Conference Summary

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A number of system concepts were described at the conference. Each, in the viewpoint of the particular author, is a form of dual-mode transportation. The range of concepts that bear the dual-mode transportation label is quite broad, revealing both a common underlying perception of the potential advantage of all such systems and at the same time an advocacy of particular technological approaches and service priorities. However, essentially all of the dual-mode transportation concepts can be included within the following definition:

> Dual-mode transportation is that broad category of systems wherein vehicles may be operated in both of two modes: (a) manually controlled and self-propelled on ordinary streets and roadways and (b) automatically controlled or externally propelled (or both) or powered on special guideways. In general, dual-mode transportation systems can include both common carrier and private vehicles and provide for the transport of both persons and freight over a common guideway facility.
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> Dual Mode Transit is a special case of dual-mode transportation. Service is provided only by common-carrier vehicles for passenger transportation. Such service may be on a personalized or group transit basis.

Dual-mode transit may be complemented by automated guideway transit service provided by single-mode vehicles on a "metropolitan guideway" network (5). The interrelation of transportation modes in the metro guideway concept is shown in Figure 1.

The most common example of dual-mode transit service described at the conference employed a small bus that was controlled by a professional driver on the ordinary street system and that could also be automatically controlled, with or without the driver remaining aboard, in operation on a special guideway. When off the guideway, the vehicle would be self-propelled. The passenger service could be of a demand-responsive nature for passenger collection or distribution or could follow prearranged routes and schedules. When on the guideway, the vehicle would be automatically controlled relative to both lateral and longitudinal position and motion over the guideway network. In some designs, the vehicle was self-powered, and, in others, electric power was obtained from the guideway.

An alternative form of dual-mode transportation employs a fleet of transporter vehicles, or "pallets," which are captive to the guideway network (i.e., not free to leave the guideway for operation on ordinary roadways). In the pallet approach to dual-mode transit, small buses are driver-controlled off the guideway and then loaded onto individual pallet transporters for guideway service. Only the pallet transporters need to be equipped with automatic features.

Both of these concepts for dual-mode transit were seen to be special cases of the broader concept of dual-mode transportation contained in the definition given above. In the more general concept, private automobiles, taxicabs, small trucks and vans, and service vehicles would be capable of automatic control or could be carried aboard pallet transporters. Guideways or roadways accommodating suitably automated automobiles, vans, and transit vehicles have been previously described or demonstrated under names such as automated highway or metro guideway.

A number of quite different concepts were also described as potentially in the dual-mode transportation category. These included piggyback service whereby road vehicles are transported on an equivalent of railroad flatcars; vehicles towed by a conveyor mechanism; and the transport of bicycles along with passengers on otherwise conventional buses and rail cars. Speakers described light rail transit and dual-powered bus systems as dual-mode transit, if they were operated both in mixed traffic (typically in outlying areas) and on special rights-of-way (e.g., underground in central areas).

Figure 1. Metro guideway functions.

		SINGLE-MODE VEHICLES (VEHICLES CAPTIVE TO GUIDEWAY NETWORK)	DUAL-MODE VEHICLES (OPERATE ON STREETS AND GUIDEWAY)
PRIVATE PASSENGER TRANSPORTATION		———	DUAL-MODE AUTOMOBILES
		AUTOMATED GUIDEWAY TRANSIT	DUAL-MODE TRANSIT
PUBLIC RAPID TRANSIT	PERSONAL TRANSIT	PERSONAL RAPID TRANSIT	(DUAL-MODE TAXICABS)
	GROUP TRANSIT	GROUP RAPID TRANSIT	DUAL-MODE DIAL-A-RIDE
	MASS TRANSIT	PEOPLE MOVERS	DUAL-MODE BUS RAPID TRANSIT
FREIGHT TRANSPORTATION		TERMINAL/TERMINAL UNATTENDED CONTAINERS	DUAL-MODE LIGHT VANS

POTENTIAL ADVANTAGES OF DUAL-MODE TRANSPORTATION

Partly because of recent research and development activity by the U.S. Department of Transportation and industry contractors in dual-mode transit, a majority of the papers at the conference were devoted to the transit aspects of dual-mode transportation, so let us consider those aspects first. Most proponents of dual-mode transit are persuaded by their perception of the urgency to upgrade the quality of public transit service and the potential performance advantages of dual mode in that regard. Some feel that dual-mode transit is an appropriate and perhaps necessary first step to more general dual-mode transportation service, while other dual-mode transit proponents feel that private dual-mode vehicle operation is undesirable or technically impractical.

The principal thesis of most dual-mode transit advocates seems to be that dual-mode transit offers more convenient and faster service than any other existing or proposed forms of public transit by providing essentially door-front pickup through demand-responsive service on local streets; by eliminating the need for transfers between collector bus service and trunk-line transit service, and the attendant physical effort, exposure, and waiting time; and by essentially nonstop service on the trunk-line facility in contrast with the annoyance and delays of station stops experienced on many transit systems. Another way of putting the case is that dual-mode transit combines the service characteristics of dial-a-ride systems for collection-distribution functions in outlying areas with the service characteristics of personal rapid transit and group rapid transit in guideway operations to stations in central areas, while eliminating the need for a transfer between such modes.

