system.

Figure 11 shows the differences in the potential service provided by the two systems. In this case the number of stations that can be reached from an average station (rail or PRT) is plotted against trip time. The actual distance is also shown. The two speed lines for the rail represent the average of existing system speeds and the proposed average speed for new systems with the same station spacing. The PRT system is shown for three line speeds: 40, 60, and 80 mph. This figure shows that even at 40 mph the PRT system will provide better service than the conventional rail system operating at the highest practical speeds.

Similar results were found in other studies of personal transit systems. For example, in a study of a large automobile-oriented city in the South (21), it was shown that a PRT system equal in length to a rail system would cost only 45 percent of the rail system but (primarily because of the shorter trip times) would attract 60 percent more riders, thus attracting 3.5 times the patronage per capital dollar of the rail system. In this case the rail system would attract 8 percent of the total person trips in the area. A network triple the size of the rail system would attract more than 20 percent of the total trips in that area.

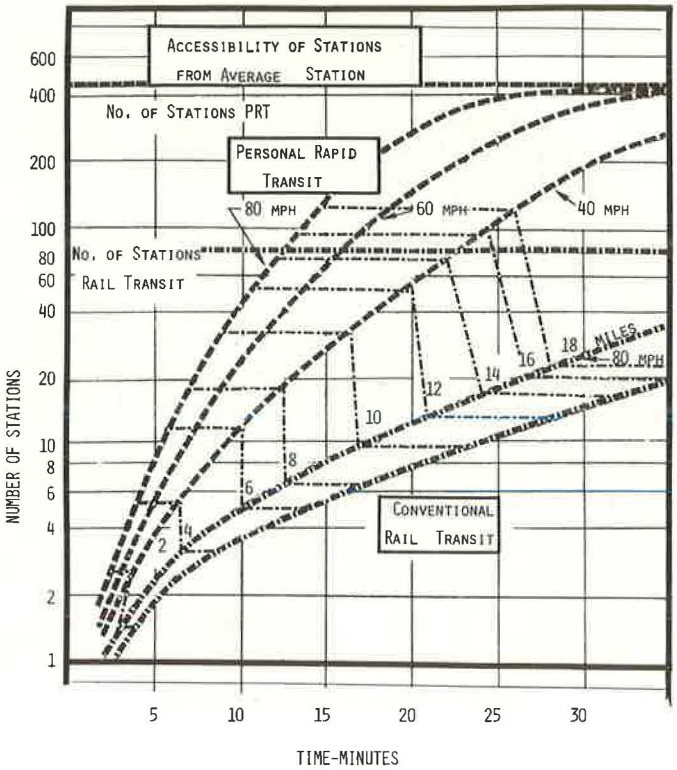

Figure 11. Comparison of potential service provided by personal rapid transit and conventional rail transit.

CONCLUSIONS

Although full-scale PRT systems may not be built for a number of years because of technical, economic, and political considerations, the fact that they can evolve from smaller systems should result in the near-term development of smaller activity center systems or the equivalent. Because of this possibility, transportation planners should be familiar with such systems.

PRT systems are not necessarily the best answer for all transportation needs. They will not replace bus systems in low-density areas or rail systems in high-demand, high-speed corridors. When their advantages are fully exploited, however, the PRT systems will permit the development of new urban forms. Greater use of parks and greenbelts between areas of the city can be provided within the normal trip time limits; basic services of a common nature can be lumped together in specialized areas (e.g., recreation, banking, and education)—all accessible from residential and other areas in an acceptable period of time; and large residential areas, apartment complexes, and similar areas can be designed without any provision for automobiles except in an emergency mode (i.e., fire and construction).

The use of a system of personal transportation should be significantly higher than that of a conventional transit system because of the following factors.

1. The total trip time can be lower than that of the automobile, thus attracting patronage that would otherwise use private automobiles;
2. The vehicle would provide privacy, safety, and comfort at least equivalent to an automobile and therefore would be attractive to passengers who avoid the transit vehicles;

3. The lower cost of guideways and compact terminals will permit the construction of more extensive networks for the same capital cost, thus providing wider service and more destinations for the passenger;
4. The low noise and pleasing appearance of the vehicle and system will permit installation of the system with minimum impact on the environment (in many cases, the vehicle can be routed through and stations located in existing buildings);
5. The system can be developed in economic stages, starting with activity center systems and gradually expanding to serve entire urban areas; and
6. The mechanical simplicity of the system and the use of automatic controls should provide low operating costs that permit economical fares.

The potential of this class of personal transportation has been established by preliminary analysis and engineering design studies. However, its acceptability to the public, the influence of the system on a specific urban area, and its implications in design freedom for the urban planner and architect can only be established by more extensive studies and demonstrations.

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A PLANNING MODEL FOR TRANSPORTATION IN URBAN ACTIVITY CENTERS

Martin O. Stern, International Research and Technology Corporation

This paper is concerned with the formulation and implementation of a planning model describing transportation in dense specialized urban activity centers, such as the central business districts of major cities. The several models developed include an activity accessibility model (AAM) to simulate the demand for trips generated in the area; an economic impact model to describe the impact of accessibility, derived from the AAM and combined with some other variables, on the area's economy; an environmental effects model to deal with air pollution and noise generated by moving and fixed sources; and a network systems costing model to derive the costs of new modes to be implanted in the AAM. This paper deals only with the AAM, a nonlinear statistical model of the generalized gravity type. The AAM is a planning model insofar as it allows testing of new policies, land uses, and technological possibilities in a quasi-equilibrium context. It is also a planning model in that the ability to predict detailed traffic patterns has been sacrificed—probably only to a slight degree—to a formulation that is explanatory and fundamental in its approach to trip-making. It should, therefore, have wide applicability. At the same time, the number of variables is held to a modest number so as to make calibration practical if not easy. Formulation, calibration, and preliminary validation in real-life situations are discussed.

•ALTHOUGH there are at least two schools of thought on whether land use shapes transportation or vice versa, there is general agreement on the importance of transportation in land-use development and economics, especially in the context of commuting between residence and work (1, 2, 3, 4, 5, 6, 7, 8).

The importance of the economically oriented, local, office-based trip, whether for business, lunch, or personal service, is less well realized outside of the business sector. Yet various urban activity centers display glaring differences from this point of view. This is indicated by contrasting the highly specialized lower Manhattan CBD with the more diffuse, all-purpose one in Milwaukee. Both have an area of less than a square mile. More than 500,000 people are employed in lower Manhattan; in Milwaukee the number is about 150,000. Both cities offer a choice of several transportation modes: five in New York—where walking is the dominant mode, and taxicabs and private vehicles are rendered almost useless because of congestion; and four in Milwaukee—where private vehicles and buses are the primary mode. There is considerable retail activity in both areas, but in New York it is largely oriented toward lunch-hour shopping and is limited in variety; Milwaukee stores cater mostly to the surrounding area and are languishing somewhat. In New York, economic activities are clustered in even more compact and specialized synergistic subregions (shipping, brokerage, financial, law, and insurance), whereas in Milwaukee a somewhat broader spectrum of sectors is geographically scattered and lacks such tight organization.

Such comparisons must not be carried too far. Certainly many of the differences can be traced to the size and specialization of the surrounding area and to past land-use

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traditions and development history. Nevertheless, it is tempting to conclude that the spatial organization of CBDs has much to do with their functional success and that ease of local trip-making may play a catalytic role therein.

The purpose of contract HUD-1067 has been to focus on the role of transportation in the economic viability of an area and to help predict whether transportation improvements, either through policy changes or investments, can improve the area's viability and evironmental quality. The program has been in existence for 1½ years. The first year was devoted to the formulation, design, and programming of a number of computer simulation models. In the present phase, these models are being applied to some real-life problems to test their usefulness and relevance. In the third phase, some model improvements and extensions will be undertaken based on the experience acquired during the present phase.

A model that simulates in adequate detail the trip-making pattern of an urban activity center is basic to the whole program. A number of transportation models were, of course, already in existence and had to be considered for adaptation. In the end, none of these were adopted outright but several were borrowed from. The discussion that follows is meant to be merely indicative of the considerations that were applied. It is not intended to be a comprehensive or critical review (1, 9, 10).

The basic Bureau of Public Roads model package (11, 12, 13) was specifically designed for predicting modal-split shifts when improvements are made in transportation or when modest population changes take place. Although the basic gravity approach was appealing, it was decided not to adopt this model directly because of the following:

1. The basic gravity approach is really not suited for a fine-grained description of an area because it produces a configuration of many small zones, each of which requires a rather large-sample and almost prohibitively expensive origin-destination survey;
2. It has forfeited considerable "explanatory" power in order to afford close calibration to an existing local situation and must therefore be used very cautiously for forecasts involving new technologies or policy changes; and
3. Its mode choice criterion, consisting of a modal split between automobile and public transit introduced following trip distribution, is too simple for our needs, and it does not consider essential behavioral factors.

Econometric models of the type proposed, for example, by Kain (14) were rejected for operational reasons. They generally contain a large number of variables in a framework of an even larger number of simultaneous equations and require a major calibration effort. Most models of any type do not spring full-blown but require numerous adjustments and changes until they are properly "tuned." This tuning is especially difficult for the econometric type of model because everything in it is coupled together. We preferred models consisting of several subcomponents that can be tested and adjusted separately.

The intervening or alternate opportunities concept (15, 16, 17) has some of the nonlinear features that play an important role in trip-making decisions. On the other hand, ready-made models based on this concept are either too large in scale (18) or share many of the shortcomings of models in the BPR package but without their history of practical application.

Quandt and Baumol's Abstract Mode Model (19, 20, 21) seemed to have some of the behavioral features we were looking for in a planning model—especially regarding treatment of modal choice—and some of their concepts were borrowed and considerably extended. In any case, this model as originally formulated could not be directly adapted to a situation with hundreds of origin-destination pairs because of the enormous quantity of data required for calibration but not readily available.

A model has been devised at Harvard for application to goods movement on a regional or larger scale (22). Although based on economic activities for generation and distribution of trips, it is too coarse-grained for our purposes and does not contain the behavioral cost component necessary to explain multipurpose trip-making.

Finally, several efforts were and have been in progress (23) to formulate micro-transportation models, but these were not far enough along to be useful to us at the inception of our program.

The task of formulating a new set of models was therefore undertaken. This was done with some trepidation because the literature abounds in models that were published but never used—usually, for lack of data with which to calibrate them. Whether the effort has been worthwhile cannot yet be determined with finality; the reader may supply an interim judgment for himself.

OVERVIEW

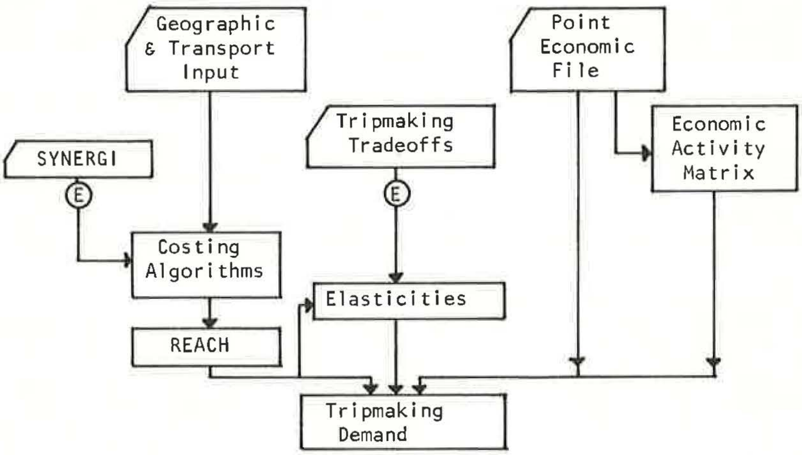
The purpose of the transportation model developed in this research program and called the activity accessibility model (AAM) is to forecast changes in trip demand or in traffic patterns due to demographic, economic, behavioral, policy-making, or technological changes, or the implantation of a new transportation system.

In formulating the model, we had to steer a course between two hazards. A model can attempt to be highly analytical; it can describe the interaction of various components in such a general way that the model can be applied to very diverse situations but at the expense of sufficient detail to represent adequately a specific situation. Or the model can, at the opposite extreme, be so phenomenological and well-calibrated for describing the status quo in a given area that it loses most of its extrapolative value. We have attempted to strike a balance between these two extremes.

The AAM uses highly detailed information about a given urban activity center (UAC) and, because of the interaction of various economic sectors within the UAC, combines this with some general but rather disaggregated information about trip-making. Forecasting in our model is accomplished by means of a generalized trip demand function, which should react sensitively to changes in the input.

The assumption is made that, within the UAC as a whole and on the average, economic activities and trip-making (other than commuting) associated with them are in a state of quasi-equilibrium at any given time. Forecasting with the model assumes that the change being examined is either localized and therefore not far-reaching enough to destroy overall equilibrium or, if not localized, is not sufficiently drastic to cause the economic description of the UAC to become invalid. Such assumptions also underlie, as far as we know, most traffic-forecasting models. Multiple iterations to determine incremental changes to the original equilibrium can, of course, be performed as long as the process converges.

Figure 1 is a schematic diagram of the AAM. The model has certain distinguishing features—some conventional, others novel—that are presented for overview.



E = Numerical Estimation Procedure

Figure 1. Schematic diagram of the activity accessibility model.

1. The distribution function has the form of a modified gravity model:

$$d_{ij} = G\, M_i\, M_j / R_{ij}$$

where

d_{ij} = number of trips generated at node i (a street intersection) that is to be allocated to trip-end node j (another street intersection);
G = a constant incorporating a weighted measure of the intensity of interaction between economic activities at the origin and destination;
M_i, M_j = measures of activity intensity at nodes i and j respectively; and
R_{ij} = an impedance or friction factor dependent on the generalized cost of trip-making between i and j.

2. The cost for a trip is treated as a multicomponent vector (rather than scalar) quantity; typically, three distinct components are included: money, time, and stress.

3. Perceptions of stress and the behavior-related cost component coefficients are quantified with the help of a stratified panel rating procedure—Systematic Numerical Evaluation and Rating by group iteration (SYNERGI).

4. Origin-destination surveys, which are ordinarily used to fix G, are replaced by an economic activity matrix (EAM) that describes trip-making intensity and propensity among economic sectors.

5. Demographic data, which are normally used to describe M_i and M_j, are replaced by employment for various sectors present at nodes i and j.

6. Each urban activity center is described in considerably more detail in the AAM than in most models, and economic, geographic, and transportation information is assembled on a block-by-block basis.

7. Trips are described in fine detail—by purpose, trip-making conditions (weather and congestion), and economic sector-to-sector interaction.

8. All modes, walking included, are described in detail; the possibilities of switching from one mode to another are also realistically represented. A route-selection algorithm (REACH) retains those "feasible" routes that are competitive with others in cost, time, and/or stress.

9. The expression d_{ij} acts as a true demand function that generates trips at the origin, allocates trip-ends to different destinations, and distributes trip-making demand among competing modal routes by means of behaviorally determined factors. It also determines how many total trips are made.

10. An accessibility index describes the relative ease with which an economic sector at a given point can interact with other sectors in the surrounding area necessary to its functions. Mathematically, this index is a ratio of the trip-making propensity of a specific activity located at a specific point to the average trip-making propensity for that particular activity in the area as a whole.

The central expression of the AAM is the trip-making demand between two points, i (origin) and j (destination). Because our model is of the generalized gravity type, the demand is determined by factors giving how many trips are generated at i and how many of their trip ends are ideally located to j. (We here adopt the terminology of the transportation engineer. We could, with equal validity, reverse the process by considering destinations as trip generators.) The ideal demand is then divided by a trip-making impedance R_{ij} (which must be greater than, or equal to, unity). Details are given in the Model Components section in this paper.

The trip-making impedance is determined through a set of costing algorithms and through the REACH network selection program. The costing algorithms fix the user cost on all links, defined as the mode-specific paths among communicating nodes. These include sidewalks for the walk mode, streets for the automobile, taxi, and bus modes; tunnels for the subway mode; and so on. User costs include money, time, and stress. Stress is determined by a stratified panel rating procedure. User costs may depend on trip-making conditions such as weather and congestion. Once the cost components are determined for each link, a trip between any points i and j can be described for any path by a succession of links. Costs are summed as the trip proceeds. The REACH program selects, out of all possible paths between i and j, those paths that have an advantage over others from the viewpoint of at least one of the cost components. The trip impedance is a function of these cost components. The trade-off coefficients between the components are functions of trip purpose and trip conditions and are behaviorally determined.

Trip generation and distribution are determined partly from a land-use file and partly from an EAM developed by ad hoc economic analysis of the UAC as a whole. The EAM determines the average number of trips generated between economic sectors. Information from the EAM, when suitably combined with employment at i and j obtained from the land-use file, results in a consistent generation of trips and assignment of trip ends.

DATA INPUTS

In this section, we shall deal with inputs in somewhat more detail. The inputs required are of the cross-sectional type. It is more important that they all pertain to the same point in time than that they be current. (Inputs are given in Table 1.)

Geographic File

A geographic data file is assembled, in which each street intersection is given a code name, and the streets linking two intersections are identified by name, length of the segment, width between curbs and buildings, and range of street numbers on each side of the street. These data are obtained from Sanborn maps.

