REPORT OF THE PANEL ON OPERATIONS AND TECHNOLOGY

Prepared for
the Office of Technology Assessment

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Summary

The primary purpose of the Operations and Technology Panel is to determine the technological development requirements for the systems considered in the report-Shuttles and Loops, Group Rapid Transit Systems, and Personal Rapid Transit. The fulfilling of this purpose is relatively straightforward once the potential a placations and the operational service characteristics have been de fined. This is not to say that the solutions to these technological requirements will be easy or inexpensive to obtain but rather that the technology cannot be separated from the social and economic considerations that determine the applicability of these systems. The basic issues center about the need and applicability of some of the concepts.

MAJOR FINDINGS

The panel arrived at several major findings that reflect the view of the entire panel.

The Group Rapid Transit Concept.—This concept is exemplified by the moderate headway (15 sec. or more), intermediate-sized vehicle (15 pass. or more) which can provide a technologically feasible and useful transit service in the capacity range between buses and rail rapid transit both in the line-haul mode of service and in the collection and distribution mode. Several of these group systems are in prototype operation and the basic needs are to bring the full automation to operational status and for product improvement in terms of reliability, performance, and cost and weight reduction of the vehicles and guideway. A small-scale urban installation of an improved system is absolutely necessary to establish design and performance standards, cost data, and the size of the potential market. Because of the uncertainty regarding the market and the substantial funding required for final development and demonstration, it will not be possible for a specific communit~- or organization to undertake such an effort without federal financial assistance. Rather, the urban installation and production engineering will require a mechanism by which the federal government can provide partial funding for these activities. The technical study and capital grant programs may be able to serve as a vehicle for such funding. Details regarding the develo~ment requirements for these systems are provided in the text of this report.

The Development of a Technological Baseline.—The Group Rapid Transit Concept needs such a baseline which should be pursued along with the initial staging of a federally owned test facility. Such a baseline can provide technical data on performance, cost, reliability, and safety characteristics which can be used to formulate specifications for deployable s wtems; can aid in identifying and examining the performance ancl cost trade-offs; and can permit the options in operational mode to be examined. The proposed UMTA HPPRT program can be reoriented to provide this development to support and ~ermit ex ansion of initial simple de loyments of Group Ra id Transit technof' ogy as advocated under#inding No. 1. The HP$RT program with proper orientation can also provide the test facility for continued development and testing of various automated transit systems and their components. System-level improvements, es ecially in automatic control performance and overall system rel' iability, are essential if initial installations are to expand to a meaningful role in urban transit.

In addition, a program should be pursued for the development of critical components and subsystems common to all systems. This activity can support the above effort and can be encompassed by the Automated Guidewa Technology program proposed by UMTA.

The Personal RapJ' , Transit Conce t.—As defined in this study, the concept a proximate most closely t E service provided by the automobile. l+'owever, the long-term development requirements, the economic viability, the intensive nature of a fine grid network, and the difficulty of introduction of such systems into an urban area resulted in skepticism on the part of the panel regarding the eventual development of these systems. However, the placing of major constraints upon automobile use in urban areas may provide an incentive for the development of these and other automated systems. The majority of the anel feels that the case for or against the Personal Rapid Transit ~ystems has not been adequately established and limited funding is justified to more fully clarify the advantages and disadvantages of this concept. One of the panel members feels that there are no conceivable conditions under which this conce t would find a significant role in transportation and recommends no k &D funding for this concept. Details are provided in the text.

Interaction by the Federal Government.—The Federal Government should interact more strongly with transit authorities in urban areas to consolidate and define the ublic transit needs of these areas in order to better determine the test methods of ap@ication for automated vehicle transit systems. This type of interaction is already present to some degree in the categories of rail and bus transit systems. It should be implemented even more vigorously with regard to automated vehicle systems so that an understanding can be obtained of the most economic spectrum of modes required to satisfy the real needs of our urban communities.

COMMON DEVELOPMENT REQUIREMENTS

Regardless of the system considered, there are certain common roblems which differ only in the degree of development required?' hese include:

Automation.-The development of fully automated transit systems will require a substantial develo~ment effort directed toward improving the performance and reliabihty of certain critical subsystems and ~arameters. These include substantial improvements in the reliability of the wayside and vehicle control systems, in communications (especially between vehicle and wayside), and in the data processing equipment. The development of software techniques to manage the vehicle fleet are required and will probably be the pacing item in the introduction of systems employing demand-actuated operation. Insufficient attention has been devoted to the methods for managing system failures and of introducing methods to keep the system operational in the event of failure. Furthermore, the improvement of methods of detecting or removing foreign objects on the guideway which may affect safe operation is required.

As the headway$ are reduced, the complexity of the system and the need for components and subsystems with improved performance and accuracy is required, Specifically, a substantial reduction in headway below 15 seconds will require Improved vehicle detection techniques, faster responding equipment, increased accuracy in speed and position control, and, eventually, the de~~elopment of a controlled deceleration profile braking s~'stem.

l?eZiaWity.-The need to improve the reliability of automated guideway systems is beyond question. The development of better reliability will require improved definition of the s~'~tem reliability goals necessary for public acceptance of the system, Improvements to the critical subsystems and components to reduce failure rates, and the development of techniques to minimize the time to restore service in the event of a failure.

There exists a need to establish a data bank on the reliability of transit system components and to develop procedures and models that permit a common basis for obtaining reasonably accurate estimates of system reliability. Such procedures are necessary to permit the development of reasonable specifications and to identify the subsystems and components for which improvements in reliability are cost effective.

Guideway Cost and Intrusion.-Since guideways represent a substantial portion (5o~0 to 7o~c) of the investment costs for all of these automated systems and also a major obstacle to public acceptance, a successful effort to reduce the cost and intrusiveness of the guideway can have an immediate impact on the successful deployment of these systems. Such an effort would require work on the design, materials, fabrications, and methods for erection of such guideways, on the minimum design requirements to meet ride qllality standards, on the vehicle support and suspension technologies that produce the least expensive and minimum size guideway, and on the techniques for ice and snow removal and for passenger evacuation from a stranded vehicle.

System Integration.—The development of reliable high performance component or subs~wtem does not insure that this item will operate as designed in a transit system unless the entire system design is carefully controlled with specific design objectives and with an understanding of the interactions between the various subsystems. This process called system integration generally represents about 10~o to 15~c of the system development and investment costs but is critical to obtaining satisfactory performance of the transit system. The system integration process requires that careful control be exercised over the system design to insure that design goals are being met and that the trade-offs in s~.stem performance are being examined. Such a process requires constructing and exercising computer simulations of the system and the extensive testing of the components and subsystems individually and then in the system as a whole.

Test Facility.—The well publicized failures of attempts to concurrently develop and implement a complex automated transit system are indicative of the risk of attempting to bypass the prototype develo - ment stage and of insufficient attention to carrying out a carefully planned test program free of the demands of revenue operation. To minimize these roblems and to provide a common basis for the develo~rnent of t[ese systems, a federally owned and operated test facihty is suggested; the facility being located at a permanent site to permit long-term development and testing. Such a facility would be available for:

- Testing critical aspects of system design.
- Estabhshing design and operational standards.
- Testing differing design approaches and components for comparison with standards.
- Testing verification of integrated automatic control systems, operational performance and reliability.
- Identifying and defining engineering trade-offs.
- Limited ~{check-out" of systems prior to urban deployment.

With proper reorientation, the HPPRT program can provide the initial stage of such a facility. It will be necessary to include as a design requirement for this facility the need to provide sufficient flexibility to permit the testing and development of alternative subsystems and components either separately or together.

The development requirements for the systems considered are given below:

1. tVLUttZe *and Loop* Systems,—Are essentially developed and available for limited operation in urban areas although the full potential of these systems has not been explored or exploited for urban transportation. The systems require product improvement and production engineering, especially in reliability, prior to urban deployment. However, the lower level of sophistication and previous experience with these systems suggest that these requirements do not pose a significant technical risk.

2. *Group Rapid Transit in the moderate headwuy* **jorm.-Can be** considered to be in the engineering development state, i.e., the feasibility of the concept has been demonstrated but significant effort is required to improve the product and to undertake production of the system. The major development requirements are given in Chapter 5 and include improvements in reliability especially of the automated control, computer software develo ment for managing the system, cost and weight reduction of vehicfes and guideways, and of methods for detecting or removing obstacles.

The initial requirements are related to the development of full automation of the systems which requires two basic characteristics: physical guidance of the vehicle and full control of the right-of-way. Neither of these requirements are related to any specific uideway or vehicle support technology. In fact, the support and gui%eway technologies require a closer examination of their impact on guideway s]ze, cost, and on the needs for lateral guidance and switching to define their applicability and potential.

3. *Group Rapid Transit in the short headway form.*—Currently under development in the UMTA HPPRT Pro ram. The concept 1s based upon the use of smaller vehicles and imp\icitly smaller guldeways to

reduce the intrusive nature of the guideways and to make them more acceptable to the community. Operation at shorter headways should permit line capacity growth and more frequent service to the diverse destinations typical of urban travel and should result in increased system patronage; the smaller vehicle requirement being the result of increased frequency cf service and an increase in the number of destinations. At peak demand periods, the system could be operated in a scheduled manner with the smaller vehicles coupled into trains. There exists, however, a considerable body of opinion that feels that the economics of such systems may be unacceptable to the community and that the increased service may be more apparent than real, i.e., that comparison of passenger travel times, for instance, a~ provided by these systems or the longer headway Group Rapid Transit Systems would be about equal. This opinion group feels that further develo - ment of these systems requires clarification of "the potential app ri-cations'' and an examination of the 'fsafety and economics. "

As already discussed in Finding Number 2 the panel suggests that the priorities of the HPPRT program be directed toward establishing of a technological baseline with emphasis upon reducing system capital and operating cost and upon increasing system reliability. A long-term goal can be that of determining the extent to which the state-of-the-art of Group Rapid Transit Systems can be advanced while still adhering to the conventional safety standards.