The objective of dual-mode transit is to produce an improved form of public transit service that is superior to or rivals the performance of private automobile service for a higher percentage of trips in metropolitan areas. Attendant advantages are foreseen to include those that might be expected to result from any increase in public transit usage, including potential savings in travel time, overall monetary cost, petroleum fuel consumption, and improvements in environmental quality. Particular advantages would be expected to accrue for the aged, young, poor, and handicapped, who have inadequate accessibility to automobile service.

The second major thesis of dual-mode transit advocates is that automation of vehicle control while on the guideway enables economies through reductions in driver labor. Such economies presuppose that in guideway operation the vehicles can and should be driverless. The potential cost savings of driverless operation on the guideway were addressed by a number of authors at the conference. Factors considered were automation cost, driver labor cost, and effectiveness in being able to productively reassign drivers to other vehicles.

The arguments for improved quality of service and minimization of driver labor are closely related. Fundamentally, for a given resource expenditure, any reductions in labor costs enable corresponding increases in guideway network and vehicle fleet size. Perhaps more significant, as one removes the driver from a vehicle on the guideway, one changes drastically the economies of scale of vehicle size and occupancy. It becomes more practical to transport people in smaller groups if they need not share a driver. In turn, vehicles transporting a smaller number of persons need not stop at every station on the guideway but only at appropriate off-line stations. This enables an express operation, which should materially contribute to travel time savings and user satisfaction. Further, the operation of a larger number of small vehicles involves shorter headways between vehicles and frequent merges from off-line stations to main-line guideways, resulting in a requirement for a more precise automatic control, thus both requiring and enabling the removal of driver control.

The proponents of more general forms of dual-mode transportation perceive the need to accommodate a wider spectrum of the totality of transportation needs of larger metropolitan areas, including those commonly provided by private automobiles, small trucks, service vehicles, and public transit. Their arguments recognize trends for an increase in the total number of trips in urban areas over time as a function of increased population and increased economic activity. The fastest growing component of such total travel is that of the longer distance trips between dispersed origins and destinations within metropolitan areas, the type of trip making that normally would be expected to use automotive vehicles on freeway and other major arterial roadway facilities. The social and economic costs of providing additional freeway and other arterial roadway facilities that would accommodate such additional travel could be substantial (5).

The principal argument that is thus advanced for general dual-mode transportation is that the automation of the roadway and the vehicles (or, correspondingly, the provision of automated transporters) will enable more effective and more efficient use of existing rights-of-way and minimize the social and economic costs of providing additional roadway facilities. Thus, if one can increase unit roadway capacity in terms of vehicles per lane per hour by enabling safer operation at closer headways between vehicles, fewer lane-kilometers of roadway would be required in an urban area for a given number of vehicle trips. Depending on the particular implementation plan that may be outlined, one could either implement some new combination of automated roadways and conventional roadways within existing freeway rights-of-way or construct wholly new facilities with minimal additional right-of-way land requirements in contrast with existing freeway design practice. In view of the strong public reaction that has arisen to many freeway proposals in recent years, dual-mode transportation may be the most effective approach to meeting the freeway type of facility needs of tomorrow's urban areas. The benefits derivable from increased roadway capacity and improved use of highway rights-of-way would accrue to the community as a whole.

Additional advantages to dual-mode transportation can be grouped into a second set, which is primarily user related. Through automation, one should be able not only to increase roadway capacity but also to increase the speed range at which that maximum capacity is realized. Thus, whereas in current highway practice maximum vehicle flow occurs at speeds in the order of 55 km/h (35 mph), a typical design objective for roadway automation is to realize the increased capacity at vehicle speeds in the order of 100 km/h (60 mph). The principal benefit is clearly in travel time savings in peak periods. Inasmuch as trends in freeway usage in many metropolitan areas have been in the direction of more uniform use throughout the day, such travel time savings would apply to a large percentage of trips forecast to be made on freeway facilities. Clearly, any reduction in freeway travel times would result in diversion of trips from surface street arterials. Within the increased capacity of automated roadways to accommodate such additional trips, the resultant diversion would reduce traffic on surface streets and produce further travel time savings.

Another important benefit foreseen for occupants of dual-mode transportation vehicles is that of the increased safety that is expected to result from the regulation of vehicle flow, the more rapid sensing of potential hazards, and the more precise control of vehicle motion and acceleration. Although some reduction in the rate of accidents is possible through the provision of additional information to the driver or through simple changes in vehicle and roadway design, major improvements in highway safety should be achievable through automation; however, absolute safety, although a desirable goal, is not fully compatible with other goals relative to capacity, performance, cost, and environmental impact.

The potential advantages that might result from redesign of automobiles, small trucks, and service vehicles for adaptation to dual-mode guideway facilities were not adequately explored during the conference. Thus, for one example, if vehicles were transported on special pallet transporters while on the guideway, their structural, control, and propulsion systems might be optimally designed for low-speed, local-area service and not have to accommodate the high-speed, longer distance profile typical of freeway operation. As a second example, vehicles designed for automated operation on guideways would necessarily have performance and reliability characteristics that would yield benefits in performance and maintainability in off-guideway operations as well. Conclusions cannot be developed relative to such potential benefits in the general case of dual-mode transportation; readers are free to draw their own inferences by extension of the analyses of dual-mode transit vehicles.