Transportation File

A master transportation file is prepared and stored, in which all existing or planned transportation modes (including walking) are described. Each transportation mode is

TABLE 1
INPUTS FOR THE AAM

Input Data	Sources
Geographic links: streets and street addresses, street and sidewalk widths, directionality of flow	Sanborn maps
Routed systems and transfers: locations of bus routes and stops and transfer points	Bus route maps, subway maps, and direct field survey
Parking, signals, and turns: intersections where there are traffic lights, nearby parking, or where left turns for vehicles are restricted	Direct field survey and Sanborn maps
Transportation system characteristics: schedule, speed, capacity, fare, and operational details	Information from transportation agencies and ad hoc studies
Land-use file: economic activity (employment by 4-digit SIC code) assigned to addresses and then aggregated to nodes	Duns Market Indicator (DMI) tapes, special census tabulations (for retail trade), and direct field surveys
Economic activity matrix: trips between economic sectors, by purpose, time of day, and other conditions	Employment derived from land-use file, trip-making coefficients from ad hoc studies and direct field surveys of sample buildings, and other transportation surveys
Trip-making stress by link: derived for different trip purposes, times of day, and other conditions	SYNERGI rating panel
Elasticities of demand for cost, time, and stress: derived for different trip purposes and other conditions	Questionnaire on trip habits

specified link by link, where a link is a segment connecting two nodes, and a node is understood to be a point at which the possibility exists for choosing between alternative routes or switching from one mode to another. The geographic location of transit nodes can be slightly distorted to coincide with the coded nodes describing street intersections.

The master transportation file is thus a collection of links, and each link is mode-specific and described by the code numbers of the nodes that it joins. In addition each link has specific descriptors, such as length, schedule, speed, fare structure, and other user costs that are detailed later.

In addition to mode-specific links, the transportation file contains a list of "dummy" or switching links. Dummy links have the same coded node number at each end, but they identify a change from one mode to another. For example, a change from private car to walking involves a dummy link for the act of parking the car. Dummy links have their own costs in money, time, and stress. Waiting time and payment of fares are attributed to dummy links, for instance, where there is a delay due to schedule and where one fare is paid on boarding regardless of length of the trip. A trip is then described as a succession of links, with dummy links inserted wherever the traveler makes a change in mode.

Land-Use File

In addition, information is obtained about economic activity at each address. This information is partly available from Duns Market Indicator (DMI) tapes, which list businesses according to four-digit SIC identity at a given address and are based on special census tabulations and other sources. Because the readily available tabulations were found to be insufficient for our purposes, additional research was required to bring this task to a satisfactory state of completion.

By means of an add-matching routine, the economic activity information stored by address can be aggregated from the surrounding area onto the nearest street intersection. Each intersection or node is then characterized by a spectrum of SIC code numbers and by their associated economic activity. Code numbers can then be grouped to form specified economic sectors.

Economic Activity Matrix

Trip-making between different economic sectors is quantified in the EAM. A given element in this matrix gives the daily trips for the entire UAC between the origin sector specified on the ordinate of the matrix and the destination sector specified on the abscissa, corresponding to a certain trip type or purpose (24). Because six trip types k are distinguished, there may be six different matrices. For example, each matrix for the lower Manhattan UAC has 18 sectors, 4 outside the study area (but within commuting distance) and 14 within the area itself. Thus, each matrix has 18 × 18 = 323 elements, some of which generally are negligibly small or zero. The matrix tends to be symmetrical about the diagonal, although this is not rigorously true in principle. The 14 UAC sectors in lower Manhattan are as follows:

Activity	Sector
Business and professional services	5
Goods and supplies (wholesale)	6
General office	7
Government	8
Warehousing and on-site manufacturing	9
Restaurants, bars, eating places	10
Retail	11
Parks and plazas	12
Miscellaneous (schools and museums)	13
Brokers	14
Exchanges	15
Miscellaneous financial	16
Insurance	17
Banks	18

TABLE 2

TRIP TYPES AND CONDITIONS

Trip Type k	Description	Good Weather		Bad Weather	
		{C}	$[v^k(C)]^{-1}$	{C}	$[v^k(C)]^{-1}$
1	Trip to work	{01100}	1.000	{11100}	$1.0[1+\epsilon_1]$
2	Office-based business trip (non-lunch)	{00100} {00001}	0.900 0.100	{10100} {10001}	$0.9[1+\epsilon_2]$
3	Office-based business trip (lunch)	{01100}	1.000	{11100}	$1.0[1+\epsilon_3]$
4	Office-based personal service trip (lunch and non-lunch)	{00000} {01100} {00001}	0.150 0.834 0.016	{10000} {11100} {10001}	$0.15[1+\epsilon_4]$ $0.834[1+\epsilon_4]$ $0.016[1+\epsilon_4]$
5	Home-based personal service trip	{00000} {00001}	0.800 0.200	{10000} {10001}	$0.80[1+\epsilon_5]$ $0.20[1+\epsilon_5]$
6	Goods delivery trip	—	N. A.	—	N. A.

There would be different sector choices for a different UAC. The six trip types k = 1 to 6 are given in Table 2.

Cost Vector

The most important information associated with each link is the user cost. User costs will be regarded as a vector having several components, typically three: money, time, and stress.

Although we are aware that nonquantitative costs such as stress are difficult or impossible to evaluate explicitly in terms of dollars, our approach assumes that it is possible to assign to them a cardinal number that specifies the quality in question unambiguously, in the sense that greater stress is always described by a bigger number than is smaller stress. The trade-off among stress, time, and fare is obtained by determining how people make modal choices for various trip types under different weather conditions. Because individuals differ in their personal utility functions, and even the same individual may rate stress differently relative to time or dollar cost depending on circumstances, there are no simple "once-for-all" relationships among the three variables.

Out-of-pocket costs and time for various link types are primarily obtained from information (fares and average speed) that is readily available. Some variable parameters can be included to render qualitatively the effects of congestion and other trip-making conditions.

Stress, like the weather (and partly due to it), is a cost item whose importance in trip-making has been realized for a long time but about which relatively little has been done (25, 26).

In our case, the quantification of stress is accomplished as follows: trip-making in an abstract (i.e., mode-independent) generalized sense has been analyzed in terms of sequential actions and situations. These actions and situations are then numerically rated by a carefully chosen stratified panel with regard to the importance of reducing the stress associated with them. The survey format is called SYNERGI (27).

The results of the survey are suitably processed to yield a stress "cost" for each link with its associated travel mode under a variety of selected environmental travel conditions. Up to now the travel conditions are specified in "black-and-white," yes-no binary variables and are listed as follows:

Condition	Component
Is the weather bad?	C_1
Are traffic conditions congested?	C_2
Is the traveler's personal schedule rigid?	C_3
Is it nighttime?	C_4
Does the traveler have baggage?	C_5

(The components take the value of 1 when the answer to the question is "yes" and 0 when it is "no.") In real life, intermediate situations (e.g., ordinary weather or moderate congestion) occur that fall between the sharply defined extremes noted. The model treats these—for the moment—by using (ad hoc) interpolation, under the assumption that trip-making demand is a monotonic function of each variable. Thus, the demand for trips via a given mode on a day of moderate congestion would presumably fall between the demands corresponding to high and low congestion.

To conclude this brief discussion of stress, we admit that our treatment of this variable is, at present, still quite primitive. Our underlying assumptions are as follows:

1. All user-perceived qualitative variables can be subsumed under the heading of stress and dealt with as a single variable that is definable for a given link and additive from link to link;
2. Stress is intrinsically quantifiable in terms of cardinal measures that obey the usual rules (transitivity, reflexivity, or commutativity); and
3. Transportation users are able to provide adequate estimates of these measures if given an appropriately structured situation.

We are, of course, aware that stress components are of different natures, are not necessarily additive or even commensurate, and may exhibit such nonlinear phenomena as thresholds and saturation. Our justification for disregarding these drawbacks is that the addition of even this primitively quantified variable succeeds in making the model significantly more realistic—and capable of describing actual trip-making behavior—than other models.

Elasticities

Elasticity coefficients α_p^{kc} giving the importance of the three user-cost components ($p = 1, 2, 3$) relative to each other must be specified as an input. It is expected that the coefficients differ for different trip types and conditions (and probably other variables, such as city size, region, and climate), so that at least six sets of three may have to be determined in a given locale.

The elasticity coefficients are determined from responses of population strata as to how they would choose to make a specified trip between fixed end points under different trip-making conditions $\{C\} = \{C_1 \ldots, C_5\}$. Because different trip purposes $k = 1, \ldots, 6$ are undertaken under different conditions $\{C\}$ and by different population strata, it is possible to derive modal choices for different trip purposes.

With the help of an exponential impedance function defined in the following section, it is then possible to estimate the α_p^{kc} ($p = 1, 2, 3$) for several k and C by using a linear estimation program.

MODEL COMPONENTS

REACH Algorithm

The urban activity center (UAC) has been described in terms of a large number of nodes, typically several hundred of them, superimposed on which is a grid of links for reaching each node. There is thus a multiplicity of ways for reaching each node from any starting point. Not only can one take an indirect rather than a more direct route from i to j, one can also switch from one mode to another in a number of different ways. Moreover, innumerable routes can be devised that no one would ordinarily take, such as roundabout routes that loop back on themselves one or more times. In order to determine traffic patterns and modal choices, a criterion will be needed to determine the one (or several competing) most practical route(s) between origin and destination.

Such a criterion is given by a route selection algorithm (REACH) that eliminates all paths except those that have at least one competitive cost component and labels the surviving "feasible" paths. Distribution among these is then determined by means of the demand function, the description of which follows.

The algorithm actually computes, in one operation, the cumulative cost of traveling from a given origin to all possible destinations in the UAC. As it reaches out for these destinations, it compares user costs for various routes to a node and eliminates all those paths for which cost components are individually greater than the components of a competing path. In other words, the algorithm eliminates, as it goes along, any path whose user appeal is "dominated" by that of other paths and retains only the dominant ones. It proceeds until it has reached and labeled all destinations. In this manner, the algorithm determines all feasible routes from an origin to all destinations in the UAC. The elimination of dominated routes is behaviorally justified if the three cost components are independent of each other and form a complete set of decision-making variables for choice of routes.

In most instances, one wishes to determine the demand for a given destination from origins in the UAC. From economic analysis one can learn something about the effective budget for the type of trip involved. We assume that there is no trip-making from regions of the UAC for which the trip costs exceed the specified budget. Thus a budget vector can be introduced as a constraint in the algorithm; in which case the algorithm computes all paths throughout a "possible region" around the given destination, which is generally considerably smaller than the UAC. In this way the computing time is much reduced, whereas the neglect of trips from areas excluded by the budget should have no appreciable effect.

By applying the REACH procedure to a given node for all types of trips beginning and ending there, coupled with information on distribution of trips in time, one can develop the flow of traffic to and from this particular node. By superposing such flows from a sufficient number of adjacent nodes (following an explicit sampling procedure), one can synthesize a traffic pattern for an area. The size of the possible region centered on a specified node is an important indicator of the adequacy of the transportation system around the node for this particular trip type.

Impedance

Gravity models are characterized by the concept, borrowed from physics, that, other things being equal, trip-making is inversely proportional to the cost, distance, or time, or a function of these, between an origin and a destination. There is another way of looking at it: Trip-making is accompanied by friction (out-of-pocket cost, time loss, and stress) that causes demand for trips between any two points to be less than some ideal value; the greater the friction is, the lower the demand is, and, as friction becomes very large, the demand should go to zero. As friction vanishes, the demand should approach a maximum value that is probably finite rather than infinite; economically motivated trip-making is not an end in itself but an exogenously stimulated activity.

In the AAM, the REACH algorithm derives the cost components for any feasible route from an origin to a destination. The friction is taken as a function of these cost components. Each cost component in this function is weighted by a numerical coefficient α^{kc} (the elasticity coefficient described previously), which has behavioral significance that is determined by how important dollar cost is in relation to time and stress for a given trip type. Because this index of importance varies from person to person, the α's are taken to represent suitable "average" values.

We then define an impedance function that has the following properties: It becomes smaller as the friction becomes smaller, but tends to a finite value (such as unity) as the friction approaches the limiting value of zero; it becomes ever larger as the friction increases; it has the right curvature to exhibit the property of diminishing returns; and it satisfies the requirement that the impedances of N links in series must combine multiplicatively to give the total impedance for the N-link sequence as a whole.

For these reasons, as well as that of mathematical convenience, we have chosen an exponential form for the impedance R_{ij} between points i and j:

$$R_{ij}^{kC} = \exp\left[\sum_{p=1}^{3} \alpha_p^{kC} X_{ij}^{pC}\right] \tag{1}$$

where

k, C = trip purpose and trip condition respectively;
X^p = user costs (money, time, and stress);
α_p = weights or "elasticity coefficients" determining the relative importance of the cost components for various k and C.

Because $(R_{ij}^{kC})^{-1}$ is a factor in the demand function, it is the $\alpha_p X^p$ that play the role of elasticities. It is also clear from Eq. 1 that the problem of estimating the α's is a linear one for this form of impedance.

Demand Function

Once we select a given origin and destination, say nodes i and j respectively, the land-use file can tell us what economic activities are present at i and j and what fraction of total economic activity in each sector for the whole UAC is carried on at these points. With the help of the EAM, we can identify the types of trips that will take place between i and j and work out the expected volume (in a statistical sense) of trips of each type generated at i and ending at j. Because the EAM is derived from total figures for the UAC, this volume would be that obtained if the friction between i and j were equal to the average friction prevailing over the entire UAC.

To obtain a better representation of trip-making between i and j, we must multiply this volume by the trip-making impedance between i and j. This is obtained by running REACH, identifying feasible routes between i and j, costing each out, deriving partial impedances if there are several routes, and thus obtaining a single combined impedance. The resulting number is the trip-making demand function between points i and j, in units of trips per day. It can be multiplied by a suitable function of time of day, dependent on trip type, to give an hourly trip distribution.

The demand function takes into account the economic activities at the two end points of the trip and the trip-making impedance between them. Intervening opportunities and peculiarities of local activities departing from the norm are not modeled in detail. Nevertheless, the same α's that represent people's evaluation of the relative importance of the user cost components, when coupled with a rough determination of travel intensity under "ideal" conditions, lead to the value of trip-making impedance in response to which economic activities have arranged themselves in an UAC, given enough time for equilibrium. Thus, although the demand function cannot model the unusual attraction presented by an outstanding restaurant, it does model the characteristic spacing of more or less equivalent restaurants, which occurs, at least partly, in response to people's unwillingness to travel very far for lunch.

By using the EAM we obtain the total number of trips from one economic sector to others with which it interacts, given the trip type. By using the land-use file, we can derive the total number of employees for the UAC in the originating sector; therefore, we can derive the average number of trips generated by one employee in that sector to all interacting sectors.

We can now implant one such employee at origin i and ask for the number of trips generated by him to the interacting sectors at j, given the spectrum of activities at j and the trip-making characteristics between the two points. By summing over all destinations j, we then obtain the number of trips generated by the one employee in the given sector at i. If we divide this number by the average number of trips generated by one such employee, we obtain the accessibility index for that sector.

The accessibility index gives an indication of how favorable a location is for the pursuit of economic activity in a given sector, given the actual location of activities with which it interacts and the ease of reaching the interacting activities from i. It plays a central role in the economic impact model.

Mathematically, the demand function is given by

$$d_{ij}^{\eta\mu,\,kC}(t) \equiv A^{\eta\mu,\,k}\, f^{k}(t)\, B_{i}^{\eta}\, m_{\eta\mu}^{k}\, B_{j}^{\mu}\, (\overline{R}_{ij}^{kC})^{-1}\, [v^{k}(C)]^{-1} \tag{2}$$

where

$d_{ij}^{\eta\mu,\,kC}(t)$ = demand (trips per hour) for trips of type (or purpose) k under conditions {C} from activity η at point i to activity μ at point j;

$f^{k}(t)$ = fraction of daily trips of type k taken in a given hourly interval;

B_{i}^{η} = fraction of activity η at point i relative to that throughout the UAC, in terms of employment;

$m_{\eta\mu}^{k}$ = number of daily trips of type k between η (origin) and μ (destination) throughout the UAC;

B_{j}^{μ} = fraction of activity μ at point j relative to that throughout the UAC;

$[v^{k}(c)]^{-1}$ = fraction of trips of type k carried out under conditions {C};

$\overline{R}_{ij}^{kC}$ = trip-making impedance (defined later); and

$A^{\eta\mu,\,k}$ = normalization factor (defined later).

$f^{k}(t)$ is one of a small set (6) of simple step-function distribution functions stored and called into play when k is specified exogenously; B_{i}^{η} is derived from the land-use file; similarly, for B^{μ}, $m_{\mu\eta}^{k}$ is one ($\eta\mu$) element of a small set (6 or less) of EAMs stored as tables. R_{ij}^{kC} is given, for the case of only a single feasible route between i and j, by Eq. 1.

If there are several competing routes, $\ell = 1, \ldots, r$, between i and j, the REACH algorithm gives us

$$R_{ij\ell}^{kC} = \exp\left[\sum_{p=1}^{3} \alpha_{p}^{k}\, X_{ij\ell}^{pC}\right] \tag{3}$$

for each. These we call the partial impedances. In that case, we might be tempted to put $R_{ij\ell}^{kC}$ into Eq. 2 in lieu of $\overline{R}_{ij}^{kC}$ and call the resulting expression $d_{ij\ell}^{\eta\mu,\,kC}(t)$, the partial demand for previously defined trips on route ℓ.

However, such a treatment cannot lead to qualitatively correct results because it combines the separate impedances as if they were resistances in parallel across a constant-voltage power supply to give the total demand. In actuality, the demand resembles neither a constant-voltage nor a constant-current supply precisely but is generally closer to the latter; i.e., trip-making on the total of several parallel paths is usually greater than it would be on any one of them alone (i.e., if it were the only one present) but far less than would be obtained by summing over all paths considered as though each one were treated in isolation. The reason is that, if one adds an alternative route to one already present, most of the trip-makers on the new route are people who formerly traveled on the old one but perceive the alternative as offering less friction; the only new trip-makers are those who considered the old route too abrasive for making the trip at all but find the new one (or the old one after it has been decongested) more acceptable.

Thus we must find a way of more correctly combining impedances of connecting routes. This will yield a mean impedance $\overline{R}_{ij}^{kC}$,, which "explains" total trip-making between i and j. The flow on a given route ℓ (among several competing ones) is then given by a function of $\overline{R}_{ij}^{kC}$ and of $R_{ij\ell}^{kC}$, which distributes the flow among the competitors. To a first approximation one may be able to use the functions $R_{ij\ell}^{-1}$, raised to some power, as a measure of relative flow.