Development of the advanced group concept will require a test facility for integrated system protot~"pe testing with specific attention to improving the responsiveness and accuracy of the longitudinal control s)-stem and to the development of a controlled deceleration braking system to replace the currently employed fixed force emergency braking.

4. *Personal Rapid Transit Systems.*—Have been discussed previously. The development requirements for these systems include establishing the basic system requirements in terms of performance, cost, reliability, service and development objectives. These requirements include demonstrating the essential feasibility of the lon itudinal control system for short headway operation and of the vehicfe design to permit controlled collisions.

In conclusion, the panel wishes again to emphasize that the technological requirements of a system cannot be separated from the economic and social considerations and that the priorities in development must be established by need. However, needs and requirements are often based upon available technology and are known to change drastically with time. For these reasons, the priorities that are established by identifiable and immediate needs should not be so narrowly defined so as to preclude the capability to investigate alternative procedures which may be needed to satisfy future requirements.

Chapter 1: Introduction

At the request of the Senate Appropriations Committee, the Office of Technology Assessment (OTA) is examining the potential urban transportation role 'of small-to-moderate size vehicles that operate under automatic control on exclusive guideways; these systems often being misnomered as "PRT's".[1] The purpose of this assessment is to determine if these systems can provide sufficiently improved service and life cycle costs compared to conventional transit systems to warrant continuing development, to identify the development and implementation requirements, and to establish the needs and priorities for development.

To aid in this assessment, OTA formed several panels to consider various aspects of these systems. One of these panels is concerned with operations and technology. This report covers the work of that panel.

The Operations and Technology (O & T) Panel in the conduct of this work considered:

- The potential urban applications of these systems as related to the level of service offered to the passengers and to the operational modes available.
- The capability of these systems to offer these services in comparison with current systems.
- The development requirements and specific issues concerning the development and implementation of these systems.
- The priorities for development of these systems based upon **identifiable needs.**

It is not possible to separate the technology requirements from the social and economic aspects of these systems. As a result, the panel was required to make judgments on the applicability of the systems based upon social and economic considerations and then to apply these judgments to the operational and technological requirements. This report reflects the views of the panel members regarding all of these considerations.

Panel Membership and Procedures

The panel membership was chosen not only on the basis of technical knowledge of the systems but also to reflect the viewpoint of different interest groups—system suppliers, consultants, transit operating agencies, and academics. The panel membership, their affiliation, and a brief biographical note on each member are given in Appendix A.

The panel members performed this work for OTA over a period of 10 weeks while attending to their regular duties. The Chairman met with individual panel members on several occasions and also discussed specific points b~~ telephone. Four of the panel members attended the briefing by UMTA officials on January 31, 1975. The full panel met only once for a two-da~' session on February 18 and 19, 1975, to formulate and discuss the primary issues.

[1] The term "PRT" in this report is specifically reserved for the class of systems called Personal Rapid Transit as defined in Chapter 3.

The panel's initial efforts were devoted to classifying automated guideway transit systems and to formulating a questionnaire to solicit various viev~points regarding these systems. The classification scheme is described in Chapter 3.

The questionnaire (Appendix B) was concerned with the principal issue of whether the use of exclusive rights-of-way, automation, and small-to-moderate sized vehicle transit systems can provide sufficient)' improvecl service and life cycle costs compared to conventional transit to warrant their continued development. The questionnaire was sent to approximately' 50 individuals and organizations. The responses listed in Appenclix C are on file at the ()TA office in Washington, D.C, No attempt has been made to correlate the various responses; ratl~w, they were usec] by the individual panel members as an aid in assessing the various viewpoints regarding the development of these automated systems.

Further, various individuals with specific technical knowledge of these systems were invited to participate in the discussions during the February 18 meeting of the panel. These individuals and their affiliation are given in Appendix D. The panel wishes to acknowledge the contribution of these individuals to the work of the panel.

The meeting on February 19 was attended onl~'. by panel members. The purpose of this meeting was to define the prlmary issues and to formulate the views expressed in this report.

SYSTEM CLASSIFICATION AND MODES OF OPERATION

The automated guideway svstems were classified according to the operational complexity' (and, implicitl)', technological complexity and according to the vehicle occupancy: characteristics, i.e., whether the vehicle is occupied by. multiple individuals or parties simultaneously (as in a bus) or by. a single individual or related party (as in an automobile). This classification scheme (Table 1) is identical to the scheme used by the other panels except that the technoloqy assessment required the system characteristics to be more explicty~' defined. Further the Group Rapid Transit concept was separated into two categories to reflect the differences in operational and technological cornplexit~- between the two categories of the Group Rapid Transit concept. system clescriptions are given in Table 1 ancl covered in more detail in Chapter 3. In general, as the vehicles considered for the various systems decrease in size, the service becomes more personalized and more complex to provide, especially in terms of the level of automation.

The classification scheme does assume certain operational and service characteristics and, implicitly, certain types of applications but it does not assume specific technologies. For example, any of the systems can use steel wheel-on-rail, rubber-tires, air-cushions, or magnetic levitation. This is not to say that such considerations are not important. The eventual capability of these system concepts to provide the service expected at minimum cost will be strongly dependent upon the technologies chosen for the various subsystems. It is incumbent upon the system designer to examine the subsystem technologies available and to choose these technologies to prowcle the best overall performance for the system.

operation of these systems can be either scheduled or demand-actuated. The schedule mode provides service over predetermined routes following a predeterrrlinecl timetable with the passenger expected to time his arrival inlrnediatelJ' prior to the vehicle arrival or with the frequencl- of service being sufficiently high so that the]Jassenger waiting ~ime is short. Demand-actuated o~)eration, on the other hand, provides a space or vehicle to a passenger in response to a specific request for service with the passenger waiting time being (lepen(]ent llpon the availabilit~- of vehicles to that station. In the multiple partjr occllpancj' case, the waiting time is dependent upon the availabilit~' of a space aboard an approaching vehicle which can provide the necessar~- service.

The dependence of these operational mocles upon the various s~'stem configurations possible is discussed below:

~huft/e.-This tJ-pe of s~'stem serves moderate traffic density (several hundred passengers **per hour) operating between two points tvpica]l~' separated b~ a few hundred feet to a large fraction of a mile. A single vehicle or train is operated in both directions on the gui(lewa~-. .Sometimes pairs of guicleways and vehicles are used to increase capacit~- and reliability; a prime example being the Tampa Airport Shuttle system. Service can be scheduled or partially demand-act uated.**

On-Line Stop.—The stations in this configuration are located so that the vehicle stops on the main line. This configuration is best suited to 1arge vehicles (e.g., 40 to 100 passengers) or trains of vehicles. The vehicles generall~- operate in a scheduled mode and are typically programmed to stop at ever)- station on the line or to operate in a skip-stop mode (e.g., everl- other station or everj' third station, etc.). I.oading dwell times in combination with time allocations for acceleration, deceleration, and safe operating headw?~-s typically require the vehicles to operate at headwn~-s of one mmute or more. Demand actuation is not usuall?: appropriate. However, the number of trains or vehicles on line is a(i]ustecl to variations of demand up to a saturation level. Since onl~~ some lines are interconnected, transfers are usual!}- required. This configuration is emplo~"ed by most existing transit s~'stems. It would also appl~" to simple multi-stop shuttle and loop s~-stems ancl could be used at line-end stations for Group Rapid Transit systems.

Of-1ine Stops.—Passenger loading and unloading is done at stations located on sidinos connected to the main line. This configuration permits the vehic res to b~'pass intermediate stations and to operate from zone to zone or m express mode to meet trip time objectives with low to moderate line speeds. Schedules and operating modes would be adjusted to meet projected demands. Shorter headwa~'s are feasible thereby effecting potentiall~- much higher main line loadings than is the case with the on-line stop operation. Current headwal-s with off-line loading are limited to about 15 seconds minim(lm.

Off-line stations are t~'pical in proposed applications of Group Rapid Transit s~stems using medium sized vehicles. This allows serving of the collection, distribution, and line-haul functions of medium densit~' urban areas using interconnected lines and minimum transfers, The service would be primaril~" scheduled, however, demand-actuation may be appropriate in off-peak periods with the smaller Group Rapid Transit vehicles. Off-line loading is required in the Personal Rapid Transit class of systems.

In addition, a differentiation must be made between those systems which in general will require a passenger to transfer and those which provide direct origin-to-destination service. The latter service is designed to provide a passenger with a trip from a station near his origin to a station near his destination withcut transfer. This service is generally associated with demand-actuated operation and is primarily of interest to Personal Rapid Transit Systems but can be implemented to a limited degree in off-peak periods ~th the group transit concept. Even in these systems, a transfer wdl be required between the fixed guideway system and the flexible route portion (auto or bus). Transfers can also be an effective method of accommodating high demands while reducing, to some degree, capital cost requirements and simplifying control system requirements. Reasonable limits must be placed on the number of transfers any one passenger must make in order to maintain an acceptable level of service and to provide a hi h ridership incentive.

The current technologicalf state-of-the-art is also an input to anysuch examination of systems. The panel, in general, was well acquainted with the current status and this kno~~'ledge was enhanced by means of the questionnaire, by discussions with the people invited to attend the February 18 meeting, and by other contracts. No definition of the state-of-the-art will be provided in this report except as necessary to the discussion of specific problems. Rather, the reader is referred to the report of the Panel on Current System Developments.