PERCEIVED DISADVANTAGES OF DUAL-MODE TRANSPORTATION

The principal disadvantage of dual-mode transportation lies in the fact that it is a new system and faces a host of technical and institutional barriers to implementation, as do other new systems. The special extent of these barriers for the highly technological and comprehensive dual-mode transportation concept was addressed by various conference speakers and panel members, and this aspect is discussed later.

Apart from implementation considerations, a number of papers considered the potential disadvantages of various particular forms of dual-mode transportation versus other new and existing modes. One contention is that it is impractical, or perhaps impossible, to develop a dual-mode vehicle with sufficient reliability for automated operation on guideways. It is argued that exposure to the unpredictable environment of ordinary streets, roads, and off-road conditions, together with inadequate maintenance and possible tampering with equipment, may result in equipment defects that would render the vehicle unsuitable for automated operation. It is argued further that it may not be possible to detect such malfunctions through any reasonable level of vehicle diagnostics or performance checks before entry to the guideway. This is, of course, a basic consideration for dual-mode systems. It is not possible to resolve this question before the determination of, first, an acceptable policy on how safe the system needs to be, second, failure modes and effects analyses to determine system performance and safety as a function of vehicle reliability factors, and, third, achievable vehicle reliability within performance and cost constraints.

A related viewpoint is that, although to achieve adequate reliability and performance in dual-mode automobiles may not be possible, to do so for publicly owned and maintained vehicles including small buses and public service vehicles should be. Those who take this viewpoint are thus of the belief that dual-mode transit may be technically feasible but more general dual-mode transportation systems are not.

A second type of argument, which Anderson effectively articulated in his paper, is that, apart from questions of technical feasibility, to implement dual-mode transit systems may not be desirable. He argues that automated guideway systems, of the personal rapid transit or group rapid transit types, employing vehicles that are captive to the guideway network, are likely to be technically, economically, and aesthetically superior. The reasons given are that dual-mode vehicles, by virtue of their need to be "roadable," are likely to be wider and heavier than vehicles designed exclusively for guideway use, and as a result dual-mode guideways will be larger, costlier, and less aesthetically acceptable than personal rapid transit structures. In addition, a greater design freedom exists in personal rapid transit for overhead vehicle suspension as well as railway and roadway forms.

Within the context of public transportation, such comparisons of dual-mode transit and personal or group rapid transit are moot points. The argument devolves into the consideration of dual-mode transit as a no-transfer combination of dial-a-ride and group rapid transit service using a common vehicle vis-à-vis separately configured dial-a-ride and group rapid transit systems. The trade-offs include the convenience of the no-transfer service versus the increased performance, efficiency, and perhaps aesthetics that may result from the specialization of the design of the different dial-a-ride and personal or group rapid transit vehicles. However, if dual-mode transit is considered as only one of the transportation modes using a dual-mode transportation guideway facility and if current dual-mode transit activities are viewed as precursory to more general dual-mode transportation, a broader range of factors need to be considered than those of dual-mode transit versus personal or group rapid transit.

RESULTS OF ANALYTICAL CASE STUDIES

Considering the pros and cons of dual-mode transportation, is it a desirable mode of urban transportation? Should it exist? During the last several years, a number of analytical studies have been made of dual-mode transportation systems in selected case study environments. The results of several of these were reviewed at the conference through technical papers and panel discussions.

Two examples will be cited of earlier case studies of general dual-mode transportation. In 1967, a systems analysis of urban transportation was conducted for the U.S. Department of Housing and Urban Development (6). Analyses were made of various transportation alternatives in the case study cities of Boston and Houston, projected to 1980. Quantitative estimates were developed for each alternative approach in regard to several categories of expected benefits. Relative to dual-mode transportation, the report concluded:

> Prominent among the most advanced developments... is the automatic, electrified guideway. For private automobiles, operation on such guideways could lead to important reductions in pollution, accidents, congestion and intrusion. For public transit, speed and comfort rivalling that of the private automobile could be provided by small vehicles operated on guideways. Utilization by both public and private modes of a single guideway system is clearly desirable for efficiency and economy. The resultant dual mode... system would provide personal transit for transit users; at the same time, it would accommodate privately-owned automobiles designed for either conventional manual operation on city streets ... or automatic operation on the guideway.

Relative to implementation strategy, the report recommended:

> Development and demonstration of the new technology should begin with personal (rapid) transit which should far surpass conventional systems in cities at considerably lower dollar cost.... Beyond this, development of the new technology must ensure that the personal (rapid) transit system can grow into dual mode (transportation) accommodating both public and private vehicles. It is the dual mode system that promises most for equalization of public and private service, for unification of all parts of the city, and for maximization of individual choice. Capability for growth to full dual mode use will cost little if designed at the outset into personal (rapid) transit. It provides a vital option: a smooth, evolutionary path to a real revolution in... urban transportation.

More recently, an analysis of dual-mode systems in an urban area was performed by personnel of the Transportation Systems Center of the U.S. Department of Transportation (1). The objective of the analysis was to obtain sufficient insight into the costs, impacts, and benefits of dual-mode transportation systems to enable the U.S. Department of Transportation to assess the potential of the dual-mode concept as an urban transportation system. The case study area was Boston in 1990, when an extensive dual-mode transportation system provides service for the entire urban region. It was concluded that, relative to Boston and other large urban areas,

> Dual Mode (Transportation) systems appear to be sufficiently attractive to warrant further technological development.
> For urban-wide applications, a Dual Mode (transportation) system which includes both buses and personal vehicles is more effective than one consisting of either type exclusively.
> A Dual Mode Transportation system benefits from the use of various Dual Mode concepts throughout its development. An effective first step might be to install a limited network Dual Mode minibus system, with capacity for ultimate growth to a longer guideway network with personal vehicles and buses.