A sophisticated way of deriving the combined impedance $\overline{R}_{ij}^{kC}$ will have to take into account a probability distribution for each of the coefficients α_{p}^{kC} and carry out the corresponding probability integrals, as done by Quandt (20). We have used a simpler, more approximate procedure, but even so the equations are complex enough to require separate treatment elsewhere (28).

The normalization factor $\overline{A}^{\eta\mu,k}$ is most simply defined and evaluated by

$$(A^{\eta\mu,k})^{-1} \equiv \overline{{}_{j}B_{j}^{\mu}/R_{ij}^{kC_0}}^{\,i} \equiv \overline{{}_{i}B_{i}^{\eta}/R_{ij}^{kC_0}}^{\,j} \equiv (A^{\mu\eta,k})^{-1} \tag{4}$$

where the overhead bars denote weighted averages over all points i with activity η, or all points j with activity μ, as the case may be, the weights being the B_i^{η} or B_j^{μ} respectively. C_0 is the standard condition for which the EAM is derived. In practice, a sampling of points may suffice to form the averages, and $A^{\eta\mu,k}$ may be quite insensitive to k and yield only a narrow range of values for different $\eta\mu$ pairs.

The trip-condition coefficient $v^k(C)$ is exogenously obtained and indicates what percentage of trips is taken under nonstandard conditions (e.g., what percentage of people taking trip type k carry baggage). For bad-weather conditions, $v^k(C)$ also contains factors $(1 + \epsilon_k)$ that adjust total trip-making relative to good-weather conditions for a given k if this additional degree of freedom is found to be necessary. The definitions of six trip types, the conditions $\{C\}$ appropriate for each trip type k, the reciprocals of $v^k(C)$, and the factors $(1 + \epsilon_k)$ are given in Table 2. The values of $v^k(C)$ are crude estimates and are for illustration only.

The demand function (Eq. 2) serves as a point of departure for the prediction of flow on links and the calculation of accessibilities for input to the economic impact model. We can define a sector-specific accessibility index in terms of Eq. 2 by calculating the number of trips generated by a single average employee in a given sector at a given point to all the surrounding activities and by dividing this quantity by the number of such trips made by such an employee on the average throughout the UAC. The expression for a simple form of the accessibility index is

$$\Delta_i^{\eta} \equiv \left[\sum_{\mu,k} m_{\eta\mu}^{k}/v^k(C)\right]^{-1} \sum_{\mu,k} A^{\eta\mu,k}\, m_{\eta\mu}^{k} \sum_{j} B_j^{\mu} \left[\overline{R}_{ij}^{kC} \cdot v^k(C)\right]^{-1} \tag{5}$$

Accessibility, rent, and environmental quality in turn serve to determine the demand for adapted space that forms the point of departure for the economic impact model.

APPLICATIONS AND EXTENSIONS

Present Work

Our present effort consists of making some improvements and changes to the models while at the same time applying them in their present form to some "real problems."

The changes consist of some minor program cleanup and streamlining but are mainly aimed at reducing the running time of the REACH algorithm, which currently takes from 1 to 2 min for all the modes and nodes in lower Manhattan from Fulton Street southward. The REACH algorithm is, by far, the most time-consuming and core-storage demanding component of the model. Any reduction in these requirements will make more computers accessible and will allow us to generate more collective information such as traffic on links as opposed to sampling information such as accessibility indexes at selected points.

The reasons for applying the models to actual problems at this stage are to determine whether planners like working with the models; whether their input data base is manageable; whether the planning process using the models produces new insights and more rational approaches and advances the state of the art in planning; and whether the forecasting ability of the models can be tested in some "before-after" situations.

In lower Manhattan, we are working with the Planning Commission and the Office of lower Manhattan Development to examine possible effects of selected closings of lower

Manhattan streets to private vehicular traffic. Effects on goods movement and delivery, cab traffic, pedestrian traffic, and shopping patterns will be examined. In Milwaukee, we are working with the City Development Commission on the effects of a major new office building complex, to be built in the CBD, on transportation and pedestrian circulation and demand for retail and office space. Other, longer range projects are under way in several cities, including one or more with the Port of New York Authority.

Extensions

For the models to achieve maximum usefulness and flexibility in application, certain extensions and modifications should be undertaken, only the most important of which are mentioned in this paper. These extensions are in addition to the very necessary tasks of making the models operational and validating them by sensitivity analysis and application to one or more real situations.

Data Methodology

The economic activity matrix is one of the unique features of the AAM. Data gathering for the EAM will always remain somewhat ad hoc, but the process can be formalized by providing a system for gathering, collating, and referencing the data, estimating their reliability, and designing a program that will generate the best fitting matrix.

A quantitative rating scheme will have to be used in every location where the AAM is to be applied in order to yield the numerical behavioral data required in the trip-making demand function. The SYNERGI scheme, as formulated under the present contract, provides a suitable starting point; however, it needs further development.

A very desirable improvement would be to undertake the exercise in a teaching-machine format, which permits instantaneous feedback. Following the initial preference rating, a participant's results would be processed through a remote terminal linked to a time-sharing computer to yield a prediction concerning modal preferences. If these are at variance with the participant's stated preferences, he receives suggestions on alternative ways of modifying his ratings to achieve self-consistency. This improvement requires fairly extensive experimentation and testing, including some software development.

AAM Model Improvements

One of the obvious ways of validating the model in a given area is to enable it to calculate traffic flows. To this end, economical algorithms should be devised for approximating vehicular traffic on a link—short of the brute-force method of doing REACHs for all nodes in a region. This will then also make it possible to calculate congestion effects.

Congestion greatly affects an area's accessibility, which in turn plays a crucial role in describing the economic impact of transportation. Congestion can affect the three user-cost components of trip-making as well as having undesirable externalities. Up to now, congestion effects in the model are crudely simulated by additional costs that can be switched in exogenously regardless of calculated traffic flow.

The alterations that we propose would involve coupling the initial traffic flow calculated as shown earlier to the user costs on a link through a typical flow-velocity relationship using information about the capacity of the link. The traffic calculation is then iterated until convergence is obtained. Once experience is obtained with this procedure, the iterative link can then be closed internally.

The model is, at present, able to include residential accessibility only crudely in terms of UAC entrance turnstile counts as inputs. Modifications should be formulated and implemented that allow the AAM to describe movements from residential areas to business districts and institutions for purposes of employment, personal service, and educational and cultural pursuits.

The AAM requires some adaptation to be suitable for the description of goods movement, goods movement accessibility, and the interaction between goods movement and trip-making traffic. The objective will be to give the model the ability to describe the effects of an implanted goods movement system on the area.

The AAM demand function is impedance-sensitive; i.e., it aims to predict how tripmaking for a given purpose changes when external conditions change (such as the weather or the transportation system). This concept remains to be validated.

In addition, various improvements and major additions should be made to the economic impact model that would allow one to handle time-dependent problems, investment constraints due to policy measures or the state of the economy, and to devise, by using network selection techniques, optimal spatial arrangements for economic activities. Although we have not discussed the economic impact model in detail in this paper, mention of these items will make what follows more intelligible.

Future Applications

Here we discuss some applications of the transportation and economic models. We indicate what special data base (if any) would be needed beyond that discussed previously and what additions to the models would be required. The reader may be able to think of numerous additional possibilities.

1. The effects of possible operational decisions can be examined and evaluated. Among these might be street closings to vehicular traffic, changes in schedules, and new fare structures (including parking fees).
2. Costs and benefits, to both users and nonusers and by economic sector, of major investment decisions can be evaluated. Among such decisions one might mention the implantation of entire new transportation systems (such as moving sidewalks) or smaller changes (such as new routes, tunnels, stations, or equipment) or zoning and policy changes.
3. The effects of major investment decisions or zoning changes on land values can be used to form the rationale for formation of an assessment district. There has been much discussion recently on whether the public can, in this fashion, recoup some of the "windfall" gains accruing to the private sector favorably affected by these public investments or zoning changes.

The following applications require the type of data base that was acquired for lower Manhattan on the present contract; no additional major model development is needed.

1. The economic impact resulting from congestion can be investigated. The relative effectiveness of possible relief measures can be examined by means of the models. The effect of public investment decisions or zoning changes on relieving or creating congestion can also be evaluated. This application would require the addition of a vehicular congestion submodel and the development of algorithms permitting the computation of traffic flows without excessive computer running times.
2. The models could be of major help in airport location and surrounding land-use and transportation planning. The economic impact model is well-suited to develop criteria for viable mixes of economic sectors, subject to restrictive constraints such as immunity to noise. The AAM would derive transportation demand and could compare various transportation systems from the point of view of costs, benefits, and externalities.
3. The models would provide a suitable tool for planning of new towns where there are few improvements at the beginning. The model would be developed in terms of the complete horizon plan (or several plans to be compared), and various staging alternatives for reaching the horizon would be compared to evaluate problems of cash flow, land values, capital improvements and investments, and growth rate. If the problem were to develop a horizon plan, branch and boundary methods would have to be developed to allocate land optimally to various economic activities. The most suitable transportation systems for the horizon year, and alternate transportation investment policies during the intervening period, would of course be selected by application of the AAM.

SUMMARY

In applications so far, the model has been useful in helping local decision-makers to weigh policy alternatives. Future applications, some requiring addition of certain features to the model, may include the following:

1. Comparison of various "implanted" transportation systems, such as people movers, to assess the demand created, capacity required, fare policies, reduced load on existing facilities, effect on accessibilities and land values, and other externalities, in order to make more comprehensive cost-benefit estimates;
2. Formation of assessment districts to defray part of the public investment in a new transportation facility, the assessment being based on the windfall land value gains accruing to owners along or near the right-of-way; and
3. Evaluation of the effect of various zoning policies (such as floor-area ratios) on the demand for transportation, the creation of congestion, and a more comprehensive approach to quantifying the costs of congestion, including many of the externalities.

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BALANCE AND INNOVATION IN URBAN TRANSPORTATION

William F. Hamilton, II, General Research Corporation

Proponents of balance in urban transportation have won a major victory. For years they have argued that the increasing dominance of the automobile was unbalanced, that public transit should accordingly be revived, and that urban life would thereby be substantially improved. Now the federal government has taken heed and is readying a national program of transit revival backed by a major financial commitment. That balance has emerged as a political success seems natural enough: No one, after all, advocates imbalance. That balance will emerge as a practical success, however, achieving the benefits ascribed to it in a manner commensurate with its costs, is not nearly so clear. At present, balance is often so narrowly interpreted as to exclude significant innovation in urban transportation. Without innovation, balance consists simply of increased investment in conventional transit, and the capability of conventional transit to induce major improvements in the quality of urban life is obscure at best. This paper first reviews the national emphasis on balance and the role in it that innovation is currently accorded. Then it evaluates conventional and innovative systems through quantitative comparisons of their projected costs and benefits with the goals of the new federal transit program. Finally, it summarizes the case for emphasizing innovation in the national effort to balance transportation.

•THE federal government began subsidization of urban transit under the Housing Act of 1961. As the pilot program got under way in 1962, President Kennedy urged Congress toward a larger undertaking: "Our national welfare therefore requires the provision of good urban transportation, with the properly balanced use of private vehicles and modern mass transport to help shape as well as serve urban growth." Congress responded with the Mass Transportation Act of 1964 and its amendments, which provided increasing support of transit through the remainder of the decade. Resultant appropriations for federal transit subsidy during the 1960s are shown in Figure 1 (1).

The renaissance of urban transit, however, has not yet arrived. If anything, the national decline of transit fortunes has accelerated, as national operating incomes reported annually by the American Transit Association reveal (2). This decline is also shown in Figure 1; in recent years, the data suggest runaway deficits rather than renewed vitality.

Now, as a new decade begins, President Nixon has proposed and obtained a new transit program for improving urban transportation (3). The program does not, however, contemplate national changes in direction. Instead, it reasserts the need for balance and employs a major subsidy increase to attain it—$1 billion per year by 1975. The President said: "We must have a truly balanced system. Only when automobile transportation is complemented by adequate public transportation can we meet [future] needs. I propose that we provide ten billion dollars out of the general fund over a twelve year period to help in developing and improving public transportation in local communities."

The President specifically called for 95 percent of the $10 billion to be devoted to capital improvements in public transportation. With the addition of the usual local contributions, this is more than $14 billion, a sum not far from the $17.7 billion announced by the transit industry as its own appraisal of its capital needs for the coming decade

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(4). If increased investment were the sole criterion, the new program would surely be judged as a major step toward balanced transportation.

Something more, however, may be vital. As data shown in Figure 1 suggest, public transit in its present form does not attract adequate patronage. Accordingly, President Nixon also called for devoting 5 percent of the new transit program to "...research and technology efforts into new ways of making public transit an attractive choice for owners of private cars."

Of seven specific research and development (R&D) efforts enumerated by the President, five dealt exclusively with improvements in bus and rail systems. The plain implication, strengthened by subsequent congressional approval, was that more innovative "new systems" are less urgently needed. Over the years, this has clearly been the federal position. Through fiscal year 1969, only 13 percent of total R&D expenditures had been allocated to new systems (5). Even so, subsequent congressional criticism of R&D focused on "rather exotic ideas...too far out to merit expenditure of money at this time" (6). In fiscal 1970, R&D allocations to new systems dropped to a low 6.8 percent of the total.

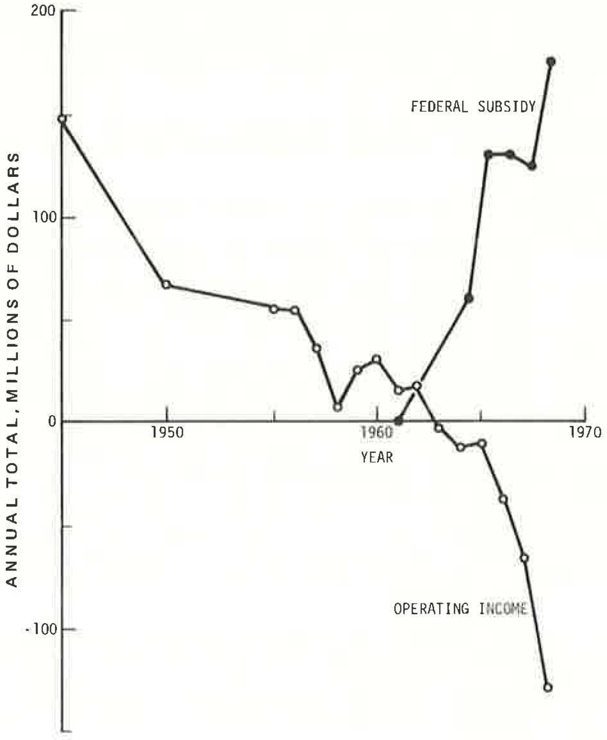

Figure 1. Trends of income and subsidy of transit in United States.

Given this background, changes planned for fiscal 1971 are truly dramatic; the new systems allocation is to increase to 39 percent of total R&D support (5). If the past is any indication, enthusiasm for this sort of change may be spotty in both government and industry. Yet detailed analyses show that it is not only desirable but also essential if the stated goals of the new federal transit program are ever to be fulfilled.

ANALYSIS OF NEW SYSTEMS

To date, federal transit R&D has concentrated on improving conventional bus and rail systems. In conventional rapid transit, many people are hauled simultaneously in a single conveyance along a single route. All passengers in the vehicle must stop for all pickups and discharges. Consequently, high average speeds are impossible unless stations are very widely spaced; but if stations are widely spaced, then most passengers must resort to inferior secondary transportation modes for access, which often consume more time than is saved aboard the primary system.

New systems, generally speaking, offer relief from the basic limitations of conventional systems. The principal conceptual opportunity is "personal transit," in which individual vehicles are provided for individual travelers. In personal transit, small vehicles rather than large ones would move automatically on electrified, grade-separated guideways. All stations would be placed on sidetracks so that only those vehicles bound for a particular station would stop at it. Accordingly, personal transit would provide nonstop service without waits or transfers between any pair of stations, at double or triple the overall speed of conventional rapid transit.

In addition, personal transit opens a major avenue for future development. With proper design foresight and the addition of suitable on- and off-ramps, a personal transit system could readily accommodate dual-mode automobiles as well as transit cars. These automobiles would be manually operated when on city streets and could be privately owned. Thus personal transit might smoothly evolve into a complete dual-mode transportation system. In addition to a breakthrough in transit performance, it would provide the equivalent of freeway automation and electrification, with attendant major benefits for private motorists in particular and the urban environment in general.

Such potential for important new functions does not exist in conventional transit. New technology is applicable, of course, but its effect will be very much limited by the basic conventional concepts. Thus redesign and automation of transit trains, for example, will eliminate none of the intermediate stops and transfers now necessary and consequently will at best provide modest changes in system performance.

To a large extent, the proper allocation of R&D between conventional systems and new systems depends on their prospective performance, impact, and technical feasibility. Considerable light is shed in this area by the series of new systems studies completed by the U. S. Department of Housing and Urban Development for Congress in 1968 (7). Among these new systems studies, the analysis performed by General Research Corporation (GRC) is especially topical because its results happen to be stated precisely in terms of the beneficial impacts cited by President Nixon in advocating balanced transportation to Congress (8).

The objective of the GRC analysis was to determine the relative merits of conventional, improved, and innovative urban transportation systems in the years to come. It was based on a series of quantitative case studies in which promising alternative transportation systems were matched with urban environments representative of the nation's larger cities, present and future. A computerized network flow model and cost-benefit assessment were employed to make a detailed evaluation of each case under study on a uniform and comparable basis.

Two large cities were selected by GRC for detailed case studies after a statistical survey of large cities revealed that results for them could be generally applied. Boston was chosen to represent transit-oriented cities, which are generally old, dense, and centrally focused. Houston was chosen to represent automobile-oriented cities, which are comparatively new, dispersed, and unfocused. Together, these two cities reasonably represent the range of possibilities of cities with total populations of more than a million—with the solitary exception of New York, which is unique by virtue of its absolute size, overall and central densities, and historic dependence on a very extensive system of rail rapid transit.