Chapter 2: Potential Role of Automated Systems

The purpose of this section is to identify the urban transportation problems that can be effectively addressed by the various types of automated guideway systems. The urban transportation problem has many facets including traffic congestion, lack of mobility for certain groups, land use, energy and environmental impacts, capital and operating cost of publicly supported systems, level of service, and safety. The role of automated transit may be brought into focus by comparing its capabilities and disadvantages with the merits and weaknesses of the automobile and present modes of public transportation.

THE URBAN TRANSPORTATION PROBLEM

Congestion is obvious to anyone who must travel major arterial streets or freeways during commuter rush hours. This problem is probably what most people think of when they refer to the urban transportation problem. Less obvious to those with access to an automobile, but frustratingly real to the remainder of the population, is the lack of mobility in our auto-oriented cities if no car is available. Only half of the American population is licensed to drive. The remainder, comprising the young, the old, the poor and the handicapped must either rely upon a friend or family member with a license or make do with the present transit systems which are inadequate in many of our cities.

The energy and environmental impacts of transportation are also important. Transportation[1] accounts directly for approximately one-quarter of our annual energy consumption—in addition, approximately half again as much fuel is consumed indirectly for production and maintenance of vehicles, highways, fuels and facilities. The transportation segment of our energy consumption is especially significant because 96% of this segment requires petroleum-based fuels. Therefore, the development of transportation modes that are energy efficient and that are less petroleum dependent will be favorable to current efforts to conserve energy and to lessen the nation's dependence on foreign oil.

The adverse environmental impact of transportation is also well known. About seventy-five percent of our atmospheric pollutants are attributable to transportation. These emissions consist primarily of unburned hydrocarbons, carbon monoxide and oxides of nitrogen. Because pollution is concentrated in areas of high auto density, the diversion of auto use to public transit in some of these regions can be important in reducing emissions,

The cost of transportation, especially mass transportation, is high. Revenues from bus and rail systems are inadequate to cover replace-

1 Hirst, E., "Automobile Energy Requirements, " Transportation Engineering Journal of ASCE, Vol. 100, No. TE4, November 1974.

ment of capital equipment and are inadequate to meet operating costs. To halt the complete deterioration of our transit systems from a vicious cycle of increased fares, reduced patronage, less frequent schedules, further reduced patronage and further increased fares, capital grants and, more recenty-, operating subsidies have been provided. However, the economic condition can be most significantly improved by increasing labor productivity and by attracting more passengers—perhaps through increasing the level of service.

Level of service refers to the convenience, reliability, accessibility, frequency of service, speed and comfort offered by a transportation model. On this basis, most public transit compares poorly with the automobile. There are, however, two areas where the level of service of the automobile is rapidly declining, and these present natural opportunities for the application of public transportation. Congested commuter routes and the dowmtown areas of many of our cities are areas of opportunity for a public transit service that can provide lower trip times and reduce land use.

Finally, about one-third of the 50,000 automobile-related deaths in the U.S. occur in urban areas. Since the evidence now available indicates that public transportation is about 30 times safer on a per person-hour of exposure basis,[2] the potential saving in life and in money cannot be ignored in the cost-benefit equation for public transit.

ROLE OF AUTOMATED SYSTEM

The development of new transportation technology has been to some degree a part of an attempt to refocus technical effort from aerospace to civilian markets in response to cuts in defense and space budgets and shifts in what are perceived to be national priorities. This involvement of the aerospace companies has been desirable in that it has helped spark a technical renaissance in the transportation industry. However, there has been some tendency to view the transportation problem in isolation from concomitant problems of economics, finance, modal compatibility, politics, legal issues and community acceptance. As a result, systems have been proposed having institutional obstacles of such magnitude as to appear insurmountable. To avoid this pitfall, realistic markets for these systems must be identified and examined. Three such markets are discussed below.

The first potential market is already' being exploited. This market involves the use of simple shuttle and loop concepts as horizontal elevators for airports, shopping centers, remote parking areas, hospitals, and similar applications. There is evidence that such applications may be financially viable without federal assistance because of the increased architectural freedom and improved land use made possible. A developer may be willing to spend several million dollars to connect two activity centers with an automated system if such a connection permits budding on a less expensive and more suitable site and reduces construction disruption in the existing areas. The technology for such applications is proven with installations at airports in Tampa, Miami, Houston, Seattle-Tacoma and Hartford which are either operational or presently under construction. In addition, the Airtrans system at Dallas-Forth Worth has gone beyond demonstrating feasibility for

[3] Starr, Chauncey, "Social Benefit versus Technological Risk," Science, Vol. 165, No. 3899, Sept. 19, 1969,

simple shuttle and loop applications by operating (albeit with well publicized problems) a simple network with off-line stations and switching.

The second use for which automated systems have promise is to circulate people in downtown areas and major activity centers. These automated systems can increase the feasibility of auto-free zones while reducing pollution, saving energy, and enhancing the mobility and quality of life in the downtown areas. Such concepts can also reduce the disproportionate amount of valuable urban real estate devoted to parking, streets and automotive support functions.

The third market for automated sytems is that of intermediate capacity line-haul systems. The use of automation permits smaller vehicles which can provide more frequent service, especially during the off-peak hours. Such line-haul concepts do not offer a replacement for the automobile and are not expected to attract more than about 10% of the total trips in an urban area. However, these systems when designed to complement the automobile offer a number of significant benefits to the community".

These benefits include provision of reliable and efficient transportation for the young, aged, disabled poor and others without access to an automobile. The system should permit orderly land use development and should reduce and control the urban sprawl induced by sole dependence on the automobile. It may prove to be the missing tool to permit a development alternative to the high density eastern city served by subways on one hand and the low density western city served solely by the automobile. The line-haul automated system, concentrated as it is on major corridors, can be expected to provide relief to the taxpayer's major complaint-rush hour traffic congestion—and will also offer benefits in reduced pollution and energy consumption. In the event of a petroleum shortage, the line-haul system can represent a nonpetroleum dependent transportation backbone to assure continued commercial viability of the community.

The major economic incentive for all of the automated transit concepts is that of increased labor productivity. Studies [3] suggest that fully automated transit systems may have operating and maintenance costs of about 60¢ per vehicle-mile, about half that of buses and a third that of manned rapid transit. These lower costs make it possible to offer more frequent service in non-peak hours-providing a frequency of service sufficient to significantly increase ridership and service to the community.

COMPARISON WITH CURRENT CAPABILITIES

The decision on the implementation of an automated system must rest on a detailed comparison with current alternatives—automobile, bus, and rail transit—for the given application and site. Such an examination is beyond the scope of this panel. However, some general commentary on this comparison is appropriate and is given below.

AUTOMATED SYSTEMS AND THE AUTOMOBILE

In most respects, the automobile as a transportation mode is without peer. It offers demand service, has low labor costs since it is self-driven, and has low capital costs associated with highly sophisti-

[3] De Leuw Cather, et al., "Automated Small Vehicle Fixed Guideway Systems Study." Draft report prepared for Twin Cities Area Metropolitan Transit Commission.

cated mass production of a thoroughly proven design. But the automobile is by no means capable of performing all transportation functions better than other modes. The primary function of transit, then, is to complement the auto mode by doing well those tasks which the auto does most poorly.

The deficiencies of the auto mode are most evident on major traffic arteries in our urban areas. Here, attempts to move large numbers of commuters by automobile have been notoriously unsuccessful. The result has been traffic congestion, pollution and excess energy consumption. Attempts to meet the need with additional freeways have met with citizen opposition to the unreasonable land requirements for multi-lane freeways and the undesirable impact upon the quality of life.

In downtown areas, the concentration of heavy auto traffic into a small area destroys the human vitality which is essential to a metropolitan area, interferes with commerce, and prevents effective human interaction. Excessive land use is devoted to parking and auto service functions. The prevalence of off-street parking prevents use of the auto for travel within the downtown area without heavy cost and time penalties. Such travel is also unattractive because of the heavy congestion on city streets, which cannot be relieved because of the high cost of land and the previous investment in valuable real estate development.

These tasks, line-haul, arterial traffic and downtown circulation, performed so poorly by the automobile, are ideal for the automated guideway transit system such as the Group Rapid Transit concept. Such systems can carry more than ten times the passengers of a freeway lane on a right-of-way that is several feet narrower. They remove noise and pollution from the congested downtown area and major line-haul arteries and offer attractive energy savings over use of the automobile, typically about a quarter as much energy per passenger mile.

AUTOMATED TRANSIT AND THE BUS

The bus, because of its low capital cost, is often promoted as the panacea for transit. However, the poor labor productivity of bus operation has lead to high operating deficits which in turn have lead to reduced service frequency and coverage during off-peak hours. Typical bus systems have about one employee for every 120 to 160 daily passengers or every 14,000 vehicle-miles.[4] Several proven operating installations, such as Tampa and Seattle-Tacoma Airports, average one employee per more than 1000 daily passenger or more than 30,000 vehicle-miles. Admittedly the operating conditions and environment are substantially different between an airport and a city but the large difference in magnitude between these numbers suggest the advantages of automation.

The labor disadvantage of the bus is magnified on line-haul routes such as the Shirley Highway Expressway by the large amount of deadheading— or travel opposite to the prevailing direction of flow— required to circulate the equipment to where it is needed. This counterflow service generates very little revenue. An automated system, because it is unattended, can better afford to circulate vehicles to meet the demand. In a downtown circulation mode, the slow speed of the

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4 **American Transit Association "Transit Operating Reports, "**

bus on congested streets reduces both its labor productivity and the attractiveness of its service to the public. In Washington, the bus takes longer to traverse a 12-block (about 1.6 mile) downtown route segment during rush hour than is spent on the entire trip segment on the longest Shirley Highway Express route (about 10.8 miles).