As one may note from these case study results, dual-mode transit is best considered as part of an overall dual-mode transportation system. Two case studies have recently been performed of dual-mode transit vis-à-vis bus rapid transit, both relative to Milwaukee, Wisconsin. The results of a 1971 study sponsored by the Urban Mass Transportation Administration were reviewed by Stuart during the conference (7). In summary, he noted:

> A hypothetical Dual Mode Transit system was analyzed and compared with a modern, conventional Bus Rapid Transit plan. The Dual Mode Transit concept was shown to be an attractive alternative offering many significant advantages. It was concluded that Dual Mode Transit systems offer higher service quality (ability to attract riders), higher labor productivity, competitive fares, benefits exceeding costs, greater attainment of regional development goals and objectives, high degree of operational flexibility to meet varying transportation needs, and, possibly most important, growth potential with good cause to expect a long-term trend of increasing utilization, total benefits, and economic operating margins.

The results of more recent studies of dual-mode transit versus bus rapid transit for the Milwaukee area were presented by Lieb (an abstract of his paper is contained in this report). Annual costs and levels of service were determined for a dual-mode bus system, an exclusive busway system, and a conventional bus system, each designed to provide the same peak-hour capability to the Milwaukee central business district, as projected to 1990. The conclusions were that

> The dual mode bus system provides a significantly better level of service than comparable exclusive busway and conventional bus systems. The dual mode and the exclusive busway systems are most nearly comparable from a cost and level of service standpoint. The dual mode system requires the passenger to wait one-third less time at the pickup point and provides a 20 percent shorter trip time than the exclusive busway system. An exclusive busway system offering service identical to the dual mode system costs 45 percent more.

Only limited analyses have been made of dual-mode transit on its own, that is, not sharing a common guideway facility with private dual-mode automobiles and other vehicles. A case study was performed by the General Motors Research Laboratories for the U.S. Department of Housing and Urban Development (3, 4) of a dual-mode bus transit system in the locale of Rochester, New York. The estimated savings in driver labor costs through automatic operation were small in comparison to the estimated annual costs of the automated facility. The conclusion was that the dual-mode transit system, using its own automated guideway facility, did not appear to offer potential performance and cost advantages over manually controlled bus rapid transit on exclusive busway facilities.

The two Milwaukee case studies appear to have yielded more favorable results for dual-mode transit relative to bus rapid transit than did the earlier General Motors study. However, unlike the General Motors study, the two Milwaukee studies were based on a shared use of dual-mode guideway facilities by both public and private vehicles.

None of the case studies that were reviewed at the conference was specifically directed to the comparative analysis of dual-mode transit vis-à-vis areawide service combining single-mode automated guideway transit with separate dial-a-ride services on local streets.

The results of more recent studies of dual-mode transportation by the Transportation Systems Center are summarized in this report. They include further investigation of the costs and benefits of dual-mode transportation and estimates of the applicability of dual-mode transportation to various metropolitan areas of the United States.

The results of the various case studies of dual-mode transportation and of dual-mode transit in various urban environments enable these conclusions to be drawn:

1. There is a clear consensus from the analytical case studies that implementation of dual-mode transportation systems accommodating both privately owned vehicles and public transit vehicles would yield greater overall benefits and would be more cost effective than alternative transportation system investments in the areas studied.
2. Dual-mode transit, as an integral part of a more general dual-mode transportation system and sharing a guideway facility with privately owned vehicles, is a more attractive and more economical solution to urban transit needs than are various forms of bus rapid transit and conventional transit systems.

Insufficient study has been given to the evaluation of dual-mode transit "on its own," that is, when not part of an overall dual-mode transportation system. The limited study findings available suggest, however, that the advantages of such a system would be marginal, at best, in comparison with alternative public transit system designs.

TECHNOLOGICAL STATUS

If dual-mode transportation is considered so favorably, why does it not now exist? One answer, of course, is that additional research and development are required to develop automated equipment of proven safety and to choose among alternative technical approaches to network, guideway, and vehicle design. A cross-sectional report on the current state of technology of dual-mode transportation was given through technical sessions in the following areas: command, control, and communications; vehicle lateral control (e.g., steering); vehicle longitudinal control (speed and spacing); propulsion and energy; guideway design; station planning and design; reliability and maintainability; and capacity and safety.

It is not possible to summarize here the findings of each of these technical sessions. Summaries of individual papers are provided in these conference proceedings. However, the following general comments can be made. A variety of dual-mode concepts exist. System concepts based on dual-mode vehicles and on pallet transporters have been investigated to the point that little doubt is expressed as to their technical feasibility. A range of feasible alternatives also exist with regard to overall network traffic control, vehicle lateral and longitudinal control, propulsion, guideway and station design, and so on. The engineering problems that remain, broadly speaking, include these:

1. Choice among candidate system configurations (the reason it is necessary to select a single configuration is explained in the next section on institutional considerations);
2. Choice among alternative subsystem technologies;
3. Design and development of experimental equipment and facilities;
4. Systems analyses, including reliability, failure modes and effects, and system performance and safety; and
5. Experimental test of systems and subsystems.