Quantitative descriptions and projections of land-use and travel demand were taken from existing transportation studies in Boston and Houston. Freeway systems in each of the cities, existing and planned, served in every case as background and context for design and evaluation of alternative transit systems. In Boston, where rail rapid transit had long been in operation, plans for extensive modernization and expansion had already been developed; these were taken as a basis for expanded systems of conventional facilities. In Houston, where such plans were not available, alternative transit networks were developed directly from analysis of land use, desire lines, and potential flows on a transit spiderweb network. Guideway route networks were developed similarly for personal and dual-mode service in both cities. In every case, conventional rapid transit was augmented with a comprehensive set of express bus feeders, while local circulation in denser areas was supplemented with a network of local bus service based on existing patterns of operation.

Guideway speed and capacity specifications of 60 mph and 6,000 cars (and passengers) per hour were selected to be reasonably conservative, yet with no undue sacrifice of performance advantages. Considerably higher performance might actually be obtained; even with considerably lower performance, guideways would be desirable and useful (9).

Prospective performance of alternative transportation systems was evaluated by means of a network flow simulation. The transportation network included all segments of door-to-door trips—walking, waiting, riding, transferring, and parking. Traveler choices among alternative modes in the network were chosen in accord with a modal-split formula that has been tested and validated for several major cities (10). In general, this modal split should be most reliable for conventional bus and rail transit because it was derived from empirical patronage studies for these kinds of transportation. For personal and dual-mode transit, its use should considerably underestimate transit patronage because it does not reflect the superior amenities of these modes relative to conventional transit. Transit fares were set for all systems at 60 percent of automobile costs.

Because congestion is potentially so important a deterrent to automobile usage and because its reduction is so important an objective of transit subsidization, the network flow simulation was arranged to deal explicitly with congestion. Separate matrices were developed to describe typical peak and off-peak (midday) travel demand, and each transportation system was tested separately for its ability to serve these very different conditions.

The network flow simulation was validated by application to surveyed conditions in Boston and Houston. In both cases, the simulation runs regenerated modal splits, artery volumes, street and freeway speeds, and other measures that were in excellent accord with actual observations at the time of the origin-destination survey and facility inventory.

About 40 alternative systems were analyzed for Boston and about 30 for Houston. For consideration here, a very limited set of 10 examples (five for each city) suffices to show comparative advantages of conventional and new transit systems. The first two examples are presented for reference as performance benchmarks; they are simply the previously noted validation runs that describe surveyed conditions for Boston (in 1963) and Houston (in 1960). The second two examples are conventional systems for the future (1975 and 1980 respectively) that have been balanced by substantial investment in new transit. In the third pair of examples, the balanced systems are improved by a 50 percent speedup of rapid transit, which is representative of a major improvement that might possibly be achieved through conventional systems R&D. The fourth and fifth pairs of examples are personal transit and dual-mode systems, which represent new systems R&D might make possible.

The basic route mileages of the examples considered here are given in Table 1. The future transit mileages shown were generally selected to give comparable dollar costs per delivered passenger-mile—about 6 cents in 1965 dollars, including all depreciation and amortization as well as direct costs of operation. In Houston, however, only the new systems could operate at this figure; rail transit costs for the systems shown were nearly twice as high and were not substantially reduced by elimination of system mileage.

COMPARATIVE EVALUATION OF SYSTEM PERFORMANCE

The proper allocation of R&D between new and conventional transit systems depends in part on the levels of costs and benefits that might be obtained through ultimate system use. Selected cost-benefit forecasts, developed as described in the previous section, are shown in Figures 2 and 3.

The proper allocation of R&D also depends on the particular goals and objectives of the new federal program for balanced transportation. These objectives were concisely

TABLE 1

MILEAGES OF GRADE-SEPARATED RIGHT-OF-WAY FOR ALTERNATIVE SYSTEM EXAMPLES

System	Boston (miles)		Houston (miles)	
	Freeway	Transit	Freeway	Transit
Reference	237	41	37	0
Balanced-conventional	375	62	261	64
Improved-balanced	375	62	261	64
Personal-transit	375	200	261	109
Dual-mode	375	600	261	193

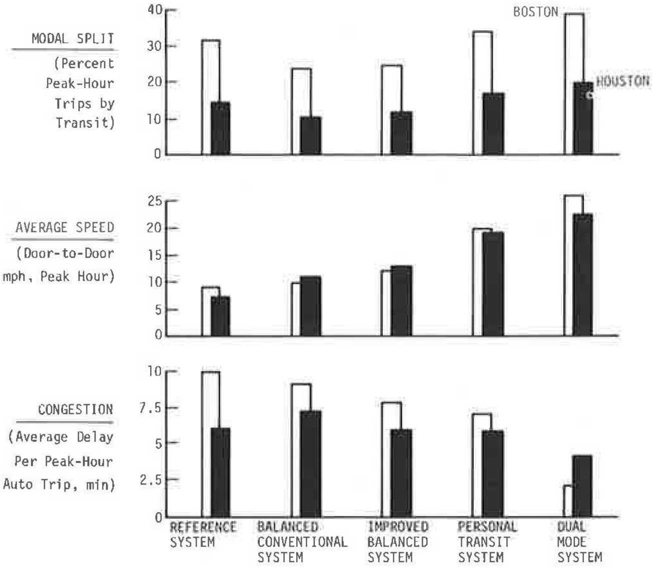

Figure 2. Transit attractiveness, service, and impact on congestion.

summarized by President Nixon in proposing the new program to Congress. The measures shown in Figures 2 and 3 were selected in accord with these objectives from the much wider range of measures originally calculated.

In this section, the President's objectives are repeated verbatim, one by one, and compared with the appropriate forecasts shown in Figures 2 and 3.

"The way to break that cycle [of declining transit patronage and impact] is to make public transportation truly attractive. . . ." The first forecasts shown in Figure 2 are

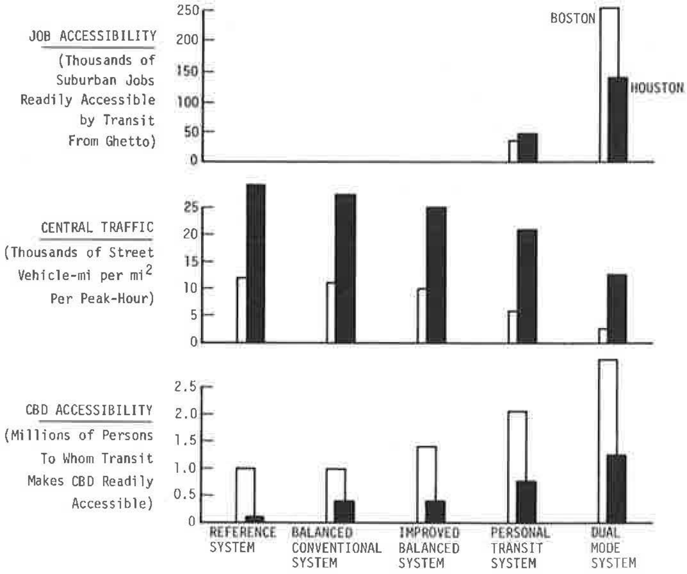

Figure 3. Transit impact on job accessibility, central traffic, and accessibility of the central business district.

modal splits, which quantify prospective patronage to be attracted by alternative transit systems in typical large cities. They indicate that increased investment in conventional transit is not likely to arrest the persistent patronage decline that plagues public transit; that R&D enabling a substantial improvement in conventional performance would not very much improve matters; and that real hope for maintaining and improving transit attractiveness rests with new systems of personal and dual-mode transit.

"The bus rider, train commuter, and subway user would have better service." The second forecasts shown in Figure 2 are door-to-door average speeds for transit travelers; because such averages reflect walking, waiting, and transferring as well as riding, they cover one dimension of overall service. The other dimension, area served by transit, has already been indicated in the system mileages given in Table 1. The figures show that balanced and improved conventional systems will indeed improve speed and coverage. Much larger increases, however, would be provided by the new systems, and without these large increases transit will continue to offer service that is a poor second to that provided by the automobile.

"The car driver would travel on less congested roads." The third forecasts shown in Figure 2 measure congestion directly. They make plain that, while conventional systems should produce worthwhile reductions in congestion, only the development of new systems promises major reductions in time losses due to traffic congestion.

"The poor would be better able to get to work, to reach new job opportunities and to use training and rehabilitation centers." The first forecasts shown in Figure 3 are the number of suburban jobs readily accessible by transit from ghetto areas, the heart of urban poverty. Total travel times of 30 min for Boston and 20 min for Houston were used as measures of "readily accessible"; these were approximately the average transit trip times for the reference systems in the two cities. The importance of suburban job opportunities is very great. In Boston, for example, all the growth in total employment projected for the period 1963 to 1990 appeared in the suburban areas. The forecasts shown in Figure 3 indicate that only the new systems will make the new jobs of the suburbs accessible to those most needy. This is partly because the new systems can economically offer much wider geographic coverage and partly because they offer the high speeds that make longer trips practical for daily commuting.

"The centers of big cities would avoid strangulation. . . ." The second forecasts shown in Figure 3 indicate the extent to which central streets are choked with vehicular traffic. They indicate that, although conventional systems offer modest reductions in traffic, personal transit promises improvements several times as great, and only the dual-mode system promises major removal of vehicles from the streets.

". . . and the suburbs would have better access to urban jobs and shops." The last forecasts shown in Figure 3 are the number of people for whom transit might make the central business district readily accessible, using the 30- and 20-min criteria of accessibility already described. They show that the total number could be substantially increased by balancing and improving conventional systems. They also show that increases three to five times greater could be obtained through new systems.

THE NEED FOR INNOVATION

Analysis of alternative systems of public transportation indicates that, in general, balancing conventional transit will produce worthwhile results and that R&D in conventional systems might produce worthwhile additional improvement. Analysis also indicates, however, that far more would be gained through the development and application of new systems.

If balanced conventional systems promised adequate beneficial impact, then new systems would be unnecessary, despite their superior potential; however, this is not the case. In terms of the express goals of the new program for balanced transportation, quantitative analysis shows that conventional systems are not enough. Only new systems of personal and dual-mode transit promise to offer service that will be generally attractive. Without attracting increasing proportions of travelers, no transit system can hope to produce the beneficial impacts that motivate the new federal program.

Past allocations of federal R&D effort overwhelmingly favored conventional systems. A change in direction is emerging, however; if encouraged and expanded, it could enable the new federal program to achieve its basic objectives.

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ECONOMIC ANALYSIS OF A DEMAND-RESPONSIVE PUBLIC TRANSPORTATION SYSTEM

Thomas F. Golob and Richard L. Gustafson,
General Motors Research Laboratories

The concept of a demand-responsive transportation system, using driver-operated vehicles providing door-to-door service, has received attention as a possible solution to certain urban transportation problems. The economic feasibility of such a system should be evaluated before it is considered for implementation. This paper discusses the methodology and results of a case study analysis of the economic feasibility of a many-to-many demand-responsive transportation system in a chosen U.S. city. Ridership was estimated by means of the market research tools of in-depth group surveys and home interviews. A flexible cost model was developed to evaluate the cost of serving various hourly distributions of demand. The estimated demands for each of a series of alternative levels of service and fare were then applied to this cost model, and the profit or loss was calculated for each level of service and fare. The sensitivity of the profit or loss to changes in demand distributions and to changes in various cost parameters was also investigated.

• THE Transportation Research Department of the General Motors Research Laboratories has conducted a study to design a demand-responsive public transportation system and to evaluate the technical and economic feasibility and the potential social and political acceptance of such a system within the environment of a selected case-study community. The system is called the Demand-Responsive Jitney System, abbreviated D-J. The D-J system is perceived of as providing door-to-door service upon user request and would utilize driver-controlled, rubber-tired vehicles. Users would share use of the vehicles in order to minimize costs. Generically similar systems have been studied under such titles as Geni, Dial-A-Bus and DART (1, 3, 5, 7, 10, 11).

Two phases of the D-J system study—measurement of user preferences and system simulation—have been discussed in earlier papers (6, 9), and the overall D-J system study has also been reported on in another paper (2).

The case-study community is a fast-growing incorporated city within a major metropolitan area. The area of the city is approximately 36 sq mi and has a population of approximately 200,000 persons. The majority of the residents are blue-collar middle-income workers, and 5 percent of the residents are retired. Only 2.5 percent of the households in the community do not have a car available. The transit system in the community offers only limited service, and only 1 percent of all internal home-based trips are made by public transit. Ninety percent of these home-based internal trips are made by automobile and 9 percent are made by school bus.

The economic analysis was divided into three major parts: a cost model, a revenue model, and a profit model. A flow diagram of the economic analysis is shown in Figure 1. Major inputs to each part of the analysis are shown in the diagram.

The objectives of the cost model were to define a fine-grained system structure that identifies the essential components required for adequate operation of the D-J system

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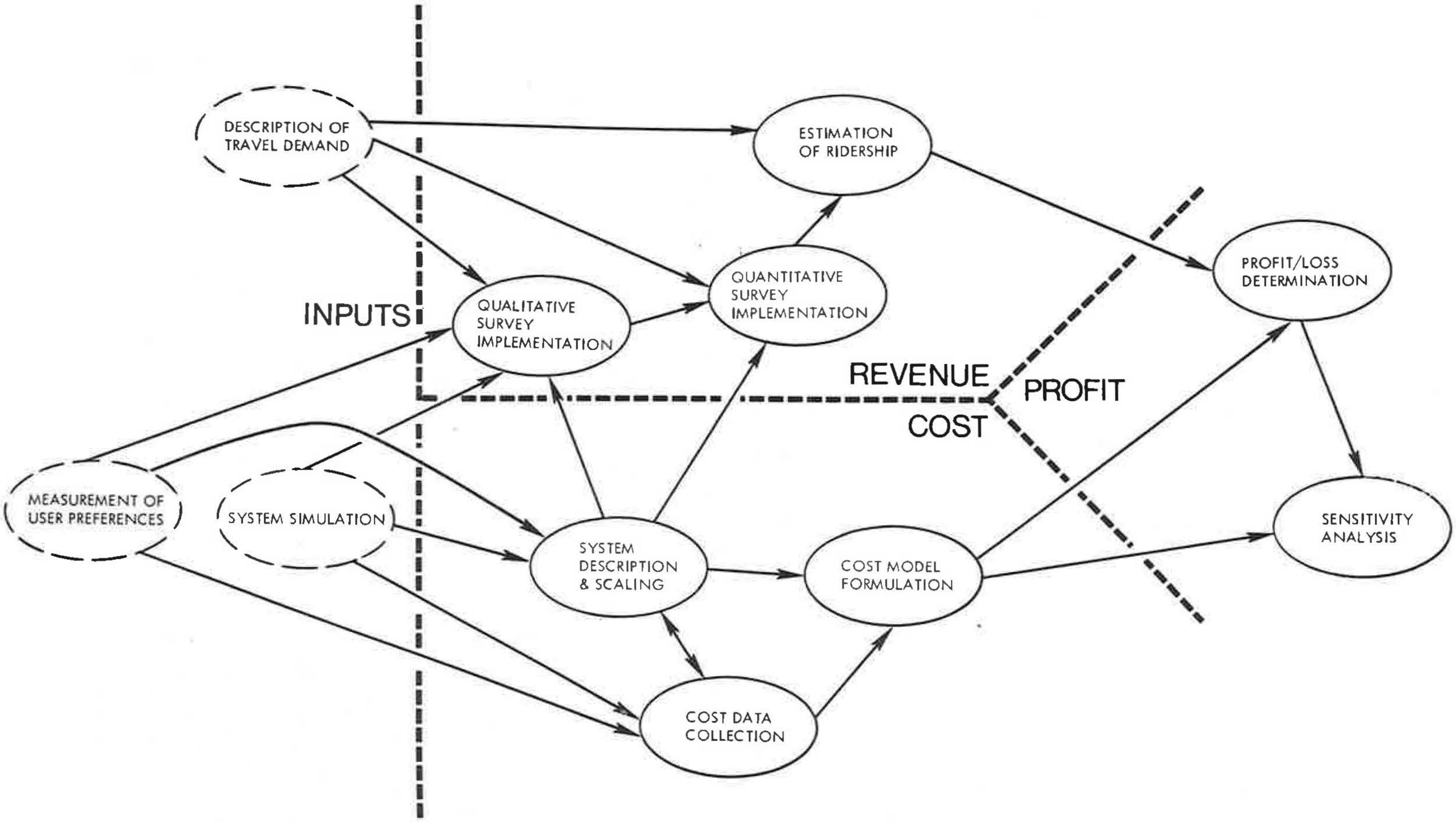

Figure 1. Flow diagram of D-J economic analysis.

and to develop equations that accurately measure costs and are consistent with current and projected public transpotation costs. The three distinct tasks of the cost modeling are system description and scaling, cost data collection, and actual cost-curve formulation.

A detailed system description was formulated and cost estimates were calculated. Realistic cost estimates for the entire operating day were generated by a consideration of the hourly distribution of demand. Factors were introduced to account for the potential inefficiency that the transportation system encounters when the demand level varies during an operating day. Both peak demand and demand for each particular hour were considered in determining the hourly costs of operation. With these considerations, a cost model was developed, and the estimates of hourly cost were expressed as a function of both the peak demand and the demand for the hour in question.

The development of the cost model for the D-J system is consistent with traditional economic procedures but is also specifically tailored to the demand-responsive transportation concept. The model is parametrically determined and as such is applicable to areas other than the case-study community by changes in one or more input variables.

The objectives of the revenue model were to establish a realistic estimation of ridership in the case-study community for alternate D-J system designs and alternate fare levels and to establish distributions of this demand with respect to time of day, trip purpose, and traveler socioeconomic and demographic variables. Included in this effort are qualitative survey implementation, quantitative survey implementation, and actual estimation of ridership.