The advantage of automated systems compared with buses are more frequent service, shorter travel times downtown and lower operating costs and, possibly, lower life cycle costs. The disadvantages are in the considerably higher capital cost requirement and the lack of ubiquity compared with the bus. The automated system is constrained to its expensive right-of-way, while the bus is free to travel anywhere and can easily adapt to changes in demand patterns.

A final advantage of the automated system is its ability to affect land development. The high investment in guideway committed by urban authorities, inspires similar investments from the private sector which can be confident the transit system will be there to improve mobility and increase land values. Conversely, no such confidence can exist that bus routes will be maintained.

AUTOMATED TRANSIT AND RAPID RAIL

Since both rapid rail and automated guided transit systems use fixed guideways, the distinction here can only be based on two criteria—vehicle/train size and degree of automation. Present practice in rapid rail transit operation requires that an attendant be present on each train regardless of its size and degree of automation. On the other hand, over four years and many millions of passenger miles on fully automated systems (Tampa, Sea-Tac, and **D/FW** Airports), has been accumulated without a single fatality, admittedly under better controlled conditions than exist for rail rapid transit. There is some evidence that the very conservative safety-first design approaches used for automated systems and the use of coordinated vehicle-station doors to prevent passenger access to the guideway, may lead to a new standard of transit safety. At any rate, the safety record during what is always the dangerous introductory phase seems to establish the high probability that completely driverless operation would be acceptable on regular transit systems. If this proves to be true, then automated transit will offer a potentially higher labor productivity than manned rapid rail. Further, this higher productivity will make possible smaller vehicles and **more frequent service—especially during off-peak hours.**[5] **Thus, the concept of fully automated fixed guideway systems, whether they be rail or some other support technology, offer a high potential for improving service and increasing the system productivity. Obviously, the benefits of full automation can be applied to existing systems, such as light rail, where applicable. In this case, the advantages of a proven support technology place less of a demand on the system development requirements.**

such system characteristics may make line haul fixed guideway systems economically viable for the large number of American cities which are too small to justify full rapid rail systems and which are too large to be adequately served only by bus transit.[6]

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[5] Vuchic V. R., "Rapid *Transit* Automation and the Last *Crew* Member, " Railway Gazette International, October 1973, pp. 382–385.

[6] Vuchi, V. R., and Stanger, R. M., "New Transit Technologies : An Objective Analysis is Overdue," Railway Gazette International, October 1974, pp. 384-387.

SUMMARY

To conclude, the auto is here to stay and no transit mode will completely replace it in the foreseeable future. However, it is essential to complement the auto mode with transit for two reasons:

- The automobile is unable to function effectively on high density commuter routes or in crowded downtown areas. It causes congestion, pollution and high energy consumption.
- Mobility must be provided to those without access to an automobile.

For lightly traveled routes, the bus will remain the preferred mode because of its ability to operate on the existing street network. On major line-haul routes or in downtown areas, where existing street networks are overcrowded, it makes sense to consider fixed guideway transit, since a single lane can carry ten times the traffic of another highway lane. By automating the fixed guideway system, a doubling of productivity seems possible compared with bus systems. When peak-hour demand exceeds 20–30,000 passengers per hour, it seems clear that conventional rail rapid transit systems, possibly automated to reduce operating costs, will continue to be the mode of choice.

The role for fully automated, fixed guideway transit will be to provide line haul and downtown circulation functions, which are presently poorly met by the automobile and require operating subsidies when met by buses. These systems will also continue to play an expanding role as horizontal elevators connecting remote parking lots and buildings within major activity centers.

Chapter 3: System Description and Development Requirements

This section describes the systems given in Table 1, below, with emphasis on the technological development requirements. These parameters are summarized in Table 2.

SHUTTLE AND LOOP SYSTEMS

Shuttle and Loop Systems represent the most advanced of the systems being considered in terms of their engineering development being in operation at several airports and other locations. The report of the panel on current status describes these applications in more detail. The basic physical difference between these systems and the other automated guideway systems is that the Shuttle and Loops do not make extensive use of operational switching in passenger carrying operation. As a result, stations must be on-line and the time allocations for stations dwell time, acceleration, and deceleration require headways between vehicles of about one minute. The required vehicle size is set primarily by the anticipated peak demand.

Because of the limitations imposed on travel time by the mode of operation and guideway layout, such systems are generally limited in length and in the number of stations that can be accommodated on a single line. However, the potential in comparison with buses for improved service at lower operating cost and life cycle cost recommends these systems for use as short-haul transit and as feeders to other transportation modes. These advantages must, of course, be balanced against the higher capital investment and the need for exclusive rights-of-way.

The potential use of these systems in urban areas has not been sufficiently examined or exploited. A partial reason may be the desire on the part of interested communities in obtaining the greater capacity and flexibility promised by the Group Rapid Transit concept, It should be noted, however, that Shuttles and Loops do possess the evolutionary potential to be upgraded as necessary to the Group Transit concept. Incorporation of operational switching could be exploited initially to permit off-line stations and, as required, to interconnect lines.

For their current applications, the Shuttle and Loop Systems can be considered to be fully developed with site-specific engineering required and, of course, some product improvement. If the systems are to be deployed in substantial urban installations, further production engineering will be necessary with emphasis on increased system reliability.

GROUP RAPID TRANSIT SYSTEMS

Because of technological differences in the characteristics and state-of-the-art, these systems are discussed according to their operational headway. For convenience these categories are listed as moderate headway (greater than 15 seconds) and short headway (less than 15 seconds).

GROUP RAPID TRANSIT SYSTEMS (MODERATE HEADWAY)

The moderate headway Group Rapid Transit, as a generic classification, represents only a slight departure from those rail rapid transit modes presently in existence. Group Rapid Transit is typically deployed in network configurations involving switching for multiple routing and involves the operation of single or trained vehicles. The typical capacity of the vehicles in those systems allows the use of fixed block train separation systems readily available with state-of-the-art technology. In general, Group Rapid Transit Systems utilize vehicles noticeably smaller than those normally associated with conventional rapid transit, but this generic classification can be considered, at the high end, to merge with the overlay with light rail transit.

Table 1 summarizes typical examples of the moderate headway Group Rapid Transit systems and their generic characteristics. Table 2 lists some of the advantages and disadvantages of these systems compared to conventional rail transit. The systems are capable of operation as intermediate capacity line-haul systems and as regional networks. In addition, they have the potential to circulate people in major activity centers and to connect major centers. The required vehicle size is primarily a function of the peak demand and the type of operation employed. The panel believes that these systems represent a much needed mode which, if satisfactorily developed, will assume a major role in urban transportation between rail rapid transit and the bus and that the deployment of these systems should be encouraged.

Group Rapid Transit Systems operating at moderate headways have been deployed in special applications, e.g., "Airtrans" at the Dallas/Fort Worth Regional Airport. These deployments are in a benign environment compared to that expected in urban deployment. Therefore, a selected urban installation will be required to "prove" these systems in an urban environment. These systems are considered to be in engineering development, i.e., the basic technology has been proven and work is required on the system design to improve the product and to prepare the system for larger scale production, The required improvements and development include:

- Substantial improvements in system reliability, especially automated control and communications, switching equipment and automated vehicle doors.
- Extensive development of computer software for managing the vehicle fleet and for accommodating the system to failures.
- Reduction in cost and weight of guideways and vehicles,
- Improvement of techniques for detecting or removing obstacles that may affect passenger safety or cause damage to the vehicle.

The substantial funding required for the engineering development is beyond the means of a specific community or organization especially in view of the current economic climate and the uncertainty regarding the market and level of federal involvement in these systems. Deployment of these systems will require at least partial federal funding for the conduct of the engineering development.

The panel specifically cautions that this consideration of Group Rapid Transit is based upon the service concept and does not imply an endorsement of any of the existing hardware,

GROUP RAPID TRANSIT SYSTEMS (SHORT HEADWAY)

The short headway Group Rapid Transit System is characterized by headways from about 3 to 15 seconds, smaller vehicles (8 to 20 seats passengers), operational switching, and off-line stations. Capacities range from 3,000 to 15,000 passengers per lane per hour. The potential application for such systems are as activity center circulation and connection and as urban network systems. These applications are based upon the premise that the smaller vehicles and, implicitly, smaller guideways would reduce the cost and the intrusive nature of the guideway and increase their acceptability to the community. in addition, the operation at shorter headways would permit line capticity growth and more frequent service to the diverse destinations typical of urban travel and would result in increased system patronage; the smaller vehicle requirement being the result of the increased service and an increase in the number of destinations. At peak demand periods, the system could be operated in a scheduled manner with the smaller vehicles coupled into trains. If the unit costs and the guideway intrusiveness are reduced, more guideways can be constructed for the same price. In turn, the added guideway will increase the system reliability as perceived by the passenger by providing multiple routing alternatives to by-pass failures.

However, the economic feasibility, the increased service potential, and the greater accept ability of the potentially lighter guideways have not been established and a considerable body of opinion exists that feels that the short headway group system will not be acceptable. This group feels that further development of these systems requires clarification of the potential applications for these small vehicle, short headway systems and an examination of their economics and safety.

This difference in viewpoint does exist within the panel especially with regard to the UMTA HPPRT Program. However, the panel does feel that the priorities of this program with proper reorientation can be directed toward establishing of a technological baseline with emphasis upon reducing system capital and operating costs and upon increasing system reliability. A long-term goal can be that of determining the extent to which the state-of-the-art of GRT Systems can be advanced while still adhering to conventional safety standards.

The decision to develop the short headway Group Rapid Transit System concept will require a test facility for integrated system prototype testing with specific attention devoted to:

- Improving the responsiveness and accuracy of the longitudinal control system including the vehicle separation detection and wayside communication,
- Development of an emergency braking system capable of providing a controlled deceleration profile independent of vehicle loading, grade, and winds while still meeting the safety and reliability goals, and
- careful intergation of the system hardware and software if the development goals are to by achieved.