The status reports given on dual-mode transit concept developments by the Urban Mass Transportation Administration (UMTA) and industrial contractors outline three alternative system configurations. Each appears to be technically feasible. Each contractor (General Motors, Rohr, and Transportation Technology) has provided UMTA with technical and cost proposals that include development and field test of experimental systems. Thus, remaining technical problems appear to be amenable to engineering solutions.

The requirements for general dual-mode transportation systems are essentially similar to those faced for dual-mode transit inasmuch as the UMTA dual-mode transit program philosophy was for a growth capacity to accommodate the heavier traffic volumes of general dual-mode transportation. However, the variety of off-guide environments poses special requirements for reliability and maintainability of private dual-mode vehicles.

INSTITUTIONAL CONSIDERATIONS

Institutional barriers must be overcome in the implementation of any new public system. Included in the institutional barriers are technological uncertainty, financial risk, institutional inertia, restrictive laws and union work rules, and sometimes the need to develop new institutional forms for system implementation or operation.

The nature of dual-mode transportation is such that each of these institutional problems is magnified: e.g., technological uncertainty and financial risk are both greater. Additional problems arise relative to the establishment of national and international standards, liability in the event of accidents, and evolutionary implementation strategies. The relation of these institutional problems to dual-mode transportation development program strategy is discussed in the next section.

Also relevant to institutional factors are the various papers included in later sections on user considerations (including the results of public attitudinal surveys), guideway design, station planning and design (including aesthetic factors and land requirements), and propulsion and energy (including air quality and fuel consumption considerations). In addition to the papers summarized in these proceedings, reference should be made to the technical literature on automated highways, which contains a number of papers on strategies for implementation of automated transportation systems, particularly a paper by Breuning (2).

PERSPECTIVE ON DUAL-MODE TRANSPORTATION

The results of analytical case studies of dual-mode transportation by various government and industry research groups have been in agreement on the potential benefits that should be expected from the development and implementation of dual-mode transportation systems. In particular, overall dual-mode transportation facilities, accommodating a variety of dual-mode vehicle types—private automobiles, small trucks, and other private vehicles as well as public transit vehicles—are, in my opinion, the optimum choice among various urban transportation system alternatives relative to user and environmental benefits.

Also, case studies of dual-mode transit service that shares a common guideway facility with private dual-mode vehicles have shown that such service is more attractive and cost effective than various bus rapid transit concepts including manually controlled buses on freeways or on exclusive busways. However, insufficient study has been done on dual-mode transit that does not share common guideway facilities with other dual-mode vehicles. There is no evidence on which to base a conclusion that dual-mode transit on its own should be a more desirable and efficient mode than other automated guideway transit systems with dial-a-ride feeder service.

Accordingly, one would be tempted to suppose that high priority in government and industry research and development would be given to general purpose dual-mode transportation. Such, however, is not the case. The level of research and development effort on dual-mode transportation is quite modest and is concentrated on dual-mode transit. The dual-mode transit effort is part of a common automated guideway technology research and development program even though it is not clear that there should be more than just a limited commonality between subsystems for dual-mode transit and personal or group rapid transit.

It is important to try to understand the seeming discrepancy between the promise of dual-mode transportation and the limited dual-mode transit research and development. Part of the explanation relates to the special nature of dual-mode transportation and the institutional challenges it faces. The following factors are among those that need to be considered.

1. A dual-mode transportation system would be a major component in the overall transportation system of an urban area. It would be used for a significant percentage of total urban travel by private automobiles, trucks, and other dual-mode vehicles as well as public transit.
2. Implementation of a dual-mode transportation system in urban areas would involve investments of public funds possibly comparable in scale to those invested in urban freeways. The guideway facilities would likely require use of existing publicly owned transportation rights-of-way and additional land acquisition.
3. A high level of technology is required for dual-mode transportation because of the variety of guideway and vehicle controls required for safe and efficient operation of a multiplicity of vehicles over a guideway network, and because of the high degree of reliability required of individual vehicles and control subsystem components. Although such capabilities are considered technically feasible, a significant level of research and development is required to produce operational equipment.
4. Unlike public transit systems that can vary widely in configuration and technology from one urban area to another (for example, differing rail gauges or electric power supply characteristics for rail transit systems), all dual-mode facilities and vehicles should be or perhaps must be functionally compatible. This is because of the economic need that dual-mode vehicles be mass produced and because of the desirability of being able to operate a dual-mode vehicle on the guideways of more than a single urban area.
5. Liability for accidents in dual-mode transportation

may require an appropriate new institutional mechanism for insurance or compensation. In present highway practice, drivers are individually responsible; in rail transit practice, a public authority or a corporation owns both the vehicles and the railway facility and bears responsibility. In dual-mode transportation, vehicles may be privately owned but subject to guideway control, raising questions as to identifying responsibility for accidents and specifying vehicle maintenance requirements.