An attitudinal survey was employed to ascertain responses from potential users of the D-J system as to whether they would use the system in various travel circumstances and for various system fares and service levels. The survey consisted of two parts. First, a qualitative survey was conducted to aid in designing the extensive quantitative survey and to gather information concerning consumer reaction to the proposed D-J system. Second, a quantitative survey was conducted in the case-study community to provide the quantitative data as the basis of the estimations of ridership on the D-J system. The data from the quantitative survey were applied together with data describing the total travel demand in the case-study area to generate the hourly distributions of D-J demand.

The objectives of the profit model were to determine the profitability of alternate D-J system configurations in the case-study community and to assess the sensitivity of the costs to various cost parameters and to accuracy in ridership estimations. The profit model can be separated into a profit-loss determination task and a sensitivity analysis task. In the profit model, the estimated ridership distributions for the case-study community were applied together with the cost equations to determine the profitability of the D-J system.

COST MODEL

The system description and scaling phase of the cost model involved an identification of the D-J system structure, a description of all elements required for operation of the system, and a determination of the scale of each element. An attitudinal-survey-based measurement of user preferences for the D-J system (4, 9) was used to guide system description. The scale (amount or size required) of each system element was determined as a function of the hourly distribution of D-J demand (determined by the revenue model) and two service parameters exogenous to the economic analysis—maximum specified waiting time prior to vehicle pickup and maximum specified D-J to private automobile travel-time ratio. The system simulation study (6) determined the number of vehicles required to service any specified demand and the average speed of the vehicles in servicing these demands. The system simulation also provided data on vehicle capacity requirements and computer specifications. The following is an outline of the system structure:

A. Operational subsystem
   1. Vehicle subsystem:
      Vehicle characteristics

    - Passenger provisions
    - Driver provisions
    - Safety provisions
    - Reliability and maintainability provisions
  2. Roadway subsystem:
    - Shelters
    - Parking areas
    - Turnouts
    - Access signal lights
    - Street service signs
    - Driver lounges
  3. Communications and control subsystem:
    - Customer to control center communications
    - Control center to vehicle communications
    - Control center communications equipment
    - Control center input-output devices
    - Control center computer (required for computer control and digital communication option only)
    - Vehicle location equipment (required for manual control and voice communication option only)
  4. Fare collection subsystem:
    - Vehicle-mounted equipment
    - Security provisions

B. Support subsystem (equipment)
  1. Vehicle support:
    - Vehicle operational support station
    - Vehicle scheduled maintenance station
    - Vehicle overhaul station
    - Vehicle emergency support truck
  2. Roadway support
  3. Communications and control support:
    - Customer to control center communications
    - Vehicle and control center communications equipment support station
    - Control center input-output devices and control center computer
  4. Fare collection support:
    - Fare collection support station
    - Exact fare refunds

C. Expendable parts and materials
  1. Operational subsystem expendable material
  2. Operational subsystem parts:
    - Vehicle parts
    - Roadway parts
    - Communications and control
    - Fare collection
  3. Support subsystem expendables
  4. Support subsystem parts

D. Real property
  1. Operations complex building
  2. Support complex building
  3. Vehicle parking
  4. Personnel parking
  5. Customer and visitor parking
  6. Land

E. Services
  1. Operational subsystem labor:
    - Vehicle drivers

    - Telephone operators
    - Dispatcher
    - Controller (required for manual control and voice communication option only)
  2. Support subsystem labor:
    - Vehicle support
    - Roadway support
    - Communications and control support
    - Fare collection support and station attendant

F. System software
  1. Operational subsystem specifications
  2. Support subsystem specifications
  3. Expendable parts and materials specifications
  4. Real property specifications
  5. Service specifications

G. System implementation plan
  1. Operational subsystem implementation plan
  2. Support subsystem implementation plan
  3. Expendable parts and materials implementation plan
  4. Real property implementation plan
  5. Services implementation plan
  6. Software implementation plan
  7. Fare structure plan
  8. System introduction plan

H. System management
  1. Operational subsystem
  2. Support subsystem
  3. Expendable parts and material
  4. Real property
  5. Services
  6. Software
  7. System implementation
  8. System operation

Only the major elements are listed in this outline; the more detailed structural levels developed in the system description are omitted.

The cost-data collection phase involved the determination of the unit cost of each system element in the system description. Interest rates and amortization periods were determined for capital cost elements. The data were derived from previously published cost studies and from information obtained from bus, taxi, and limousine operator, vehicle manufacturers, and computer and communications companies.

The cost-curve formulation phase involved the aggregation of unit-cost functions in order that the total cost of the D-J system could be expressed in terms of the hourly demand distribution to be served and the exogenous variables. The distribution of demand over n-hours of system operation was described by 2n parameters, the demand for each hour (d_i, i = 1 to n), and the ratio of the demand for each hour to the peak-hour demand (ρ_i, i = 1 to n). The two service parameters were both assigned two values, and four system configurations were thus identified through the combinations of these parameters. The four systems, for which separate cost models were developed, are as follows:

System	Waiting Time (sec)	Ratio of D-J and Automobile Travel Time
A	15	2:1
B	25	2:1
C	15	3:1
D	25	3:1

The fixed costs of operation are determined only by the peak hourly demand that establishes the necessary system capacity. The variable costs of operation are dependent on the demand for each hour and thus must be calculated for each hour during which the system is in operation. Moreover, it is unrealistic to assume that labor efficiency is perfect or that exactly as many drivers (and related service personnel) would be available as would be needed to service the demand for any particular hour other than the peak hour. It was assumed that drivers would work in shifts of some guaranteed minimum time duration, and, if the demand at a certain hour was below that of the previous hour (requiring less vehicles to be utilized), an excess number of drivers would be on duty at that time. In order to account for this labor inefficiency caused by the fluctuating characteristic of the hourly demand distribution, it was assumed that the number of drivers employed during a certain hour would be the number needed to service the demand for that hour (as determined by the system simulation) plus one-half of the number needed to service the difference in demand between that hour and the peak hour.

These cost effects attributed to the distribution of demand were handled by separately determining the costs of each hour of operation and then aggregating these hourly costs over all hours of system operation to arrive at a total daily cost. The cost of serving demand levels up to 2,500 demands per hour were calculated from the aggregation of the unit-cost functions for each element of the system, given the service parameters defining the system. These costs were calculated also as a function of the ratio ρ_i. Curves of hourly cost, c_i, versus hourly demand, d_i, parameterized by ρ_i were thus generated. The curves for system D are shown in Figure 2. The curves for systems A, B, and C are similar.

The costs for each value of ρ were regressed on demand, and it was found that a linear relationship accounted for at least 98 percent of the variance in each case. The

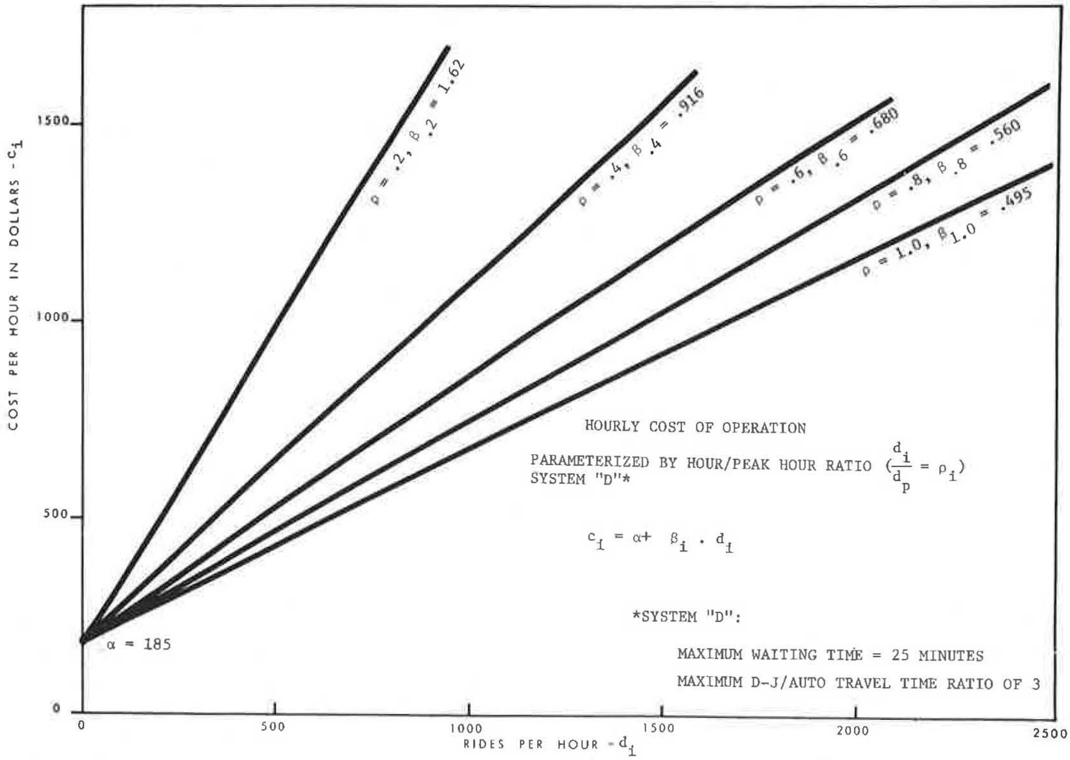

Figure 2. System D cost curves.

equations for system D are shown in Figure 2. For a particular system, the intercept of the linear cost equations, α, represented the fixed cost for the system and was independent of ρ. The linearity of the parameterized cost curves can be explained by the fact that the D-J system is labor intensive, and the relationship between vehicles needed (and hence driver and supporting labor) and demand served was found through applications of the simulation model in the case-study area to be approximately linear.

One of the important questions for a many-to-many D-J system is, At what point does the cost of a manually routed and scheduled system exceed that of a computer-aided system? For system D the manually routed system was found to be less expensive than the computer-routed system for peak-hour demands ($\rho_1 = 1$) of less than 225. The costs associated with the computer-routed system (the curves for system D shown in Fig. 2) are below those associated with the manual system at all points above this level of peak-hour demand, and the difference between the costs of the two systems increases with increasing demand.

REVENUE MODEL

The first part of the revenue model, the qualitative attitudinal survey, served (a) to aid in the construction of the home interview questionnaire needed to quantify consumer demand and (b) to seek qualitative information as to how and why people would react to the introduction of such a transportation system into the case-study community. Specifically, the survey provided data needed to answer the following questions:

1. What do residents of the case-study community feel are the system's most important advantages and disadvantages?
2. What actions and strategies will be required to implement the system?
3. What problems might arise if such a system were implemented in the case-study community at the present time?

Inputs to the qualitative survey phase included information regarding preferred system design, determined through the analysis of user preferences (4, 9); the system configurations for which ridership was to be estimated, determined by the combinations of the two exogenous service parameters; the range of fare for which ridership was to be estimated, determined by preliminary analysis of the cost model; and information regarding the types of trips and characteristics of the trip-makers, determined from the description of travel demand in the case-study community (based on a previous extensive transportation survey).

The qualitative survey was composed of five in-depth group interview sessions; the participants in each session were drawn from residents in the case-study area who were all classified into one of the following five market subgroups: housewives; female heads of households employed full-time in the community; male heads of households employed full-time in the community; teenagers; and adults from households in which a car was not available. Each session involved approximately ten respondents sitting in discussion for 1½ hours with a trained market research analyst. The analyst posed subjects for discussion, encouraged group participation in discussing these subjects, challenged individual responses, and forced respondents to clarify or rationalize opinions. Attempts were made both during and after the sessions by the analyst and by observers to hypothesize the consumer opinions reflected by the groups.

The use of in-depth group interviews for the pre-testing of questionnaires is an accepted market research procedure and guards against the introduction of a questionnaire containing ambiguous or misleading descriptions or instructions in a quantitative survey. The use of the in-depth interviews to gain insight into peoples' perceptions of the D-J system provided valuable information for analyzing the social and political acceptance of the system, for validating and clarifying the measurements of user preferences concerning the system design, and for developing market strategies. Both the qualitative and the quantitative surveys were developed jointly by the Transportation Research Department and an experienced market research firm. The surveys were implemented by the market research firm in order to ensure objectivity on the part of the interviewers and respondents.

The quantitative survey phase of the revenue model represented the major data collection effort of the ridership estimation phase of the D-J system study. Interviews were conducted with residents of the case-study community at their places of residence to gather information on their anticipated use of the D-J system if it were implemented in the community. The survey was administered by trained interviewers, and visual aids were used to describe the D-J system. Every attempt was made to present the D-J system design in a thorough, straightforward manner that would not bore the respondents with numerous details but that would leave the respondents with a clear, unbiased picture of what the system would be like if it were implemented in the case-study community.

The questions contained in the home-interview questionnaire can be classified into two categories: questions dealing with the respondents' demographic and socioeconomic characteristics and questions dealing with the respondents' attitudes toward use of the D-J system. Three groups of attitudinal questions were used to provide information needed for the ridership estimates. First, questions concerning the projected percentage of D-J usage for each type of trip investigated supplied the information needed to estimate the demand for the D-J that would be diverted from existing modes of transportation. Second, questions concerning the projected numbers of additional trips that would be made on the D-J system that are not now being made on existing modes supplied data on the elastic or latent component of demand. Third, questions concerning the characteristics of particular trips reported as being switched from existing modes to the D-J system supplied supplementary data on user behavior necessary for the comprehensive analysis of ridership on the new system.

Almost 1,100 home interviews were conducted in the case-study community during the spring of 1970. A modified probability procedure was used to identify the sample of households, and specific quota requirements guided the selection of the respondents. A predetermined procedure was used to replace sample households at which an interview could not be obtained after two call-backs. At least 10 percent of each interviewer's returns were validated by means of a telephone inquiry.

The home-interview survey provided data on the percentage of total trips of a particular type that respondents reported would be switched to the D-J system. For each of nine respondent types (each representing a quota sample) and seven trip types (such as shopping trips or work trips), the mean percentage of D-J usages was established for a matrix of 16 system configurations. The system configurations are determined by the combination of each of the four system service specifications (systems A, B, C, and D) with each of the four fares ($0.50, $0.75, $1.00, and $1.25).

For system A at $0.50 fare (most preferred system), the highest percentage of D-J usages was indicated by teenagers (shopping and social-recreation trips), members of no-car households (shopping and personal business trips), and housewives in one-car households (shopping trips). For system D at $1.25 fare (least preferred system), the highest usages were indicated by members of no-car households (shopping, personal business, and social-recreation trips). The teenagers and housewives who indicated extensive use of the most preferred system showed a relatively elastic demand with respect to fare and service times and consequently indicated little use of the least preferred system. The demand by members of no-car households was relatively inelastic.

In the third phase of the revenue model—the estimation of ridership on the D-J—an extensive home-interview study previously conducted in the case-study community for a metropolitan area-wide transportation study provided the data base needed to translate figures on percentage of D-J usage into actual one-way trip counts. The survey, conducted approximately 4 years before the ridership estimation survey, estimated the number of internal person trips generated by residents of the community on a given weekday as a function of the time of day, purpose of trip, and socioeconomic and demographic characteristics of the trip-maker.

Counts of the total internal one-way trips by person type, trip type, and time of day were obtained from the transportation survey data by aggregating the responses on a basis consistent with the coding scheme utilized for the ridership estimation survey. The D-J trips for each hour of the day were estimated by multiplying the number of potential trips in that hour by the percentage of D-J usage for that person and trip type combination and that system configuration under consideration. The trips for all combinations of person and trip types for each hour were summed to establish the distribution of D-J trips for the system configuration. One such distribution is shown in Figure 3. The general shape of the graphed distribution is characteristic of all of the distributions. The distribution of estimated D-J trips does, however, exhibit a shape different from that of the distribution of total trips because for each hour there is a different mix of trips by respondent type and trip type, and consequently a different mix of percentage of D-J usage figures is applied to obtain the assignment. In general, trips during the early evening hours are less easily switched to the D-J because a high proportion of these trips is made by male heads of households who indicated a lower percentage of D-J usage.

Curves of the total percentage of D-J usage versus system fare for each of the four systems—so-called modal-split curves—are shown in Figure 4. These curves are well-behaved in the sense that the partial derivatives of demand with respect to fare, waiting time, and riding time all exhibit the expected negative sign. Demand is relatively more sensitive to riding time than to waiting time (each parameter calibrated in the units used in the attitudinal survey) because systems B and C are trade-offs in these parameters and system B dominates system C in terms of demand.

The elastic or latent component of demand for the D-J system is measured in terms of additional trips that would be made on the D-J system but that are not currently being made because of unavailability of transportation at certain times. Estimates of latent demand were not included in distributions of assigned D-J trips because of serious questions as to respondents' ability to forecast such changes in their trip-making behavior and because of the objective to provide conservative ridership estimates. The latent demand estimates were used, however, in evaluating the impact of the D-J system and in studying the total system patronage picture.