PERSONAL RAPID TRANSIT SYSTEMS

The Personal Rapid Transit (PRT) System, as defined in this report, is considered to provide non-stop service from an origin to a destination station for an individual or related group of passengers.

Demand-actuated service is provided using small (4-to-6 passenger) vehicles. To achieve adequate capacity, headways of one-half to two seconds are required. Since these headways are below the headways that can assure an emergency stopping distance without collision, the system must be designed to be highly reliable and the vehicles designed to accept only seated passengers and to be crashworthy in the event of a collision. The proponents of these systems see them as eventually providing area-wide coverage with a fine-grained network of guideways and stations.

The PRT concept is based upon the premise that the only means by which a significant fraction of the urban trips may be attracted from the automobile is to provide a service comparable to that of the automobile, that is a personal vehicle with accessibility to a major portion of the urban area with trip times, cost, and direct service competitive with that of the auto. To obtain this service level, the system would require spacings of guideway and stations of approximately one-half mile and fleet sizes of the order of 10,000 vehicles for a city of one million population. Supporters of this concept feel that a large market for these systems exists because of the need to suppress the automobile. As a result, the economics of mass production will reduce the capital and operating costs to a level comparable to that of the auto.

The opposing viewpoint questions whether the PRT even with its claimed service could attract a significant fraction of the urban automobile trips unless severe restrictions are placed upon the use of the auto. Impedances such as the walk to and from a station and the difficulty of handling and storing packages are often cited as constraints on the use of such a system. The primary questions, even for those who accept the service concept, focus upon the economic viability and community acceptance of a fine-structured elevated guideway network which would essentially duplicate the existing street system and the capital and operating costs of a large fleet of vehicles designed to accommodate single party occupancy. The arguments for the large reduction in capital costs by means of mass production are not generally accepted nor are the means to attain the market required for mass production adequately defined.

The panel, as a whole, is skeptical regarding the eventual development of PRT Systems because of the long-term development requirements, the economic viability of the system, the intrusive nature of the fine grid network, and the difficulty of introducing such systems into an urban area. The majority of the panel feel that the case for or against PRT's as defined in this report has not been adequately established and that limited funding is justified to more fully clarify the advantages and disadvantages of this concept by a group of knowledgeable persons other than the system proponents.

One of the panel members feels that the PRT concept is inherently self-contradictory combining small vehicles optimal for dispersed travel with expensive fixed facilities which are economically viable only in high density corridors. He also claims that it can be shown that the claimed performance of this mode in terms of fractional second headway with acceptable speeds and safety cannot be physically achieved. Further, the inefficiencies of small vehicles in terms of energy, costs, and complexity in control and operation place these systems outside the realm of reality. He feels that there are no conceivable conditions under which this system would play a significant role in transportation and that with current trends with respect to energy the chances for these systems are even less likely in the future. As a result, this panel member recommends no R&D funding for this concept.

Another panel member who also believes that the economics of the larger vehicle sytems are likely to prevail supports limited funding for the Personal Rapid Transit concept because the technological advances resulting from such research will be applicable to the broad spectrum of automated transit and because the evolution of technology has in the past provided viable concepts that were originally believed to be uneconomic.

A decision to pursue the development of the Personal Rapid Transit concept will require resolution of the problems described for the other systems and, to some extent, can be aided by these developments. However, in view of the exploratory nature of this concept, emphasis should be placed upon establishing the basic economic and technological feasibility of these systems prior to undertaking major development. Thus, attention should be devoted to:

Basic system recquirements to provide service.

- Performance-speed, headways, acceleration and deceleration requirements.
- **Service—capacity,** passenger waiting and travel times, accessibility, and availability.
- Development objectives-Safety and reliability goals, cost goals, guideway and vehicle envelopes, station throughputs and configurations.

Demonstrating feasibility of longitudinal control systems for short headways (0.5 to 2.0 sec.).

Determining the requirements to be imposed on the vehicle and on other parts of the system by permitting controlled collisions.

Examining the fleet management requirements for short headway operation.

The decision to initiate a development and implementation program for a Personal Rapid Transit System must recognize that the system deployment can be a decade or more away and that the management, financing, and risk exceed in magnitude any other development program ever undertaken by the Urban Mass Transportation Administration, The need for careful long-range planning and for a commitment on the part of the federal government to such a program, if initiated, cannot be overstated.

Chapter 4: Discussion

This section discusses the systems covered in Section 5 with emphasis upon the technological development requirements common to all of the systems and upon a development plan for these systems.

General Comments

All of the systems in this assessment operate automatically without attendants or drivers in the vehicles. The objectives of this automation are the reduction and stabilization of operating costs, the improvement of service to the passenger, and a reduction in life cycle costs compared to other modes using drivers such as buses and manually operated rail systems. No one class of these systems is clearly superior for the entire range of applications envisioned. Each system has a range of conditions for which it may be best suited and it is only natural to expect that an urban area will be best served by a multi-modal approach incorporating these systems and conventional transit.

The complexity of the systems considered increases as the size of the vehicle and the headways decrease and as the operation expands to demand-actuated and origin-to-destination service. The introduction of this complexity is an attempt to increase the attractiveness of the system to the potential passenger and to reduce the trip impedances normally associated with transit use. There is no doubt that increasing the system accessibility to the passenger and reducing the passenger's waiting time and trip time are desirable and necessary attributes of a system if the potential ridership is to be increased. However, even in this case quantitative measures of the impact of time saving on the modal split are arbitrary and in need of further study. Other attributes such as no-transfers and single party occupancy are even more difficult to assess. For example, the public apathy to transfers is probably based upon current systems where the transfer takes place at an unprotected location with long or at least uncertain waits for the arrival of the next vehicle. Transfers may not be considered odious if they occurred in a protected environment and were simple and quick as has been done with some subway systems. The use of transfers would, in general, reduce the cost and complexity of the transit system. In effect, the panel requests that more study be given to this subject so that the necessary system attributes can be separated from those that may be desirable but may have only a small effect on the service provided or on the level of ridership.

Although prototypes of these automated guideway systems do exist and some are in operation in limited and special purpose installations, none of the systems are operating in a true urban environment. Urban operation places severe requirements upon a system in comparison with operation at airports, universities, or other activity centers especially in terms of the maintenance and reliability requirements and for operation under varying climatic conditions. At the same time it must be noted that the well publicized problems of automated systems me not a reflection on the concept but rather a problem in management and hardware; problems inherent in the introduction of new equipment.

It is not sufficient for these new systems to be shown to be operationally and technically feasible prior to their introduction into urban transportation. In addition, their role in urban transportation will be determined by their capability}' to offer a service and cost "package" which is superior to or at least equal to such "packages" offered **by** existing modes. It is incumbent, therefore, upon the agency developing these new systems to conduct an objective analysis of the system for comparison with conventional modes; the analysis taking account of the experience of transit planners and operators.

COMMON DEVELOPMENT REQUIREMENTS

The major technical problems that need to be resolved regardless of the system considered are the development of reliable automation for the control of the system, the increase in overall system reliability, the development of less intrusive and less expensive guideways, and the assurance that system integration has taken place in accord with the development objectives. These items arc **discussed** below.

CONTROL SYSTEM AUTOMATION

Full automation implies automatic functioning of three distinct operational responsibilities. The first is system management of vehicle movements, schedules, fleet size, and operating strategies under normal and degraded conditions. The second is control of vehicle propulsion and braking, door operation, station stopping, and the like. The third is the prevention of vehicle collisions and the protection of system equipment, personnel, and passengers under emergency conditions.

Neer systems such as BART employ computer installations to automatically maintain or adjust schedules and fleet size. The second function is performed in existing systems with widely varyring levels of automation depending on site specific and system specific considerations. Extensive use is made of automated equipment to perform the third function in existing rail systems.

The automated systems considered in this report differ from automation in current systems mainly by complete removal of the vehicle operating crew. This full automation promises reduced operating costs and, perhaps, life cycle costs, increased service by providing the opportunity to run smaller vehicles or trains at greater frequency, and in compaison with manual operation, some possible benefits in energy consumption, ride comfort, capacity, and schedule maintenance. These advantages are purchased at the price of increased investment costs and complexity.

For the automated guideway systems, the major R&D problems for full automation are those associated with management of the vehicle fleet, especially in dermand-actuated operation, and with the control of individual vehicles in short, headway operation. These are discussed below :

Vehicle Management

The vehicle and traffic management function of automated guideway transit systems provides the overall opertitional control for the vehicles in the system and as such implements the real time decisions pertaining to the disposition of vehicles in the fleet, The major subfunctions which the vehicle and traffic management system must perform are:

Provision of a vehicle to serve a trip.

Regulation of traffic flow on the guideway network to prevent saturation.

Adaptation and reconfiguration of the system in response to anomalous conditions arising in the network.

Scheduling vehicles for periodic servicing such as cleaning, washing, and inspection.

Providing system status to supervisory personnel and implementing their decision.

The development of the vehicle and traffic management system for an urban installation requires work in three areas:

(a) Development of algorithms for performing the required automated functions.

Most of the attention in this area has been directed at demonstrating the feasibility of algorithms for nominal operational.[1,2,3] The work in deman-activated operation has developed algorithms for regulating the number of vehicles in use relative to the total trip request rate, for circulating vehicles to locate them near anticipated trip origins, and for regulating the flow of vehicles at merge junctions and stations. Algorithms for performing the automatic detection and evaluation of anamalous operating conditions and for implementing the required response remain to be developed. This development to some extent has been delayed by the dependence of the algorithm on the network configuration and hardware selection.