6. The process of dual-mode transportation system implementation needs to be thoughtfully conceived to permit orderly technical evolution and to ensure social and political acceptance. As part of this, one must avoid the chicken-and-egg problem: individuals not purchasing dual-mode vehicles because insufficient kilometers of guideways exist, and communities not building guideways because too few vehicles are available to use them. In addition, one must assure equity and justice in the distribution of costs and benefits of guideway implementation; e.g., the facilities should not be useful only to the affluent, who might be able to afford a more costly dual-mode automobile. For example, an advantage that may be cited for a pallet transporter configuration is that it might be immediately usable by a wide variety of conventional vehicles.

Such institutional considerations have influenced the course of dual-mode transportation system development. In the United States, this course has evolved to where the direction and funding of dual-mode transportation research and development are through the federal agency that is concerned with urban public transit.

First of all, it should be noted that dual-mode transportation facilities would be much like highways or railways, requiring continuous exclusive rights-of-way. The right-of-way requirements for the dual-mode guideway would probably be satisfied in part by joint use of existing public rights-of-way such as freeways, in part through air rights above other public rights-of-way and railway easements, and in part by acquisition of land for new rights-of-way, stations, and entry-exit facilities. Because of the extensive use of public rights-of-way and acquisition of new land, it is most reasonable to assume that such guideways can be built only as public facilities. At present, comparable facilities like freeways and rail rapid transit are built by local or regional transportation agencies with federal funding support.

In addition, functional commonality in dual-mode transportation is needed. Any dual-mode vehicle should be able to operate on any dual-mode guideway and not be restricted to use in one particular region. A private industrial company should not be expected to assume the technical burden and financial risk of overall system research and development. Instead, some feel it is desirable that overall system design be pursued by government. Because of the need for at least national commonality and because of present policies on transportation facility funding, this means the federal government and, in particular, the U.S. Department of Transportation. That agency should then establish overall functional specifications for vehicle and guideway performance and technical interfaces. Individual industrial companies could develop proprietary designs of vehicles and other subsystems that are compatible with the functional specifications but that may be proprietary in design. The federal government can also act as an agency in the possible establishment of international specifications.

If dual-mode transportation research and development are the responsibility of the federal government agency, it is not difficult to understand why priority is established for the public transit component of dual-mode transportation. The technical and financial investment required for dual-mode transportation is high, and prudent public administrators need to seek a way to minimize risk. Technical uncertainty for dual-mode transit is less than for general dual-mode transportation (e.g., the headway control requirements for the former are less severe since dual-mode transit would be only one component of total dual-mode transportation demand). Also, the costs of mounting a technical demonstration program could be reduced by concentration on one aspect of the overall system requirement. Moreover, public administrators may feel more comfortable in giving first priority in the allocation of public funds to those aspects of dual-mode transportation that relate to public transportation rather than to those that relate to general dual-mode vehicle usage and that would result in benefits to private automobile users.

In any event, the most common plan for dual-mode transportation development is an evolutionary sequence involving the development and demonstration of a dual-mode transit system that has growth potential for evolving into a full-blown dual-mode transportation system. Therefore, it is not surprising that within the U.S. Department of Transportation the responsibility for research and development of dual-mode technology is lodged principally within the Urban Mass Transportation Administration.

Within UMTA, as in other government agencies, public officials are inevitably faced with conflicting pressures for fund allocation: for the maintenance of existing transit systems and the proliferation of existing technology versus the development of new systems; in the pursuit of "gradualism" versus "innovation" in transportation improvements (6); and in the allocation to dual-mode transit versus other new systems of those funds that are deemed appropriate for research and development. To make best use of the limited funds available for transit research and development, dual-mode transit research and development have been coordinated with similar activities for personal rapid transit and other new systems under a common automated guideway technology (AGT) research and development program. Within the foreseeable future, it is likely that advances in dual-mode transportation technology will be dependent on the UMTA AGT program.

SUPPLEMENTARY APPROACH TO THE EVALUATION OF DUAL-MODE TRANSPORTATION IN URBAN AREAS

These conference proceedings include summary reports on and references to a number of analytical case studies of dual-mode transportation in various urban applications. The consensus of these studies is that important and widespread benefits would result from the development and implementation of dual-mode transportation. Dual-mode transportation facilities would provide for a wide range of travel needs in large urban areas, including the accommodation of person trips by private automobiles and public transit and the movement of goods. Dual-mode transportation should, therefore, be further evaluated for its potential use in meeting future urban transportation requirements. The evaluation should be done within the context of comprehensive urban transportation planning and by extension of the current techniques of urban highway system planning.

Some previous case studies of dual-mode transportation by general systems analysis groups have an abstract space-age quality about them; further study within the context of conventional planning methods should produce further insights into the advantages and limitations of dual-mode transportation in a real-world framework that is more credible to public officials. Additional work may be identified that might be undertaken by various agencies in the U.S. Department of Transportation to supplement the current dual-mode transit activities under the automated guideway technology research and development program of the Urban Mass Transportation Administration.

An approach to such further analysis and evaluation of dual-mode transportation is suggested below. It is based on some elementary work by the author on the extension of highway functional classification theory as a tool in the analysis of new systems of urban transportation.