All respondents indicating greater than 5 percent usage of D-J system A (maximum specified waiting time of 15 min and maximum specified D-J to automobile travel-time ratio of 2) at $0.50 fare were questioned as to the number of additional trips for each trip purpose (except work trips) they would make on the D-J. Statistics on the mean number of added trips per month per person were consequently generated for each combination of respondent and trip type. The highest numbers of mean-added trips

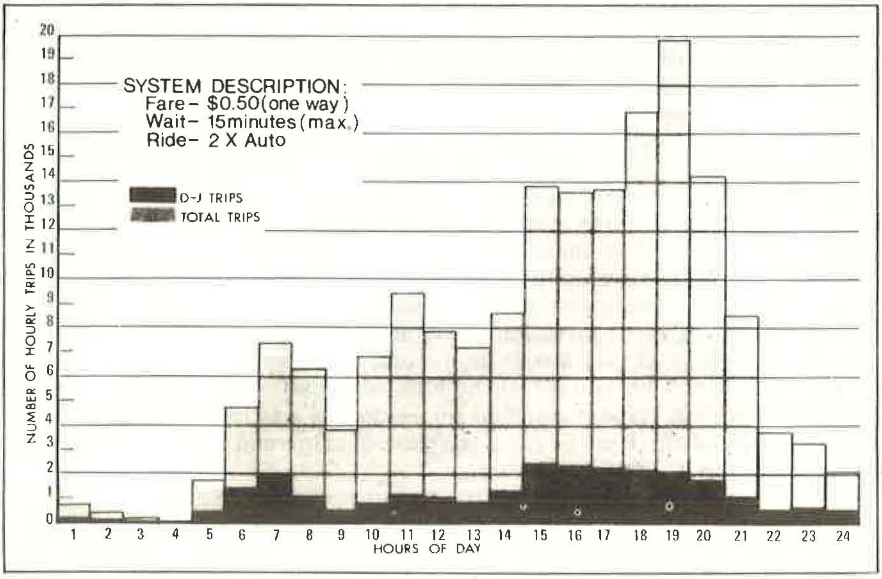

Figure 3. System A hourly diversion to D-J.

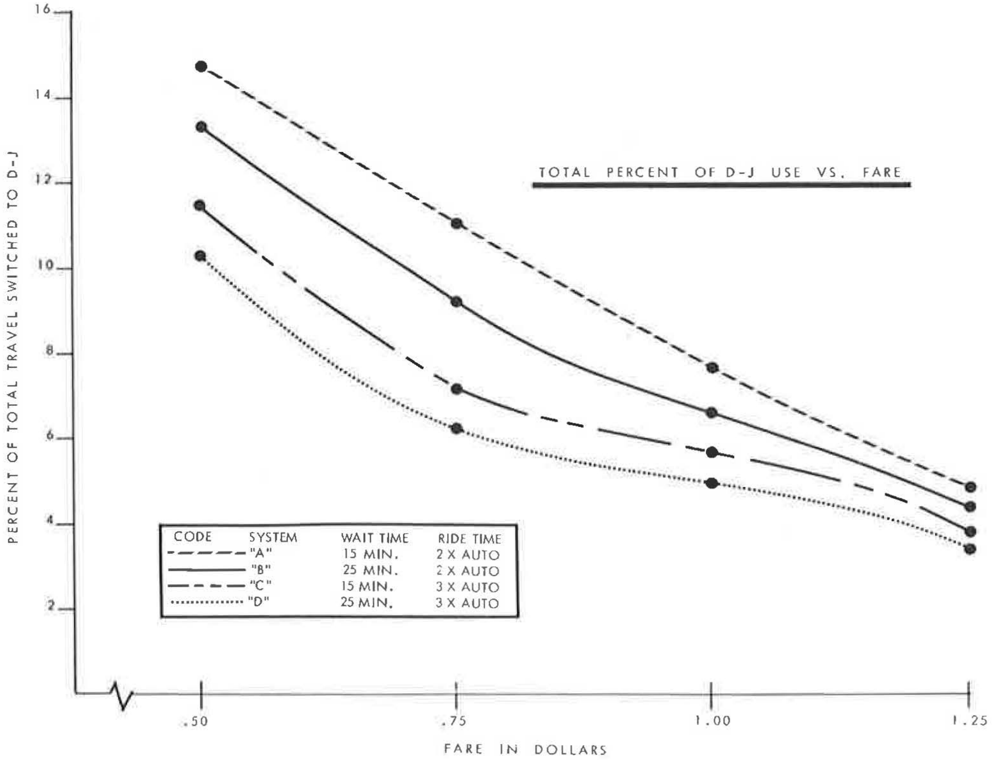

Figure 4. Modal-split curves.

were found for teenagers (social-recreation trips and shopping trips) and housewives in one-car households (personal business and shopping trips).

The statistics on added trips per month per person were translated to statistics on added trips per day per person and this figure was applied to the total D-J trips assigned for each person and trip type combination to generate the total added trips per day. For system A at $0.50 fare, the total number of added trips is 478. This number represents less than 5 percent of the total D-J trips assigned and represents approximately 0.5 percent of the total number of internal trips in the case-study community.

PROFIT MODEL

The profitability of the D-J system was determined by comparing the total daily cost (determined by the cost model) to the total daily revenue (determined by the revenue model). Profitability curves were generated for the four systems, each at four fare levels (Fig. 5). The system profit as determined by the profit model is approximately $80 per day for system D at $1.25 fare. Losses are projected for all other D-J systems over the entire range of fares for which demand was estimated.

Without financial assistance system D at $1.25 fare is the only profitable alternative, but with a willingness of a community to accept financial losses the optimal system depends on the size of the accepted loss and the objectives of the system operator. If the operator's objective is to maximize ridership, system D is the optimal system for losses up to $400 per day. For losses between $400 and $750 per day, system B has the highest ridership. System A is the busiest system in terms of ridership for losses greater than $750 per day. If we assume that the objective of the operator is to minimize the fare with the least amount of loss, system D offers the lowest fare for any level of financial loss.

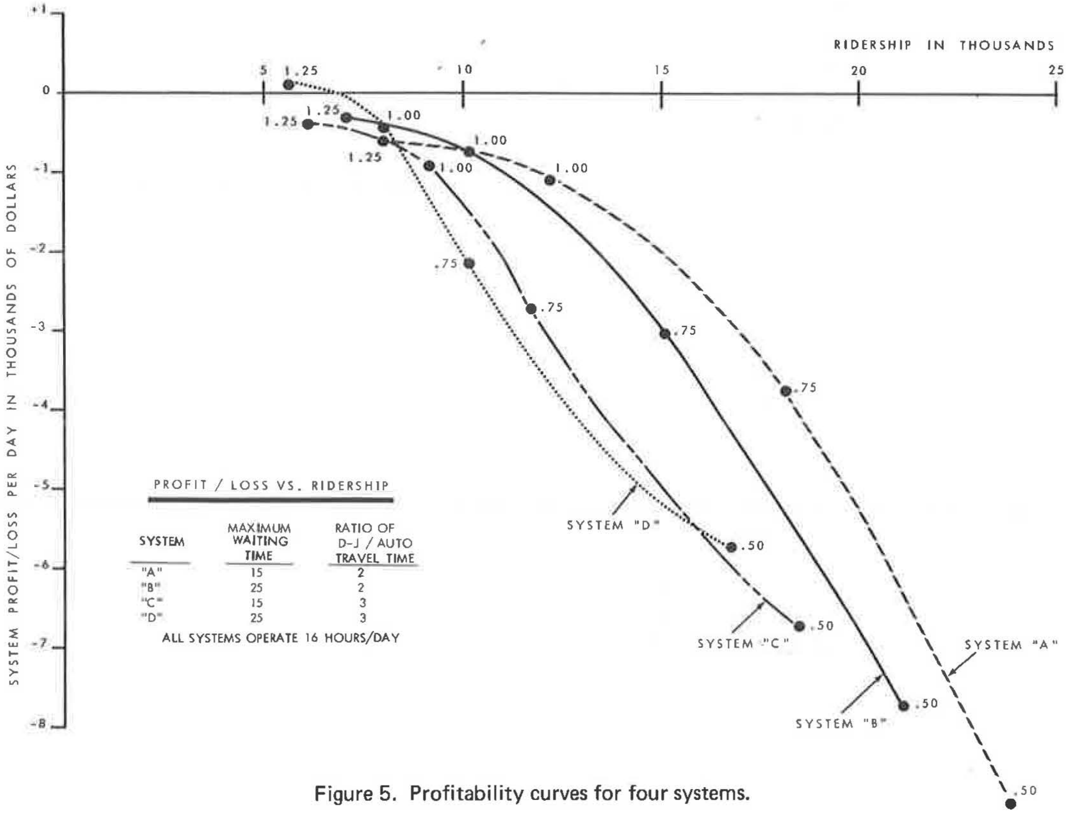

Figure 5. Profitability curves for four systems.

Measuring the effect of lower demand on profitability is important in case the actual demand does not equal the estimated demand. The estimated demand levels for system D were reduced in five steps (by 10, 20, 30, 40, and 50 percent), and the profit model was applied with each of these five reduced-demand levels (Fig. 6). The hourly distribution was assumed to be the same. The profit function indicated that the actual demand had to be 93 percent of the estimated demand in order for the system to break even in terms of costs and revenues.

Several cost inputs were varied to determine the sensitivity of profit to these factors. Three cases are analyzed here: (a) federal grant for two-thirds of the capital investment, (b) interest rates of 5 percent and 15 percent in addition to the nominal rate of 10 percent, and (c) wage rates of $2.00, $2.75, $3.25, and $5.00 in addition to the nominal $3.90-wage rate.

Figure 7 shows the profit-loss curves for systems receiving a federal capital grant. All systems are financially feasible in the higher range of fares. The break-even system with the highest ridership is system A with a fare level slightly below $1.00 and a ridership of approximately 14,000 rides per day. The effect of the capital grant is a substantial increase in both level of service (in terms of waiting and riding times) and ridership for systems generating a net profit.

Because the D-J system is labor intensive (approximately 65 percent of total costs are for labor), the cost of the system proved not to be very sensitive to changes in the interest rate but quite sensitive to wage rate changes. The prevailing wage rate of $3.90 for unionized transportation workers in the central city of the major metropolitan area adjacent to the case-study community was used. After cost calculations accounting for sick leave, vacation, fringe benefits, and taxes, the effective wage rate was found to be $5.40. A $2.00 per hour wage rate for drivers (as opposed to $3.90) would lower the break-even fare for system D below $0.75, and ridership could be increased

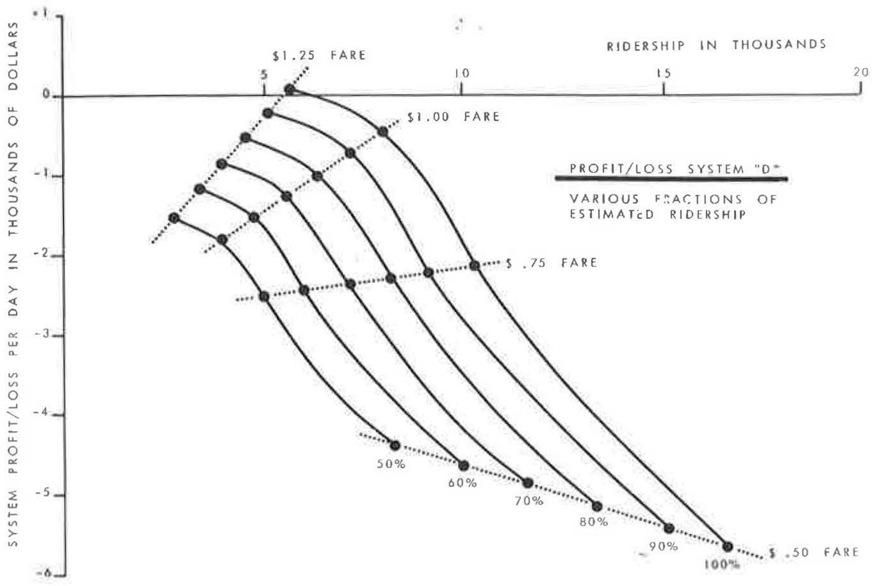

Figure 6. D-J reduced-demand levels.

to 17,000 per day (Fig. 8). The break-even point for system D, at $3.25 per hour, is approximately at $1.00 fare. A $5.00 per hour wage rate would result in unprofitable operation for all systems for any service level and for all fares investigated. With lower wage rates the profitability of the system is significantly increased.

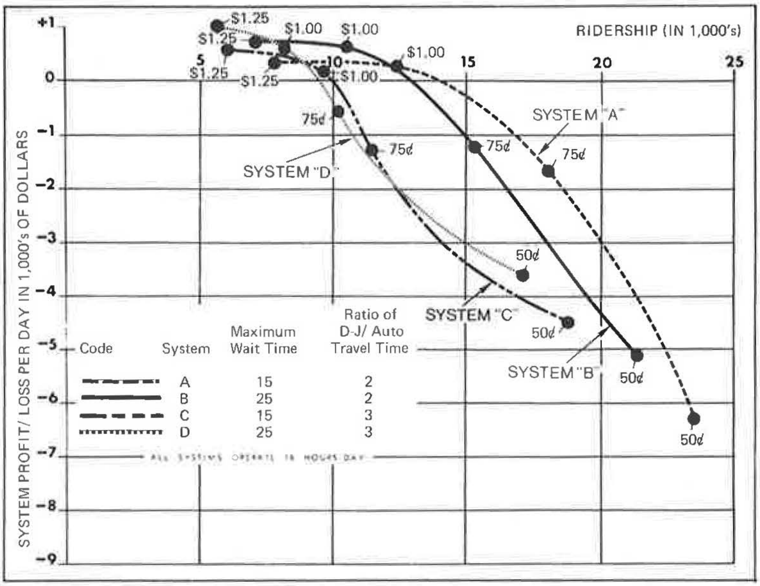

Figure 7. Profit-loss versus ridership (two-thirds capital grant).

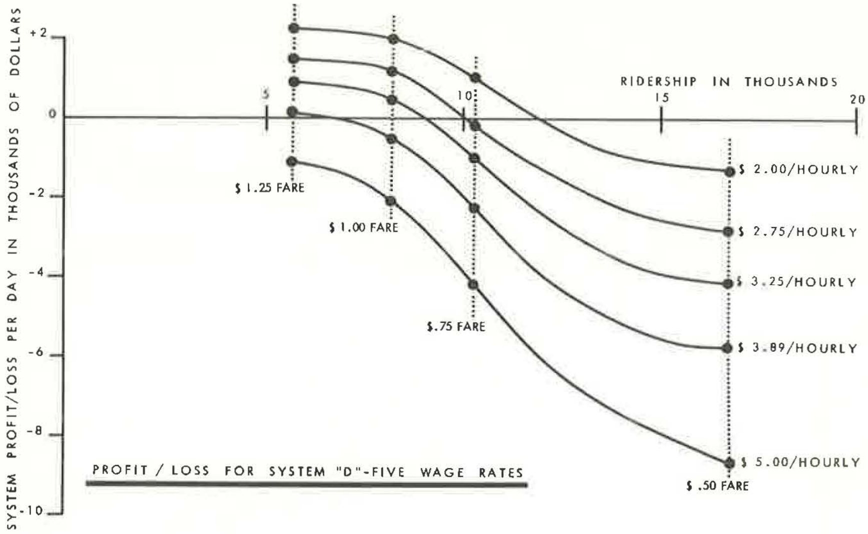

Figure 8. System D profit-loss wage rates.

SUMMARY AND CONCLUSIONS

Through application of the revenue model, the highest estimated ridership on the D-J system in the case-study community was found to be approximately 15 percent of all internal trips for the system with a fare of $0.50 and shortest specified service times. The lowest estimated ridership was approximately 3.5 percent of all internal trips for the system with a fare of $1.25 and longest specified service times. All of the market subgroups stratified in the survey sample indicated significant use of the systems at $0.50 fare. In general, the demand was for shopping and work trips in contrast to social-recreation and personal business trips. At this low level of fare, the D-J systems would indeed compete with the existing automobile mode of travel.

For systems at $1.25 fare, demand varied considerably among market subgroups and trip purposes. Housewives and teenagers in one-car households indicated substantial use of the system for shopping trips, secondary workers indicated use for work trips, and members of no-car households indicated use for shopping and personal business trips. It is postulated that the demand for the $1.25 systems is directly related to the availability of an automobile; those people who do not have access to an automobile or cannot drive would use the system for the most essential types of trips. At this high level of fare, the D-J systems provide a complement rather than a substitute for the automobile mode.

Latent demand, as measured by the increase in the number of trips being made as the result of the availability of the new mode, was small even for the $0.50 system with the shortest specified service times; an increase in total internal trips of 0.5 percent of all trips was recorded for this system. The impact of a D-J system in the case-study community should therefore be considered in terms of providing a competitive or complementary mode to the automobile (depending on the fare level) rather than in terms of solving serious transportation problems of immobility.

The system described as including service guarantees of 25 min maximum waiting time, a maximum D-J and automobile travel-time ratio of 3:1, and a $1.25 fare was financially self-supporting and would serve 5,600 demands per day. All other systems were not financially self-supporting. The cost estimates utilized appropriately high wage and interest rates, and conservative estimates of system profitability resulted.

Both computer- and manually-routed systems were studied, and the manually-routed system was economically superior only for fewer than 225 demands per hour. Also, the possibility of an incorrect demand estimation was investigated, and it was found that in order for the D-J system to break even the ridership would have to be at least 93 percent of the estimate.

The possibility of a federal grant for two-thirds of the capital investment was investigated and found to substantially enhance the profitability of the system. A system with 15 min maximum waiting time and a D-J and automobile maximum travel-time ratio of 2:1 would be financially feasible at less than $1.00 fare; more than 14,000 demands per day could be served by this system.

The sensitivity of system cost to changes in the wage rate and interest rate was analyzed. Because the system is quite labor intensive, cost was highly sensitive to changes in the wage rate. A reduction in the wage rate of $0.65 ($3.89 to $3.25) results in the lowering of the break-even fare for system D from $1.25 to less than $1.00, increasing daily ridership from 7,000 to 9,000 riders per day. Changes in the interest rate did not have as great as effect on system costs.

In brief, for the case-study community one configuration of the D-J system was found to be marginally profitable, and the application of federal capital assistance grants resulted in all systems becoming profitable over a considerable range of fares. The sensitivity of costs to labor rates and the high-wage scale in the case-study community is a severe test of the financial feasibility of the D-J system. Conversely, the relatively low sensitivity of system costs to capital cost items allows a high degree of variability in these items without an adverse effect on profitability estimates and consequently adds to the degree of confidence to these estimates.

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PARAMETRIC STUDY OF ACTIVITY CENTER TRANSPORTATION SYSTEMS

D. H. Maund, Ford Motor Company

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 $2\frac{1}{4}$-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):

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

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.