(b) Development of real-time communications, computation, and display hardware system.

The hardware components for such systems exist but the collection and integration of these equipments into a cost-effective system needs to be performed for a particular application. Better estimates are required of the storage and timing requirements of the various software algorithms. These estimates will help prevent the recurring problem of undersized computers.

(c) Development of real-time computer software for executing the control programs.

The development of the real time software has lagged behind the conceptual hardware design. This software which is dependent upon the selected hardware controls the implementation of the vehicle management algorithms, set priorities within the equipment on which algorithms are to be operated, and controls the input and output of data from the machine.

Headway Control

The safety standards for guided systems have historically required the headway be limited to the "brick-wall stop", i.e., the spacing between vehicles be constrained to a value exceeding that required

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1 "Personal Rapid Transit, " edited by J. E. Anderson, et al.
2 "personal Rapid Transit I I ," edited by J. E. Anderson, et al.
3 "Command and Control Status Report, " edited by E S. Hinman. UMTA DOT Report available from NTIS PB–231 681/SET.

for a vehicle to come to a full stop under emergency braking conditions. The braking distance 24 is a function of the vehicle speed, the braking rate and jerk (usually the guaranteed minimum rates), the detection and reaction delays necessary to recognize the existence of an emergency and to implement braking, and the state of the vehicle at the time of the emergency, e.g., whether the vehicle is accelerating or traveling at constants speed. Current systems employing fixed block detection techniques will have a minimum headway of 10 to 12 seconds at 40 feet per second. The development of high resolution separation detection devices in place of the fixed block scheme and the use of accelerometers to detect vehicle overspeed will decrease the headway to approximately 6 to 8 seconds. These developments together with the development of a braking system capable of providing a controlled deceleration profile independent of vehicle weight, grade, and winds should reduce the headway to about 3 seconds. Such emergency braking systems which would replace the constant force emergency brakes currently in use are being proposed for development in the HPPRT Program.

Further reduction in headways to those proposed (2 to ½ sec.) for the Personal Rapid Transit concept will require the "brick-wall stopping" criteria to be abandoned in favor of a criteria which emphasizes high reliability and which permits occasional collisions between vehicles in the event of a failure. The requirements for these systems are discussed in Section 5.

Further work is also needed on identifying and seeking solutions to the social and legal problems that may be encountered as full automation is introduced into an urban area.

SYSTEM RELIABILITY

One of the most important aspects of the practicality of automated guideway transit is the degree to which travel may be made reliable. This is especially true for the automated systems which employ a large number of vehicles. Methods for expeditiously and economically handling failures in the system and for maintaining service to as high a degree as possible must be designed into both the traffic management system and the hardware subsystems.

The reliability of a system is dependent upon:

(a) System availability goals for public acceptance. The availability goals are often expressed as: On the average, a passenger should not be subjected to more than one 5-minute delay in 10 trips or no more than 1-hour delay in 1 year. Too often these values are set without a careful analysis of the passenger's acceptance criteria. Since low values may reduce the public acceptability of the system and high values will result in higher costs, the availability goals must be established on a firmer footing than current practice.

(b) Subsystem and component failure rates. Procedures and a data base with which to estimate the reliability of typical components used in automated systems are only beginning to be available; e.g., data to establish appropriate derating factors for the application of electronic components in a mass transit environment. Such information will allow the critical components with high failure rates to be

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[4] Hinman, E. J. and Pitts, G. L., "Practical Headway Limitations for Personalized Automated Transit Systems." Proceedings of IEE Conference on Control Aspects of New Forms of Guided Land Transport, London, England, August 1974.

identified and to be improved by controlling the environment in which the part operates, by derating the component, and by adding redundancy to the system for those subsystems and components where reducing the failure rate is of critical importance. In all such cases testing of the components and subsystems and of the total system are necessary to establish the failure levels of the system.

It has been shown [5] that the reliability dependent, subsystems of an automated transit system are a relatively small percentage (about 20%) of the total system costs. If this factor remains valid, additional funding to develop improved reliability of these subsystems can have a marked impact upon the overall system reliability without significantly increasing the system costs.

UMTA should consider the establishment of a data bank on transit system components with the information provided and used by the transit operating agencies and other transit-related organizations. The existence and organization of such information can of itself provide an incentive for manufacturers to improve component reliability.

(c) Time to restore service. Failures which require long periods to repair and restore service will affect proportionately higher numbers of passengers and reduce the public acceptance of the system. Efforts, then, to develop means of rapidly identifying failures and to take quick corrective actions are of prime importance to these automated systems and are in need of development. It should be noted that if for the same investment the smaller scale vehicles and guideways permit more dispersion of guideways than the larger scale systems, then the additional routes available can provide a means of quickly restoring service even with a blockage in the system.

There is a need for design procedures and methods to permit determination of the system availability especially for the smaller vehicle systems. Such analysis will ultimately require a computer simulation to evaluate the numerous design variations which affect system reliability. Such work must be performed during the planning and specification stage for any automated system.

It is necessary to remember however, that mathematical modeling will not make a system reliable. Rather, it is the combination of design procedures, modeling, production quality control, and testing which is required. Such programs are generally expensive but experience has taught that their successful application has been worth the price.

GUIDEWAY COST AND INTRUSION

Two of the most critical factors facing the implementation of automated guideway systems are the cost of the elevated structure, which represents 50% to 70% of the total investment cost, and the community acceptance of the elevated structure. Significant attention to these items is required. This work should include:

- Introduction of realistic design standards for guideway design. This work should include design studies on innovative structures that can reduce guideway cost and size such as those being undertaken by various architectural and engineering firms for the moderate headway group systems.

[5] Smith, Frank C., "System Assurance ; Current and Future Guideway Transportation Systems," First International Conference on Dual Mode Transportation, Washington, D. C., May 1974,

- **Introduction of production and assembly techniques to reduce the cost of the guideway elements and to reduce the disruption associated with on-site construction. Pre-cast concrete is particularly adaptable to this requirement.**
- **Determination of realistic ride quality standards. Current standards appear to be overly stringent resulting in higher costs and larger guideway structures than are necessary.**
- Development of cost effective methods of minimizing the effect of ice and snow on system operation.
- Development of techniques or various elevated guideway configurations for providing for safe and rapid evacuation of passengers from a stranded vehicle.
- Examination of guideway configurations and vehicle support technologies to establish the trade-offs in terms of cost, guideway size, energy consumption, operational reliability and foul weather performance.

The final item includes the need for additional development of the basic lateral guidance and switching concepts as related to the support technology. To-date, most automated group system vehicles have employed rubber tires although alternative suspension concepts have been proposed using steel wheels and rail, air cushions, and magnetic levitation. Currently, the basic lateral guidance and switching capabilities of steel wheel technology still a pear to be superior to that of rubber-tired systems although the adhesion for fail-safe emergency braking may limit the headway capabilities of a system employing steel wheel technology. Further work is necessary to define the applicability of these various suspension concepts and the effect of the suspension on guideway size and cost and on the lateral guidance and switching.

SYSTEM INTEGRATION

The development of a reliable high performance component or subsystem does not insure that this item will operate as designed in a transit system unless the entire system design IS carefully controlled with specific design goals and with an understanding of the interactions between the various subsystems. This process called system integration generally represents about 10% to 15% of the system development and investment costs but is critical to obtaining satisfactory performance of the transit system. The system integration process requires that careful control be exercised over the system design to insure that design goals are being met and that the trade-offs in system performance are being examined. Such a process requires constructing and exercising computer simulations of the system and the extensive testing of the components and subsystems individually and then in the system as a whole.

It should be noted that the systems integration process has been informally applied to many transit projects. However, the increasing complexity of the automated systems and the interdependence between subsystems requires that this process be formalized and controlled. System integration does not insure absolute success of the system development program but neglect of the process almost positively insures that the design goals will not be achieved.

TEST FACILITY

Many of the problems encountered in attempting to introduce automated systems are the result of attempting to undertake concurrent development and implementation of a system. Further, the pressure for implementing the system has tended to reduce the time available for system testing, check-out, and debugging. As a result, failures which could have been avoided by developing and testing of a prototype system occurred with embarrassing frequency in revenue operation,

To minimize these problems and to provide a common basis for the conduct of the above developments, a federally owned and operated test facility is suggested; the facility being located at a permanent site to permit long-term development and testing. Such a facility would be available for:

- Testing critical aspects of system design.
- Establishing design and operational standards.
- Testing differing design approaches and components for comarisen with standards.
- Testing and verification of integrated automatic control system operational performance and reliability.
- Identifying and defining engineering trade-offs.
- Limited "check-out" of systems prior to urban deployment.

With proper reorientation, the HPPRT program can provide the initial stage of such a facility. It will be necessary to include as a design requirement for this facility the need to provide sufficient flexibility to permit the testing and development of alternative subsystems and components either separately or together.

As noted by one of the panel members, there may be justification in certain cases for limited funding to specific vendor/manufacturers to construct a limited test facility for supplying specialized data.

DEVELOPMENT PLAN AND RECOMMENDATIONS

In view of their development status, the Federal Government should be receptive to providing capital grant support for initial deployments of the systems now available which are shown to be the best alternatives for the proposed application. The deployments should be carefully planned to permit modest improvements in the performance and reliability of these systems with sufficient schedule allocation to permit these improvements to be accomplished with confidence. The initial deployments should be planned to permit incorporation of improvements in performance and expansion capability derived from parallel R&D programs to enable extension and upgrading of these systems while mimmizing the interruption to existing service.