The arguments for and against dual-mode transportation can be treated in a theoretic framework akin to the functional classification of roadways. Highway functional classification methods are extensively used in the traffic engineering discipline. A hierarchy of functional classifications is defined, beginning with freeways and other limited-access expressways and proceeding through major and minor arterials to collector streets and local access streets (Table 1). At the freeway-arterial end of the spectrum, the principal function is to move large volumes of traffic smoothly, swiftly, and safely. The principal function of local access streets, or capillary roadways, is land access rather than traffic handling. Roadways of intermediate functional classifications are intermediate in regard to their geographic separation, the volumes and speeds of vehicle flow, and the separation of allowable entry-exit points. Through functional classification, an orderly structure of major and minor roadways may be defined for a community, geometric design specifications may be set for each roadway type, and harmony may be fostered between highway planning and access to land use activities.

The freeway has been a major roadway innovation during the last 2 decades. It is clearly distinct from lower functional classifications of roadways in regard to lane capacities and safe operating speeds. This is partially a result of geometric design—lane widths, grades, curvature, sight lines—and of the separation between interchanges—typically spaced about 3 km (2 miles) in suburban areas or equal to the geographic spacing of major surface arterials and more closely spaced in central areas. Only a limited range of traffic types and speeds are permitted—no pedestrians, only automotive vehicles (e.g., automobiles, trucks, buses, certain motorcycles)—and minimum and maximum speeds are defined. Traffic flow is intended to be uninterrupted not only along the roadway but also at entrance and exit ramps.

Guideway facilities for dual-mode transportation can be defined, analyzed, and evaluated in the framework of highway functional classification. The automated roadway (or transporter facility) can constitute a new functional classification above that of the urban freeway. Then, almost in a "checklist" fashion one may ask: Are the performance objectives of the dual-mode facility appropriately established? Is the capacity suitably above that of the freeway? Is this greater capacity achieved at a higher effective speed? Are the expected rates of accidents significantly lower? One may also infer the appropriateness of various design and operational factors: limitation of vehicle types to specifically equipped dual-mode vehicles (or transporters) and no intrusion by conventional vehicles; strict regulation of vehicle speeds (e.g., synchronous control); and access possibly at widely separated points (e.g., 10 km or 6 miles) in outlying areas, perhaps directly from intersecting freeways.

There are reasonably well-developed methodologies that have evolved during the last quarter of a century for the planning of regional highway networks and for resource allocation among the various highway functional classifications. With such methods, one determines whether a freeway is required within a smaller urban area (other than for intercity purposes) and what the proper extent and form of freeway networks should be in larger urban areas. These methods should be extended to include an additional functional class of roadways corresponding to the automated highway function of dual-mode transportation, and appropriate parameters—capacity functions, operating speeds, and unit construction and maintenance costs—should be assigned in an analogous manner to that of current functional classes. This extended methodology could be employed to evaluate the potential utility of dual-mode transportation facilities in medium-sized metropolitan areas and the desired extent and form of dual-mode networks in the largest urban areas.

The principal orientation of such further evaluation studies should be to move the dual-mode transportation concept closer to the process of serious planning of future investment in urban transportation facilities. When and if dual-mode transportation sheds its "Buck Rogers" image and is viewed by local planners as a needed and useful component of urban transportation systems, a more adequate level of system development effort is likely to ensue.

EVALUATION OF DUAL-MODE TRANSIT

An equivalent theory to that of functional classification of highway facilities has not yet been adequately developed for the functional classification of public transit facilities (i.e., transit ways) and services. However, one may attempt to define a hierarchy of transit ways topped by urban fast transit links such as modern rail rapid transit facilities. Somewhere below, one can define a number of functional classifications for bus transit roadways, in a one-to-one correspondence with conventional highway facilities, from freeways down to local streets (Figure 2). Automated guideways for dual-mode transit, personal rapid transit or group rapid transit, and exclusive busway facilities would occupy a functional classification level intermediate between the rail rapid transit facility and the freeway.

In this context, one may examine various public transportation modes relative to the functional levels of roadway types over which they operate. Traditional urban bus service has been restricted to arterial streets. When urban areas were smaller and more dense, a network of bus routes along arterial streets sufficed to provide transit accessibility throughout the area. As metropolitan areas expanded and became less dense, the geographic separation between arterial streets increased so that a smaller fraction of the total area is within convenient walking distance of possible bus services along such arterials. In addition, the length of such arterials has increased, resulting in extended travel times along bus routes between suburban areas and central cities and in increased bus operating costs. These factors have contributed to the general decline in transit ridership in the United States during the 2 decades between 1950 and 1970.

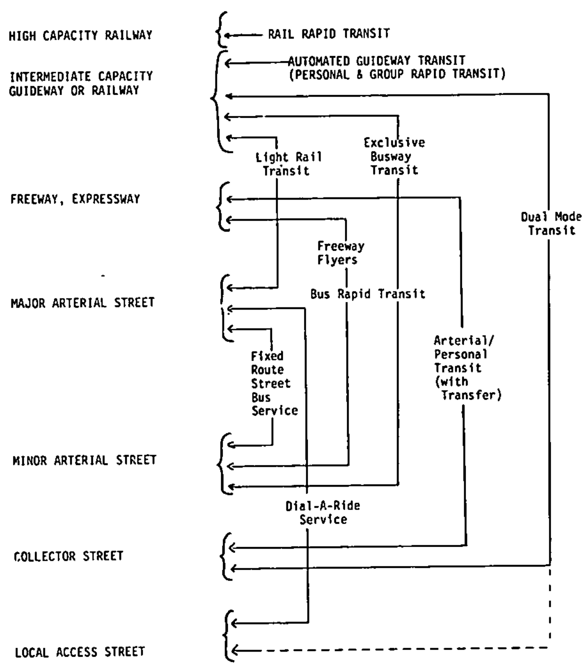
Innovations in bus transit systems that have been finding increasing favor include bus rapid transit, dial-a-ride, and combinations of dial-a-ride with arterial and express services. These are shown in transitway functional classification terms as in Figure 2. Bus rapid transit operates over a number of functional classifications of facilities ranging upward from arterial streets and including various limited-access roadways, the former for passenger collection and distribution and the

Table 1. Example of highway functional classification.