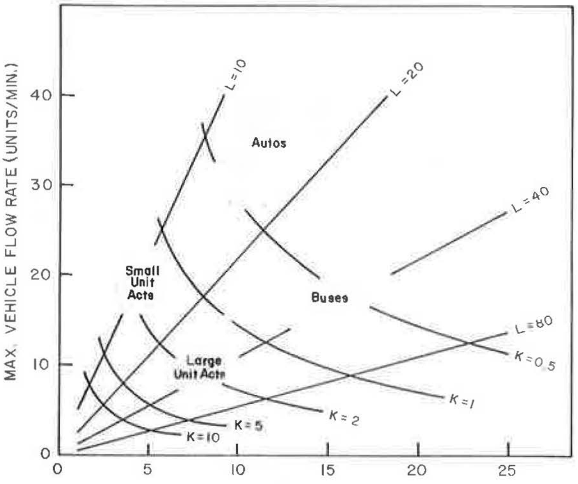


Figure 1. Maximum vehicle flow rate as function of critical velocity, length of vehicle L, and control factor K.

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

$$N = (ST_D/P) - (\nu/2) \tag{5}$$

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

$$N = (ST_DC/F^*) - (\nu/2) \tag{6}$$

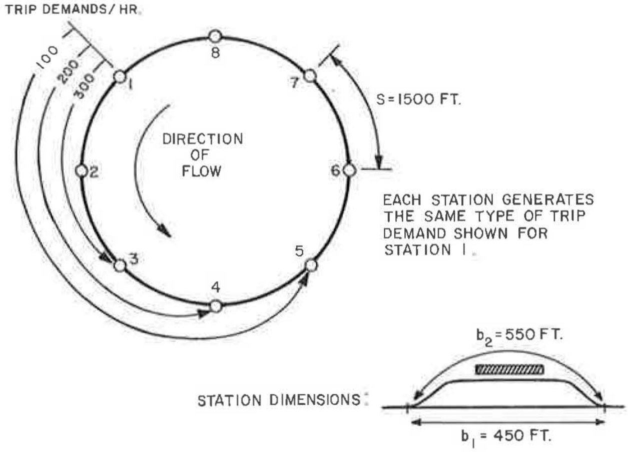
ANALYSIS OF TYPE A SYSTEMS

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

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

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

$\nu = 24$

OPERATING PARAMETER:

$a = 0.125g = 4.0\ \text{ft/sec}^2$

$j = 0.091g/\text{sec} = 2.9\ \text{ft/sec}^3$

$t = 20$ 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

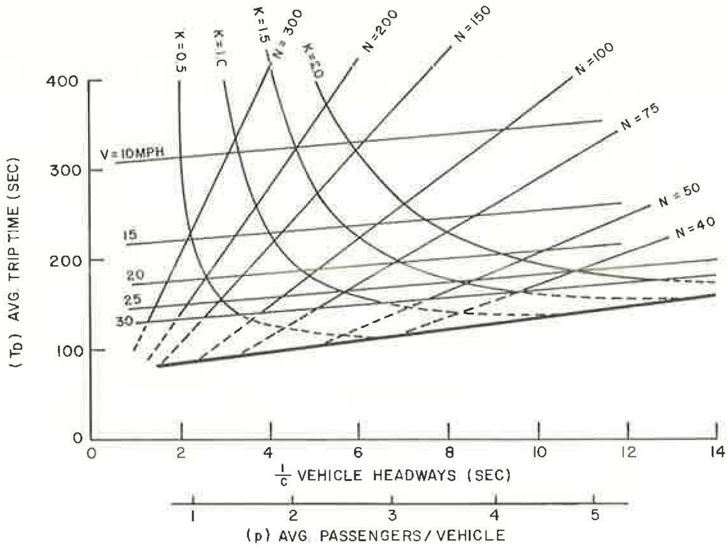


Figure 3. Operating characteristics of Type A system.

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.

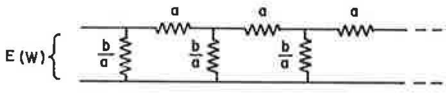


Figure 4. Expected guideway merge delays for Type A system.

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.

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

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

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.

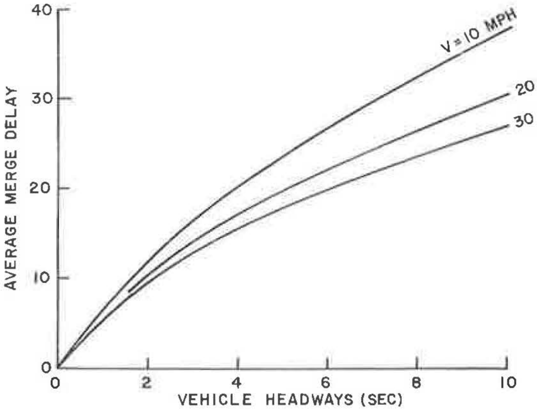


Figure 5. Operating characteristics of Type B system.

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 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

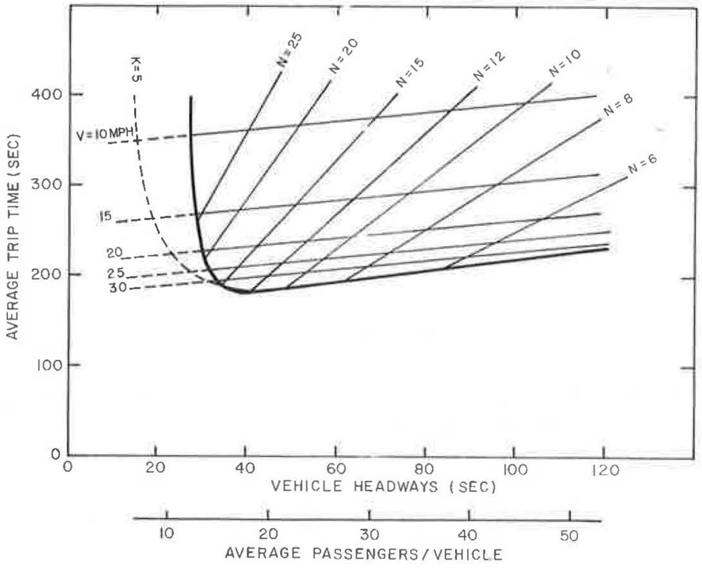

Figure 6. An infinite resistive ladder network with effective resistance of E(W).

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

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

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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POTENTIAL DEMANDS FOR DEMAND-SCHEDULED BUS SERVICES

E. Archer, Air Canada; and
J. H. Shortreed, University of Waterloo

•DURING the past few years there has been considerable interest in demand-scheduled bus systems (DSB) as a potential urban transportation mode. This system consists of buses running on city streets with routes adjusted to meet the demands of new riders as well as to serve the needs of passengers already on the bus.

A potential passenger calls the bus company and gives his origin and destination. The bus company examines the buses available and the destinations of on-board passengers and then assigns the new passenger to a bus. The bus is contacted and assigned a new routing so that the new passenger as well as those already on the bus can be picked up and discharged. The system is shown in Figure 1.

There are clearly two objectives for this type of bus service: first, to maximize the level of service to the passengers and second, to minimize the costs of operation and control of the bus system. A great deal of research has been carried out in recent years by M. I. T. (1, 2), Northwestern University (3, 4), and General Motors (5) on the operating and control characteristics required to optimize a DSB system given the capital and operating costs and a predetermined level of demand.

This paper describes research at the University of Waterloo on the supply portion of DSB system. It is clear that the supply portion of a DSB system is not a predetermined variable but is a function of the operating characteristics of the DSB system being considered. For a complete optimization then, both the demand and the supply characteristics for DSB must be considered together. In the consideration of the demand for DSB typical potential operating characteristics for DSB systems were taken from previous research results.

The DSB system has been proposed in two basic operating modes—the one-to-many and the many-to-many. The former is exemplified by trips to a rail head (one destination) from many dispersed trip origins. The second type of service is from any origin in the city to any other destination. The research for this paper was limited to considering the many-to-many operating mode for DSB (7).

STUDY PROCEDURE

The study was carried out in six distinct phases.

1. Decision made to study the demand of DSB.
2. Study area selected (Kitchener-Waterloo); road and transit networks for 1965 and 1968 prepared on a generalized cost basis; minimum cost, district-to-district trees, and district-to-district work-trip matrices for 1965 and 1968 (only partial matrix for 1968) prepared.
3. Criterion developed for traffic model characteristics and selection.
4. Model calibrated to 1965 data and tested with 1968 data.
5. Demand simulated for DSB for different operating characteristics of DSB and also tests made of sensitivity of the results to assumed behavioral parameters.
6. Results, discussion, and conclusions generalized.

STUDY LOCATION

As with most transportation problems the results can only relate to a specific location, and then these results can be generalized. The study location was the urban area

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comprising the cities of Kitchener and Waterloo in Ontario. Total population in 1965 was 119,000. Travel data were available from a 3 percent random sample traffic survey in 1965 and a specialized cluster sample in 1968 of 3,500 household days. The area was divided into 29 districts as shown in Figure 2. The 1965 road and bus networks are shown in Figure 3.

The study was limited to work trips, and Table 1 gives the work-trip characteristics for the study area in 1965. Data for 1968

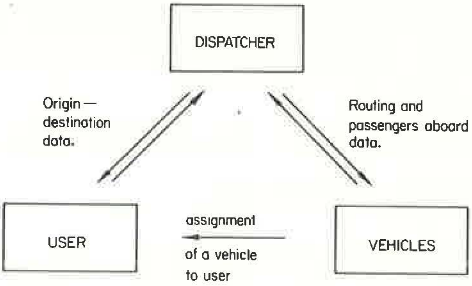

Figure 1. Conceptual operation of a DSB.

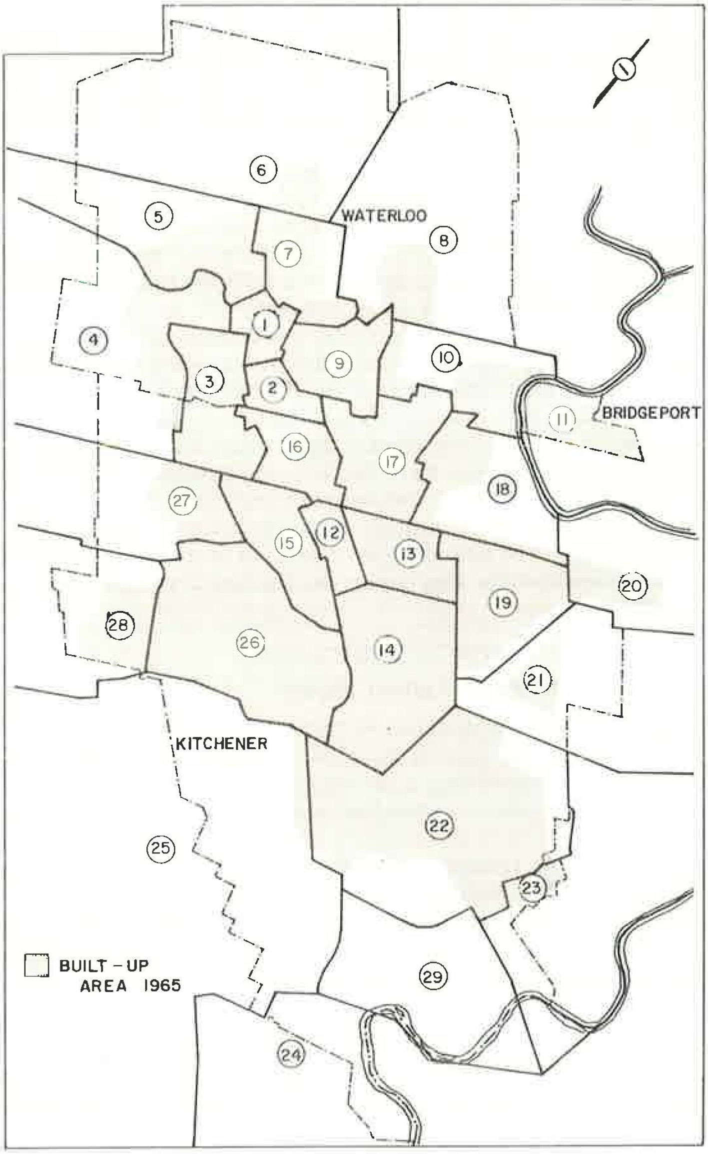

Figure 2. Study area district.

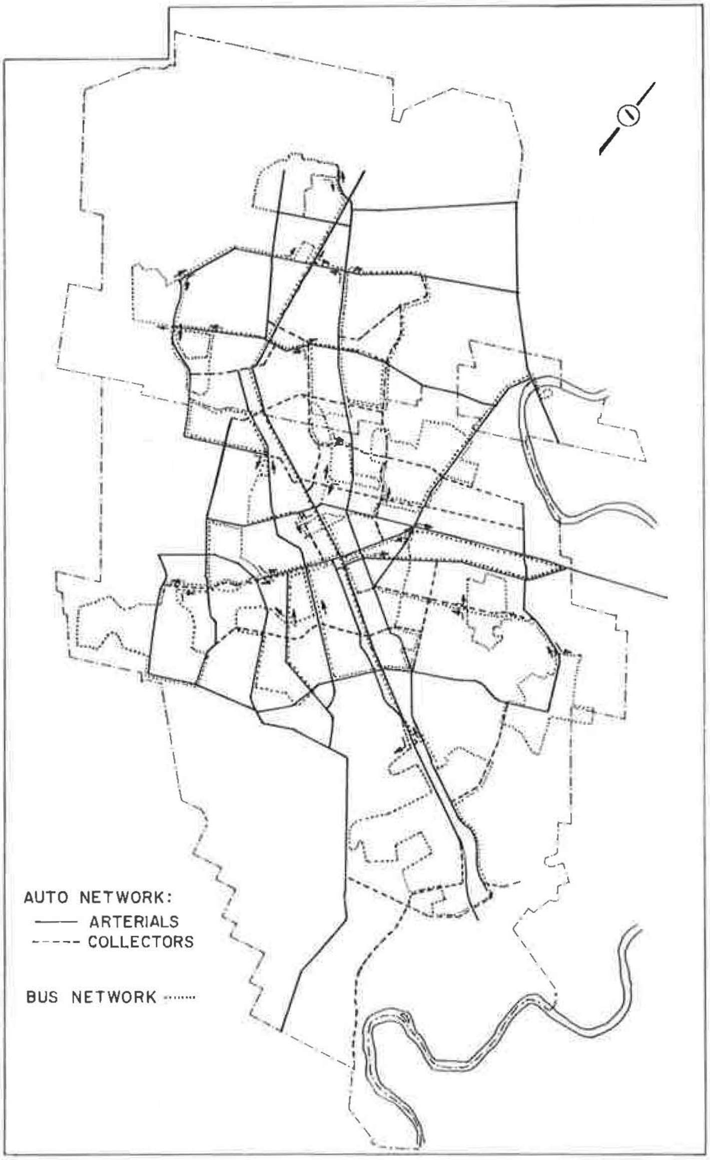

Figure 3. 1965 automobile and transit networks in study area.

are similar except the population had increased to 137,000 and the percentage of work trips by transit had decreased to about 8 percent. For purposes of the traffic model, a generalized cost of travel was used (Table 1). The generalized cost of travel used for 1965-68 was the following (6):

$$\text{Automobile trip cost} = (1/O)[(P/2) + C_m \cdot d_1] + K\,[T_1 + 60\,(d_1/V_1] \qquad (1)$$

and

$$\text{transit trip cost} = F + K\,[T_2 + 60\,(d_2/V_2)] \qquad (2)$$

where

O = average occupancy, 1.50;

P = parking cost per day (in CBD only, 50 cents);
C_m = out-of-pocket driving cost per vehicle mile, 4 cents;
K = time cost per minute, cents;
T_1 = automobile trip walking and waiting time (non-CBD, 1 min, and CBD, 3 min);
d_1, d_2 = trip length (miles from the networks, 1 for automobile and 2 for transit);
V_1, V_2 = speed, mph, from the networks;
T_2 = transit trip walking, waiting, and transfer time (walking rate 2.5 mph and waiting times ½ headway); and
F = fare (1965, 13 cents per trip, and 1968, 20 cents per trip).

TABLE 1

1965 SOCIOECONOMIC AND TRANSPORTATION CHARACTERISTICS OF STUDY AREA

Characteristic	Amount
Population	119,000
Average annual household income, $	4,000 to 9,313
Automobiles owned per person	1 per 3.2
Daily home-to-work trips	34,432
Work trips by transit, percent	14
Transit routes, miles	53
Main automobile routes, miles	320
Automobile work trips	
Length, mi	2.32
Time, min	9.17
Cost, cents	29
Transit work trips	
Length, mi	2.51
Time, min	33.06
Cost, cents	82

The values used in the generalized cost function were average estimates taken from the literature. It was thought that, because the travel model would be calibrated to both these costs and the same costs used in the analysis, the estimates were of sufficient accuracy. Also the model calibration resulted in a good fit for both the trip distribution function and the modal-split function. This gave added confidence in the costs used.

The generalized transit cost for a zone without bus service was taken to be $3.00 (taxi ride).

TRAVEL MODEL

In the problem definition phase several criteria for the traffic models to estimate demand levels for DSB were developed:

1. The model should perform trip distribution and modal split and be compatible with new modes of transport;
2. The model must be practical for the computer and computer time available (IBM 360-175);
3. The model should be able to reproduce the 1965 survey data, and then the calibrated model should reproduce the 1968 survey data; and
4. The model variables must be compatible with the data available.

Several models were examined for their suitability, including conventional models (17), disutility models (8, 11), probabilistic models (9, 10), discriminate analysis (12, 13, 14), and entropy maximizing models (15, 16).

Wilson's model (18) was selected on the basis of the criteria. It does trip distribution and modal split at the same time. Through the generalized cost function it can deal with new modes of transport, and the data and computer requirements were met.