In the R&D area, the development of a technological baseline for the Group Rapid Transit concept should be pursued along with the initial staging of a federally owned test facility. Such a baseline can provide technical data on performance, cost, and component characteristics that can be used to formulate specifications for deployable systems, can aid in identifying and examining the performance and cost trade-offs, and can permit the options in operational mode to be examined. The HPPRT Program can be re-oriented to provide this

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development and to be the initial stage of a test facility for continued development and testing of automated transit systems and their com- orients. Such improvements, especially in automatic control per- formance and overall system reliability are essential if initial installa- tions are to expand to a meaningful role in urban transit.

In addition, a separate program to pursue the critical component and subsystem development common to all systems should be pursued. Further, the majority of the panel feels that the issues surrounding the Personal Rapid Transit concept warrant limited exploratory funding to determine if the economic and technological feasibility exists and if the systems can be acceptable to the community. This study should be carefully addressed to the feasibility issues and include proponents and opponents of these systems. The study should also be staged so that the need for further study can be determined and directed.

Finally, the Federal Government should interact more strongly with transit authorities in urban areas to consolidate and define the public transit needs of these areas in order to better determine the best methods of application for automated vehicle transit systems. This type of interaction is already present to some degree in the categories of rail and bus transit systems. It should be implemented even more vigorously with regard to automated vehicle systems so that an under- standing can be developed of the most economic spectrum of modes require to satisfy the real needs of our urban communities.

TABLE 1.–AUTOMATED GUIDEWAY SYSTEM CLASSIFICATION AND DESCRIPTION

System classification	System chaaracteristics	Examples	Vehicle occupancy	Pro service modes	Intermediate stops and transfers	Station location	Routing capability	Appilcations actual (A), proposed (P)
Shuttle and loop transit systems.	Large vehicles (30 to 00 plus passengers); headways equal 1 minute or greater; limited operational switching; capacity from 3,000 to 5,000 pass/lane-hour.	Tampa Airport, Seattle/Tacoma Airport, Houston Airport.	Multiple party.	Generally scheduled but may operate only in response to observed demand.	Yes-------	On-1ine----	None ------------------	Special purpose short-haul A); feeder to other transit modes (P).
Group rapid transit systems:								
Moderate headway.	Moderate-to-large vehicles (15 to 40 plus passengers); headways equal 15 seconds or more; operational switching capacity from 3,000 to 15,000 pass/lane-hour.	Dallas/Fort Worth Airport "Airtrans," Morgantown,	... -ado-----	Generally scheduled although demand responsive service possible.	Possible.. -	*On-* and ofl-line.	Limited alternative routing.	Intermediate capacity line-haul (P); *regional* network (P); circulation (A).
Short headway.	Moderate sized vehicles (8 to 20 seats); headways equal 3 to 15 seconds; operational switching; capacity from 3,000 to 15,000 pass/lane-hour.	HPPRT program (UMTA).	.--do----	Scheduled and demand-actuated. Possible origin-to-destination service at low demand	-----do----	Generally Off-line	Moderate alternative routing.	Regional network (P); activity center circulation and distribution (P).
Personal rapid transit systems.	Small vehicle (4 to 8 passengers) all seated; headway equal 0.5 to 3 seconds; rapid switching capability; from 1,000 to 10,000 pass/ lane-hour.	Aerospace concept (United States)–prototypes: Cabinentaxi (GermanY), CVS (Japan).	Single party.	Origin-to-destination demand actuated Service.	No--------	Off-line ---	Generally conceived as having many alternative routes,	Fine-grained regional network (P).

TABLE 2.—SYSTEM COMPARISON AND DEVELOPMENT REQUIREMENTS

System classification	Comparison with conventional transit: Advantages	Comparison with conventional transit: Disadvantages	Comparison with previous category: Advantages	Comparison with previous category: Disadvantages	Development Status	Development requirements	Development time	Risk of succesa- techno- development
Shuttle and loop transit system.	Lower operating cost per passenger possible lower life cycle cost; improve service and reduce travel time to passenger; potential reduction in energy consumption per passenger-mile.	Higher capital investment. Requires guideway.	-------------------------------------		Essentially developed (Site specific engineering required).	Product improvement especial reliability (for larger installations).	-----------------	None.
Group rapid transit								
Moderate headways.	Above, plus smaller vehicle t!l an rail rapid transit permit use of smaller guideways; shorter trip times than buses; may be able to combine intermediate line haul with limited circulation in activity centers.	Above plus; complexity with implied higher initial maintenance costs to obtain required reliability.	-------------------------------------		Engineering development revenue operation systems in existence).	Selected urban installation; product improvement especial reliability, cost and weight, reduction of guideways and vehicles; obstacle detection and removal; fleet management software.	Development, urban implementation, 3 to 5 years.	Very low.
Short headway-.	Above, plus provide higher performance than minibus or taxi; existence of system in activity center could generate demand; could provide means to encourage auto-free zones if travel times are sufficiently	Above ----------	Higher service capability direct service and fewer transfers; routing options would exist and demand-actuated-Service possible; vehicles and guideways should be smaller.	More extensive guideway net- interchange required for land; increased complexity; higher energy consumption per unit passenger Space.	Advanced development; (prototype design)	Above plus: longitudinal vehicle control including vehicle separation de- t8&fmnwayaidecommu- ; braking System development; system integration.	Development, urban imple mentation; 3 to 6 years.	Moder- “
Personal rapid transit systems.	Basically acts as an automobile alternative since it provides single party occupancy, origin-b destination: service over trip length highest level of transit service.	Change in current safety criteria; requires significant development.	Single party occupancy; direct origin-to-destination service.	Extensive guideway network; highest level of . plexity; requires significant advances in state-of-art.	Exploratory development.	Establish system requirements; determine feasibility of: longitudinal control; braking and propulsion; collision protection; vehicle fleet control.	Development, 3 to 5 years; urban implementation, 4 to 7 years.	High.

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APPENDIX A

BIOGRAPHIES OF MEMBERS OF THE PANEL ON OPERATION AND TECHNOLOGY

Robert A. Makofski
Manager, Urban Transportation Programs
Applied Physics Laboratory
The Johns Hopkins University
Silver Spring, Maryland

Mr. Makofski has been involved in the research and development of automated transit systems since 1963. This work has covered a broad spectrum of technology in automated systems with emphasis on the command and control aspects of these systems. He is also a Senior Research Associate of the Center for Metropolitan Planning and Research of the Johns Hopkins University.

Richard H. Donlon
Director of Operations
Transportation Technology Division
Otis Elevator Company
Denver, Colorado

Mr. Donlon has 24 years of experience in a wide range of advanced technologies with emphasis on technical program management, engineering, and research. He has devoted the last seven years to the development of advanced automated vehicle transit systems. Mr. Donlon was a founder of Transportation Technology, Inc.

Eugene Jones
Senior Vice President
Frederic R. Harris, inc.
Stanford, Connecticut

Mr. Jones has been involved in the planning and design of transportation facilities for over 25 years. He serves on the Board of Directors of Northeast Utilities, the State National Bank of Connecticut, and the Stanford Area Commerce and Industry Association. He was Chairman of the Committee on New Towns and Urban Development for the Consulting Engineers Council.

Thomas McGean
De Leuw Cather and Company
Washington, D.C.

Mr. McGean provides technology and system engineering support on a nationwide basis—most recently including studies of transit alternatives for the Twin Cities, Denver and Santa Clara. Prior to joining De Leuw Cather, he was involved in numerous major federal transportation programs including tracked air cushion vehicle research, the TRANSPO '72 People Movers, Dual Mode, the Rapid Rail Research Program and the HPPRT program.

David R. Phelps
Director of Systems Technology
Transit Development Corporation, Inc.
Washington, D.C.

Mr. Phelps is responsible for the management of funded programs and offers technical direction in providing work scope for proposed programs. He was previously with GE where he was Manager of Development Engineering and Systems Engineering. He was responsible for advanced preliminary design and proposal activity on transit and commuter rail car design. He received a BSEE with honors from Lehigh University and is a registered Professional Engineer.

Stanley A. Spinwebber
The Port Authority of New York and New Jersey
ONE World Trade Center
New York, New York

Mr. Spinwebber has served as Supervisor of the Ground Transportation Projects Section since 1972. He has a BS Degree from Pennsylvania State University, MS Degree from Stevens Institute of Technology, and is a licensed Professional Engineer and Planner. He is responsible for planning, developing, and implementation of all ground transportation projects for Kennedy and La Guardia Airports, including rail access, bus programs, and automated passenger and baggage handling systems.

Dr. Vukan Vuchic
Department of Civil and Urban Engineering
University of Pennsylvania
Philadelphia, Pennsylvania

Dr. Vuchic holds a diploma from the University of Belgrade, master's and Ph. D degrees from the University of California (Berkeley). In addition to his academic work he has been consultant to many firms and to the U.S. Department of Transportation. He has lectured at a number of universities, professional and public forums and published over 30 professional papers here and in Europe. His specialties are urban transportation systems, public transportation, urban and national transportation policy.

APPENDIX B

OPERATION AND TECHNOLOGY PANEL QUESTIONNAIRE

Your response to the questions given below are solicited by the Operations and Technology Panel to aid in their deliberations. Due to the short time available to the panel, a response by February 10 would be appreciated.

To provide a basis for responding to the questions, the automated, fixed guideway transit systems under consideration have been classified as: Loops and Shuttles, Group Rapid Transit, and Personal Rapid Transit. A brief description of this classification is given in Attachment A. It should be noted that the emphasis of this classification has been placed upon driverless, self-propelled vehicle systems that employ exclusive rights-of-way.

In responding to these questions, please cite or, if possible, supply documentation that would assist the panel in its work.

QUESTIONS

1. What do you foresee as the potential urban transportation role, if any, for the automated, fixed guideway systems described in Attachment A? What service attributes, operational modes, and life cycle cost advantages must these systems possess to fulfill that role? Life cycle costs are taken as being the total capital and operating costs over the useful life of the equipment including labor, material, energy, replacement parts and maintenance.