Functional Class	Functional Characteristics
Dual-mode guideway (automated roadway)	Increasing emphasis on traffic functions (capacity, speed)
Freeway	
Expressway	
Major arterial street	
Minor arterial street	
Collector street	
Local access street	Increasing emphasis on land access functions

Note: With the exception of the dual-mode guideway functional class, the above breakdown is typical of functional classifications previously described by organizations such as AASHTO, ASF, ASPO, FHWA, and NCOT and by several transportation planners, each using somewhat different nomenclature.

Figure 2. Examples of transit service coverage by transitway functional classification.



latter for long-haul service to urban centers (this is considered by some to be a form of dual-mode transit service). In contrast, dial-a-ride service extends over a range of functional classifications downward from major arterials and includes minor arterials, collector streets, and local streets to provide essentially door-front service in many areas. (Some dial-a-ride systems do not provide service in cul-de-sacs and other streets below the collector street functional level.) A number of areawide arterial-personal transit systems are planned for areas such as Orange County, California, and Rochester, New York. These combine fixed-route scheduled bus service on major arterial streets with demand-responsive bus services permeating the capillaries of the street network and have appropriate means to ensure convenience of transfer.

In a number of communities including Bay Ridges, Ontario, dial-a-ride systems or local bus services provide access to rail rapid transit facilities. The present intention is that similar means of access will be provided to various planned intermediate capacity transit systems including automated guideways for personal rapid transit or group rapid transit and various forms of light rail transit.

In this context, dual-mode transit is a bold service concept that spans a broad range of several roadway functional classifications from the automated guideway to the collector streets or local street level. The potential user may be pleased with this proposed service, as the results given in the papers by Costantino, Dobson, and Canty and by Wachs indicate. Users may perceive that a personalized rapid transit system is in effect being brought to their doorsteps upon their commands. However, one needs to consider whether the potential benefits derivable from obviating the need for the transfer are justified.

A formidable competitor is the combination of dial-a-ride service and fixed-guideway service whether of the group rapid transit or rail transit type. The question may hinge on whether the specialization of separate vehicle functions for guideway service and for dial-a-ride service may enable performance improvements and service economies that outweigh the convenience of no-transfer service. This subject may be important enough to warrant appropriate study. My view is that it seems highly probable that such specialization of functions should indeed enable significant performance improvements and service economies over dual-mode transit and that the inconvenience of transfer can be minimized by proper facility design.

If such were so, and if all other things were equal, dual-mode transit would not appear to be a viable competitor to other public transit systems involving a combination of local bus service and fixed guideway service. However, all other things may not be equal. In particular, if a general purpose dual-mode transportation facility exists in a community, dual-mode transit service could be implemented at minimum cost as contrasted with costs of other types of fixed guideway transit service requiring specialized facilities.

In conclusion, the variability of dual-mode transit, in my opinion, depends on the viability of more general dual-mode transportation facilities and services. Dual-mode transit possibly is not the best choice all on its own but is an attractive component of an overall dual-mode transportation system. The potential benefits of dual-mode transportation for general transportation purposes, including automobile, small truck, and service vehicle, and for public transit will determine whether dual-mode transportation facilities have a useful role in the overall highway system and in which urban areas. That in turn will likely determine the scope of application of dual-mode transit.

Dual-mode transportation is that broad category of systems in which vehicles may be operated in both of two modes: (a) manually controlled and self-propelled on ordinary streets and roadways and (b) automatically controlled or externally propelled or both on special guideways. In general, dual-mode transportation includes the use of both public (i.e., common carrier) and private vehicles and provides for the transport of both persons and freight. Dual-mode transit is a special case of dual-mode transportation, providing only for passenger transport via public vehicles. Thus, a typical dual-mode transit system has suitably designed small omnibuses that are operated by drivers on ordinary streets for passenger collection and distribution off the guideway in outlying areas and that are either automatically controlled or carried aboard special transporters for operation between stations on the guideway, including access to central parts of metropolitan areas.

Of the variety of dual-mode transportation concepts described, a number have been investigated to the point where little doubt is expressed as to their technical feasibility. Technical problems remain and need to be resolved, as do choices among alternative technological configurations. However, such technical problems are judged to be amenable to engineering solution within the current state of the art. Dual-mode transportation facilities may present a physical and aesthetic intrusion into the urban environment, but the adverse environmental impact of such facilities is likely to be less than that of expanded highway facilities that might otherwise be necessary and can be minimized by effective use of existing transportation rights-of-way. The results of a number of case studies show that dual-mode transportation would be a superior solution to a broad range of urban transportation requirements.

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