Wilson's model is of the following form:

$$T_{ij}^{kn} = A_j^{n} B_j \, O_i^{n} D_j \, e^{-\beta^n C_{ij}^k} \tag{3}$$

where

T_{ij}^{kn} = number of trips between i and j by mode k by person type n;

$$A_i^n = 1/\sum_{j} \sum_{k \epsilon y\,(n)} B_j \, D_j \, e^{-\beta^n C_{ij}^k};$$

$$B_j = 1/\sum_i \sum_n \sum_{k \epsilon y(n)} A_j^n O_i^n e^{-\beta^n C_{ij}^k};$$

O_i^n = number of trip origins (productions) in zone i by persons of type n;
D_j = number of trip destinations (attractions) in zone j;
$y(n)$ = set of modes available to persons of type n;
C_{ij}^k = generalized cost ("general measure of impedence") of traveling from zone i to zone j by mode k; and
β^n = parameter that determines the mean of the trip length distribution (in cost terms) for persons of type n.

The equation is subject to the following three constraints:

1. $T_{i*}^{*n} = O_i^n$;
2. $T_{*j}^{**} = D_j$; and
3. $T_{**}^{*n} C_{**}^{*} = C^n$.

C^n is the total expenditure on transport by persons of type n, and * denotes summation over that particular subscript or superscript.

It is observed that the modal split is given directly by the trip distribution function. A recent application of the model in Manchester, England, is documented (18). A_i^n and the B_j are solved by an iterative process, and the model is calibrated over the β^n. Person types, n, can be defined by income class, car ownership, and so forth. Initially the model was calibrated for the whole of the study area. Later the model was calibrated for each district (n = district population) on the basis of district income.

During the calibration procedure one change was made in the form of the model. β^n was replaced by a linear function of cost, i.e., instead of $e^{-\beta^n C_{ij}^k}$, we have $e^{-(\beta^n - \alpha^n C_{ij}^k)}$ C_{ij}^k. This was found necessary to fit the Kitchener-Waterloo data. This form of the function is supported by the recent work of one of the authors in London, although the function may not be linear. This change in the model has the advantage that the calibrated model fits for both trip distribution and modal split. In previously reported work (18) two values of β^n were required, one for trip distribution and one for modal split. (Recent conversations with Professor Wilson suggest that this formulation implies a logarithmic perception of travel costs similar to human perception of other stimuli.)

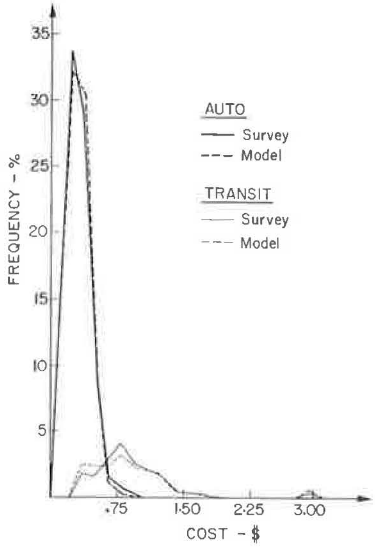

Figure 4. Cost distribution of 1965 automobile and transit work trips.

Further details of the model calibration are found in another report (7). Only a few indicative results of the calibration are presented here.

Figure 4 shows for automobile and transit trips the trip cost distributions for the survey and Model 1. Model 1 used only one person type, and the fitted impedance function was $e^{-(4.5 - 1.0 C_{ij}^k)}$, where C_{ij}^k is the generalized cost in dollars.

One sensitivity check of the results and the model parameters was made. The parameters of the fitted impedance function estimated a 14.6 percent work-trip bus usage for the whole study area. With everything else constant, one of the impedance function parameters was changed to 3.75 instead of 4.5. The results were an estimated 13.8 percent work-trip bus usage. Thus the model results are not sensitive to the models' fitted parameters (i.e., 0.75/4.5 > 0.8/14.6).

For testing purposes and with the 1968 cluster data, Model 2 was developed from the 1965 data where each district was taken as a person type n. Two characteristics were used for each district: (a) the average household income and (b) distance from the CBD (either less than or more than 6,000 ft). The latter generally measured higher density and older areas of the city. The impedance function for Model 2 for distances less than 6,000 ft from CBD was $e^{-(\beta - \alpha C_{ij}^{k}) C_{ij}^{k}}$. For distances more than 6,000 ft from CBD, $\beta = -5.0 + 0.002\,I$, $\alpha = -1.15 + 0.0005\,I$, $\beta = 9.4 + 0.002\,I$, and $\alpha = -3.1 + 0.0005\,I$, where I = average annual household income.

Little confidence can be placed in the parameter values of Model 2 because the data were very limited. The fit of Model 2 to the 1965 data was judged to be as good as but no better than that of Model 1. Of course, the ability of Model 2 to forecast was better because it included income effects directly.

For validation purposes the calibrated models were applied to the 1968 cluster sample. The accuracy with which the model predicted the survey data is given in Table 2. Model 2 was used and adjusted to the incomes of the cluster samples. It should be remembered that from 1965 to 1968 transit patronage in the study area decreased from 14 to 8 percent. Data given in Table 2 indicate that the model is able to forecast transit patronage very well under these rapidly changing conditions.

DEMAND FOR DSB

The analysis to estimate the demand response of the Kitchener-Waterloo population toward the DSB was performed directly with Model 2 by simply varying the value of the different parameters of the cost function relevant to the DSB system. In all cases, the range of the parameters used was taken from representative values in the literature. It was assumed that the DSB system was in existence in 1965 and that it was also the only transit system available at the time. The DSB travel times were varied from 1.5 to 3.0 x automobile times. This ratio of the DSB travel time to that of the automobile is referred to as the travel time ratio (TTR).

At the same time, waiting time was introduced into the cost function. This represents the approximate time that a user would have to wait to be picked up by a vehicle. The values used were 2, 3, or 4 min.

Finally a range of fares of 30 to 60 cents was used for the DSB service. In addition, for some analysis a modal attribute or attraction benefit of up to 15 cents was assigned to the DSB system. That is, in making their modal choices patrons would perceive DSB as being 15 cents cheaper per trip than the generalized cost would suggest. The basis for this perceived benefit was that the model was calibrated to a regular bus system and DSB has door-to-door service, smaller vehicles, a more personalized service, and so forth. Thus it is conceivable that such a service would be perceived as better than the fare and travel time alone would indicate.

Clearly the value of such a modal attribute cannot be measured until an actual DSB is put into operation. For this analysis a modal attribute of 15 cents for DSB is taken to be the upper limit estimate of possible ridership for the service.

TABLE 2

RESULTS OF VALIDATION TESTS ON 1968 DISTRICT DATA

District	Percent by Transit		Mean Travel Cost (dollars/trip)			
			Automobile		Transit	
	Survey	Model 2	Survey	Model 2	Survey	Model 2
3	8.18	5.48	0.255	0.238	0.840	0.829
6	0.00	0.63	0.268	0.262	—	—
8	3.03	5.49	0.300	0.350	1.085	1.193
9	1.89	2.32	0.231	0.231	0.785	0.820
13	7.63	4.48	0.247	0.213	1.260	0.560
14	16.42	10.00	0.268	0.250	0.860	0.649
17	0.97	0.44	0.304	0.168	0.670	0.745
19	8.56	6.39	0.351	0.284	0.868	0.694
21	2.69	0.22	0.352	0.264	1.146	1.047
22	1.27	0.20	0.385	0.266	2.050	1.228
26	9.38	7.24	0.297	0.285	0.813	0.714
28	0.00	0.71	0.405	0.331	—	—

TABLE 3

ESTIMATED 1965 TRANSIT WORK TRIPS

District	Income (dollars)	Number of Transit Users		Percent by Transit	
		Bus—Survey	DSB—Model 2	Bus—Survey	DSB—Model 2
1	4,423	43	203	9.0	42.6
2	5,300	128	241	15.5	29.2
3	6,764	217	268	9.9	12.2
4[a]	8,194	0	55	0.0	3.6
5	9,313	26	5	7.4	1.4
6	6,344	263	152	23.8	13.8
7	6,558	234	175	17.1	12.7
8[a]	7,417	0	92	0.0	6.2
9	7,063	136	176	7.8	10.0
10[a]	8,385	0	12	0.0	3.8
11	6,600	33	46	6.9	9.6
12	4,379	373	236	48.1	30.0
13	5,433	354	239	16.7	11.2
14	5,957	559	286	14.8	7.6
15	4,305	257	346	16.5	22.2
16	5,034	233	154	20.6	13.6
17	5,240	389	289	15.8	12.1
18	6,763	315	163	24.1	12.5
19	6,132	476	409	17.3	14.9
20[a]	6,000	0	11	0.0	17.2
21[a]	5,417	0	110	0.0	24.7
22	6,148	565	574	14.4	14.6
23	4,500	51	36	48.6	34.3
24[a]	4,000	0	7	0.0	38.9
25[a]	4,000	0	33	0.0	34.0
26	5,589	737	1,050	16.5	23.6
27	6,158	93	121	12.4	16.1
28	8,022	0	22	0.0	3.4
29[a]	6,000	0	17	0.0	14.7

Note: Travel-time ratio = 2.5, fare = 30 cents, waiting time = 4 min.

[a] Not directly served by bus service in 1965.

In a similar fashion, the modal forecast of ridership can be considered to be a conservative estimate of ridership because the special attributes of DSB are not directly included in the analysis.

For a fare of 30 cents, a travel-time ratio of 2.5 (x automobile-travel times), and a waiting time of 4 min, the forecast by Model 1 of the percentage of 1965 work trips by DSB for the entire study area was 14.4 percent or approximately equal to the bus patronage for that year. The ridership on both systems is given in Table 3. Clearly they are not directly comparable. As indicated, eight districts in 1965 were not served by bus routes. However, the general pattern is as expected. DSB patronage for the journey to work has the same pattern as bus patronage in 1965. The average expansion factor for the 1965 survey was 25; therefore, many survey figures represent only one or two observations.

Table 4 gives for the entire study area the percentage of work trips for the 1965 forecast by DSB under different waiting times and travel-time ratios. In each case the distribution of demand is similar to that given in Table 3. As data given in Table 4 indicate, the level of ridership was not sensitive to the waiting time but was very sensitive to the travel-time ratio.

Table 5 gives the predicted level of DSB patronage for a constant travel-time

TABLE 4

PERCENTAGE OF 1965 WORK TRIPS BY DSB FOR VARYING TRAVEL-TIME RATIOS AND WAITING TIMES

Travel-Time Ratio	2.0-Min Wait	3.0-Min Wait	4.0-Min Wait
1.5	23.69	22.58	21.53
1.6	22.73	21.67	20.65
1.7	21.82	20.79	19.82
1.8	20.95	19.96	19.02
1.9	20.12	19.17	18.27
2.0	19.33	18.41	17.55
2.25	17.50	16.67	15.89
2.5	15.88	15.13	14.41
2.75	14.43	13.75	13.10
2.0	13.14	12.52	11.93

Note: Fare = 30 cents.

ratio of 2.5 and varying fares. Sensitivity of patronage to waiting time is low. Sensitivity of patronage to fares is high and of the same order as the sensitivity to travel-time ratio.

TABLE 5

PERCENTAGE OF 1965 WORK TRIPS BY DSB FOR VARYING FARES AND WAITING TIMES

Fare (cents)	2.0-Min Wait	3.0-Min Wait	4.0-Min Wait
30	15.88	15.13	14.41
45	11.06	10.55	10.06
60	7.78	7.43	7.10

Note: Travel-time ratio = 2.5.

Table 6 gives and Figure 5 shows the estimated patronage for DSB, with a waiting time of 3 min for a range of travel-time ratios and fares. Also shown as a set of dotted curves is the upper limit (UL) estimate of patronage, based on a perception of DSB special attributes being worth 15 cents. The shaded area shown in Figure 5 represents the bus system in Kitchener-Waterloo during 1965-68, which had a travel-time ratio of 3.6.

Figure 5 shows clearly that for a DSB system to attract as much patronage as the existing bus system it would have to have a travel-time ratio of 2.5 or 3.0 and a fare of 30 to 40 cents. The system selected would depend of course on the trade-off between fares and travel-time ratios on the operational side of the DSB analysis. On the demand side, Figure 5 shows that for levels of patronage of 15 to 25 percent on DSB very low fares and high travel-time ratios would be required. In general, previous research (2, 4, 8) has indicated that feasible DSB systems would have travel-time ratios of more than

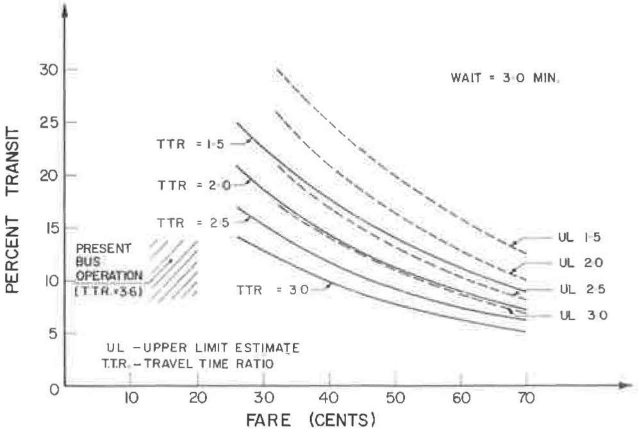

Figure 5. 1965 DSB ridership versus fare and travel-time ratio.

TABLE 6

PERCENTAGE OF 1965 WORK TRIPS BY DSB FOR VARYING FARES AND TRAVEL-TIME RATIOS

Fare (cents)	Travel-Time Ratio				Upper Limit			
	1.5	2.0	2.5	3.0	1.5	2.0	2.5	3.0
30	22.58	18.41	15.13	12.52	—	—	—	—
45	15.79	12.85	10.55	8.74	22.58	18.41	15.13	12.52
60	11.08	9.03	7.43	6.18	15.79	12.85	10.55	8.74
75	—	—	—	—	11.08	9.03	7.43	6.18

Note: Waiting time = 3.0 min.

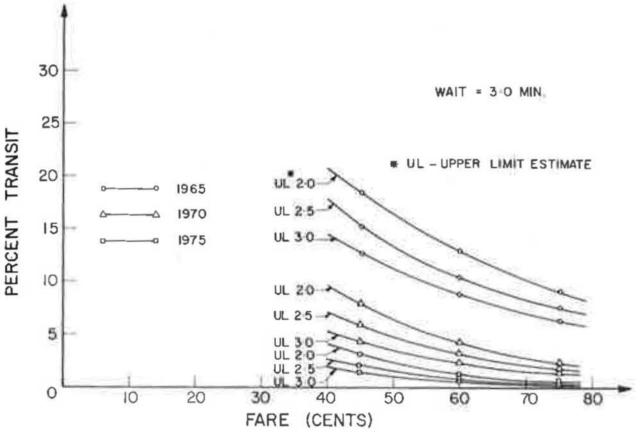

Figure 6. 1965, 1970, and 1975 DSB ridership versus fare and travel-time ratio.

TABLE 7

PERCENTAGE OF 1965, 1970, AND 1975 WORK TRIPS BY DSB FOR VARYING FARES AND TRAVEL-TIME RATIOS

Year	Fare (cents)	Upper Limit		
		2.0	2.5	3.0
1965	45	18.41	15.13	12.52
	60	12.85	10.55	8.74
	75	9.03	7.43	6.18
1970	45	8.03	5.87	4.38
	60	4.19	3.10	2.35
	75	2.29	1.73	1.33
1975	45	3.09	2.01	1.36
	60	1.12	0.75	0.53
	75	0.45	0.32	0.23

Note: Waiting time = 3.0 min.

2.5 and fares of more than 45 cents. This indicates a maximum DSB ridership for the study area work trips of 11 to 16 percent (Fig. 5). In general, then, one can conclude that the prospects for patronage for a DSB system in 1965 in Kitchener-Waterloo would not have been much different from the existing bus system, which had 14 percent ridership.

To examine the future prospects for DSB, we increased the income of the 1965 population of the study area 5 percent per year to 1970 and 1975 levels. Then Model 2 was used to estimate the DSB patronage. The upper limit estimate was used, and the results are given in Table 7 and shown in Figure 6. The resulting patronage is very low. If one keeps in mind that the existing bus patronage fell from 14 percent to 8 percent from 1965 to 1968, the figures seem more credible. This future analysis clearly demonstrates that DSB, unless it is heavily subsidized, will not be able to serve a significant portion of the transport demand in the future.

DISCUSSION OF RESULTS

The results for the study area indicate for even a heavily subsidized system a very low demand for DSB transportation system in the very near future. Because the Kitchener-Waterloo area is typical of North American cities, it is expected that similar results would be forthcoming in other cities, and that the results presented here could be used for other cities. Recent work at General Motors supports the range of ridership predicted.

With such a low level of ridership it would seem inappropriate for any public agency to invest in this type of system as its primary public transport system. In fact the results give some indication that a fixed-route bus system would provide the same levels of ridership at a lower cost. This was not tested directly in this study because only the demand was examined.

It seems clear from the demand model that the travel-time ratio of an alternative mode of public transport must be very close to one to ensure substantial level of ridership. Thus the DSB concept's main obstacle to success is its high travel-time ratio. If further development work on DSB is carried out, it should concentrate on operational methods of reducing the travel-time ratio.

CONCLUSIONS

1. A Wilson type of gravity model (15) with a modified impedance function is a satisfactory travel model for forecasting the demand for a DSB system;
2. For a DSB system (many-origins-to-many-destinations operation) with operating characteristics indicated from previous research, the demand for the journey to work would not be much greater for such a system than for a typical existing urban bus system;
3. The future work-trip patronage prospects for a DSB system are not good (DSB systems with travel-time ratios of 2.0 or less and fares of 45 cents per trip would, at the most, serve 3 percent of the journey-to-work trips for the study community, Kitchener-Waterloo, in the year 1975); and
4. The levels of patronage for DSB systems for nonwork trips were not estimated by the study.

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