2. Can these service attributes be provided by modifying or upgrading current urban transportation systems? What advantages, disadvantages, and risks would accrue from such an approach?

3. Based upon cost considerations and upon the service attributes and operational modes described above what range of trip demand densities can these systems be expected to serve?

4. The Group Rapid Transit Concept is often considered to be a retreat imposed by technological considerations from the Personal Rapid Transit Concept. However, the Group Rapid Transit, concept does appear to have considerable flexibility in \'chicle size, in ability to train vehicles, in providing scheduled or passenger-actuated operation, and in possibly being able to provide Personal Rapid Transit capabilities in off-peak hours. How can the potential service capabilities of the Group Rapid Transit concept be exploited? Can the same service be provided by conventional means in a more "cost-effective" manner?

5. The automated systems currently being considered employ driverless, self-propelled vehicles operating on a fixed and exclusive guideway. Can lower capital cost systems (cost per route mile) using less complex technology be devised that will provide a level of service better than that of current transit? How would the operating cost and life cycle cost characteristics of such an approach compare with the automated guideway alternatives? Please provide details on how such an approach may be implemented and the level of service to be achieved.

6. In your view, what is the development status of systems described in Attachment A, particularly in the category of the Group Rapid Transit? What additional development should be performed to assure successful large scale urban deployment? It is appropriate to express such development requirements in terms of procedures, time. and cost to reach the stage at which prototype technology can be implemented at an acceptable risk to the community, assume an urban system consisting of 150 to 200 miles of one-way guideway, 60 to 70 stations, and 2,000 to 2,500 vehicles. An urban system of such scale would necessarily be implemented in an incremental fashion.

7. Given a limited level of R&D funding, should the priorities be placed upon continuing the development of systems currently undergoing prototype development and testing or on advancing the technology to improve the performance, service level, and cost characteristics of these systems.

8. For the classes of systems given in Attachment A, identify the R&D requirements that are critical to the eventual development of these systems and that will have a major impact on the capital and operating costs. Estimate the cost and time of developing a solution to each of these requirements.

9. What are the reliability requirements that must be imposed upon the systems described in Attachment A for these systems to provide a viable urban service? How can these requirements be attained and at what cost?

10. One of the long standing controversies regarding automated systems is the need and safety of short headway operation. From a technological point of view, what are the major development requirements, time, and costs to develop prototypes of systems capable of operating at headways of 20 sec., 10 sec., 6 sec., 3 sec., 1 sec., and 0.5 see?

11. What is your estimate of the current status of software development for the management of the fleet of vehicles? What are the critical development areas? How much of this development can be performed independent of site-specific applications?

12. Would the development of these systems be helped or hindered by establishing standard sets of specifications for these systems?

13. The systems described in Attachment A implicitly assume a large portion of elevated guideways in urban areas. Inevitably the question of guideway esthetics and intrusiveness and of public acceptance becomes of critical importance to the eventual development of these systems. Studies in cities such as Minneapolis suggest that guideway locations along freeways, railroads, and certain major thoroughfares may be acceptable but that locations in residential neighborhoods may not be acceptable. From both technological and environmental-architectural points of view, what can be done to improve the acceptability of the aerial structure to the community, particularly in residential and semi-residential neighborhoods? What impact will such changes have on cost? Will the need to locate guideways for public acceptance seriously hinder the operational modes and service capabilities of these systems?

14. There has been considerable discussion on how the development of these s stems should be funded and who should set the standards and specifications. The federal government presently controls the market by control of capital grant funding. What should be the role of the federal government? Should the federal government sponsor prototype development and depend on industry and the transit authorities to take the prototypes to production status? Should the federal government set standards for the different system applications?

15. Please supply additional information or statements that you believe would be of use to the panel.

AUTOMATED GUIDEWAY SYSTEM DESCRIPTION

A brief description of the system classification employed in this questionnaire is given in the table below. It is recognized that the relation of the system description to the passenger service concepts are not based upon a 1: 1 correspondence. Rather, the classification is to be used as a basis for responding to the questions. Alternative classifications are welcomed.

The possible overlap in system classification and the wide variety of technological and service options are recognized but are not included for simplicity of presentation. Two GRT concepts are given to reflect differences in current and future technological developments.

Some of the terms employed in the table are given below:

Single-party occupancy ---- _._. --	Vehicle occupied by 1 or more passengers traveling as a grou from the same origin to the same destimation.
Multiple-party occupancy- -----------	Vehicle occupied by 2 or more unrelated parties.
Routing capability ----- -------------	Determines if network employed permits a choice of 1 or more routes from origin to destination under normal operating conditions.
Special purpose circulation--- - _ _ --- _ --	Limited network or guideway layout that may be employed for special purpose movement of people such as at airports, universities, amusement parks, etc.
Collection, circulation, and distribution-	Implies a more extensive network application such as in CBD's, large airport complexes, major activity centers, etc.

ATTACHMENT TO APPENDIX B

AUTOMATED GUIDEWAY SYSTEM CHARACTERISTICS

System	Characteristics	Vehicle occupancy	Service mode	Intermediate stops	Transfers	Station location	Routing capability	Possible application	Example
Loops and shuttles.	Generally larger vehicles (site dependent); moderate headways (~1 min.+); switching not normally employed m passenger service.	Multiple parties.	Generally scheduled but may operate only in response to observed demand.	Yes-	Yes	On-line - -.	None ------	Special purpose circulation; feeder; collection, circulation, and distribution; possible line-haul applications.	Tampa Airport; - [illegible] Field; etc.
Group rapid transit (I).	Bus-sized vehicles (20 to 40 pass.); moderate headway (-15. sec. +).	. . do-----	Probably scheduled although demand responsive service possible.	Possible---	Possible---	Off-line and on-line.	Limited alternative routing.	.- ..do ----------------	Dallas/Fort Worth **"Airtrans";** Morgantown.
Group rapid transit (II).	Somewhat smaller vehicles (~12 ass.); short headway (-7.5 sec. +); rapid switching capability at line speeds; requires advanced technology.	-.. do-	Both passenger-actuated origin-destination service and scheduled operation.	.--do ------	-.-do ------	Generally	---**do**------	Above; possible regional application.	HPPRT (UMTA).
Personal rapid transit.	Small auto-sized vehicles; short headways (<1 sec. +); requires advanced technology.	Single parties.	Origin-to-destination, passenger-service.	No-.	No--------	Off-line ---	Alternative available.	Collection, circulation, distribution; regional application over extensive network.	

APPENDIX C

LIST OF QUESTIONNAIRE RESPONDENTS

Given below is a list of respondents to the questionnaire of Appendix B as of April 1, 1975. The panel wishes to thank these respondents for their aid and interest in this effort.

1. The Aerospace Corporation, Harry Bernstein, Los Angeles, California.
2. Alan M. Voorhees & Associates, Inc., Thomas B. Deen, McLean, Va.
3. Alden Self-Transit Systems Corporation, William L. Alden, Milford, Mass.
4. American Public Transit Association, John B. Schnell, Washington, D.C.
5. Applied Physics Laboratory, W. H. Avery, Silver Spring, Maryland.
6. Battelle Memorial Institute, Roger L. Merrill, Colombus, Ohio.
7. Bendix Aerospace S stems Division, T. T. Trexler, Ann Arbor, Michigan.
8. Boeing Aerospace Company, A. E. Hitsman, Seattle, Washington.
9. Department of Transportation, E. L. Tennyson, Harrisburg, Pa.
10. Department of Transportation, Charles E. Zen, Sacramento, California.
11. Dallas/Fort Worth Airport, Donald J. Ochsner, Dallas, Texas.
12. Ford Motor Company, Russell F. Thielman, Dearborn, Michigan.
13. General Railway Signal Company, Peter M. Kirk, Rochester, New York.
14. Honeywell Systems and Research Center, Nell C. Sher, Minneapolis, Minnesota.
15. IBM Corporation, J. F. Obendorfer, Gaithersburg, Maryland.
16. Kaiser industries Corporation, Farrel L. Schell, Oakland, California.
17. LTV Aerospace Corp., C. R. Hickox, Dallas, Texas.
18. The Mitre Corporation, Reed H. Winslow, McLean, Virginia.
19. Otis Elevator Company, E. K. Latvala, Denver, Colorado.
20. Princeton University, Alain K. Kornhauser, Princeton, New Jersey.
21. Frank C. Smith & Associates, Frank C. Smith, Dallas, Texas.
22. Southern California Rapid Transit District, Richard Gallagher, Los Angeles, California.
23. Transportation Research Board, Wm. Campbell Graeub, Washington, D.C.
24. Tri-State Regional Planning Commission, J. Douglas Carroll, Jr., New York, New York.
25. West Virginia University, Samy E. G. Elias, Morgantown, West Virginia.

APPENDIX D

LIST OF NONPANEL MEMBERS ATTENDING FEBRUARY 18, 1975 MEETING OF THE PANEL ON OPERATIONS AND TECHNOLOGY

1. Dr. Harry Bernstein, Aerospace Corporation, El Segundo, Calif.
2. Mr. Charles Broxmeyer, Urban Mass Transportation Administration, Department of Transportation, Washington, D.C.
3. Mr. Eugene J. Hinman, Johns Hopkins Applied Physics Laboratory, Laurel,
4. Mr. Robert Macguire, Tampa Airport Authority, Tampa, Fla.
5. Mr. Robert C. Milner, Boeing Aerospace Corporation, Seattle, Wash.
6. Mr. George Pastor, Urban Mass Transportation Administration, Department of Transportation, Washington, D.C.
7. Mr. Frank C. Smith, Frank Smith and Associates, Dallas, Tex.

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