SUMMARY REPORT

ADVANCED GROUP RAPID TRANSIT (AGRT) PROGRAM REVIEW

March 1983

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on

ADVANCED GROUP RAPID TRANSIT (AGRT) PROGRAM REVIEW

by

OFFICE OF SYSTEMS ENGINEERING, URT-12
URBAN MASS TRANSPORTATION ADMINISTRATION
U.S. DEPARTMENT OF TRANSPORTATION

March 21, 1983

EXECUTIVE SUMMARY

The Advanced Group Rapid Transit (AGRT) program is developing the basic technologies of a system that would accommodate the peak-hour passenger demands of medium-density urban areas yet provide dispersed origin-to-destination service without transfers. It is not intented to develop a complete deployable system. More effort would be required before this could occur.

This program review addresses the AGRT program and technology currently under development. It was conducted by the Urban Mass Transportation Administration (UMTA) Office of Systems Engineering/URT-12.

The major objectives of the review were to define the present status of the program and to clarify the expected results. This was accomplished by compiling and analyzing available information about the AGRT development program and determining (1) the status of the AGRT program, (2) the technical and economic feasibility of the AGRT systems as presently defined, (3) the potential for applying AGRT-developed technology to other transit systems, and (4) the potential for applying magnetic levitation (MAGLEV) and propulsion technology to Automated Guideway Transit (AGT) and AGRT systems.

In AGRT, single vehicles with as few as 12 passengers will operate on exclusive guideways at headways as small as 3 seconds. Stations will be off-line and there will be extensive switching. Origin-to-destination service can be provided. No AGRT systems are presently in operation.

The AGRT development program was initiated in February, 1974 as an outgrowth of Transpo '72. Its objective was to develop an advanced AGT system that would accommodate the peak-hour passenger demands of medium-density urban areas yet provide dispersed origin-to-destination service without transfers.

Three prime contractors (Boeing, Otis and Rohr) were initially funded; only Boeing and Otis remain today. In the recent past, the program has focused on portions of a complete AGRT system. Since 1977, the AGRT program has encompassed the development of two engineering development systems (EDS) and a MAGLEV technology.

The present EDS development efforts are directed toward the critical zone and vehicle-borne command and control (C & C) subsystems. Both Boeing and Otis use hierarchical, microprocessor-based electronics which provide moving block collision avoidance for vehicles. The hardware and software developed for the C & C subsystems are well advanced. Demonstration/testing should occur after 1985.

Conclusions

The conclusions presented below were formulated during this program review:

1) Applications of AGRT Technology. Subsystem and component technology of the type being developed on the AGRT program may be able to improve the performance and productivity of AGT and existing conventional transit. Further, the private sector might benefit from the research resulting from the AGRT program and vice versa.

2) Program Costs. The AGRT program costs already expended through FY 1982 are in excess of $36 million. It appears that at least $53 million more will be required to carry the program, as presently defined, through EDS testing. The exact total depends on the level of fiscal year funding made available.

3) Additional Work Required. Following the completion of the EDS activity, it will be necessary to develop engineering prototype systems (EPS) in order to have a complete AGRT system suitable for urban deployment. This additional effort is estimated to cost at least $34 million.

4) AGRT Goals/Requirements. The goals/requirements in the original AGRT Specification, taken together, are very advanced compared to the performance of present transit systems. It is not clear whether all can ultimately be met without relaxing some. However, individually the goals/requirements are technically feasible. Recent experiences have shown that the likelihood of a successful program is greater when a series of manageable steps are planned than with a single step.

5) Level of Service. Studies have shown that AGRT may provide a higher level of service (e.g., shorter trip time) than existing AGT systems.

6) Verification of Command and Control Subsystems. The performance of key aspects of the EDS command and control subsystems for AGRT will be verified by both Boeing and Otis. Based on current funding, such verification should occur after 1985.

7) Similarity of Command and Control Subsystems. Both Boeing and Otis have developed microprocessor-based control and moving-block collision avoidance subsystems using different design concepts. Although each design has distinct advantages and disadvantages, the two have evolved to the point where they are functionally quite similar.

8) MAGLEV. High speed magnetic levitation (MAGLEV) and propulsion technology development has advanced substantially in recent years, especially abroad. More MAGLEV development and system level studies are needed to establish the extent to which this technology is applicable to conventional transit and AGT/AGRT systems.

9) Mag-Transit Study. Boeing has made significant progress in the development of the Mag-Transit concept. However, the study is presently too limited in scope to establish the viability and advantages of using Mag-Transit in urban transportation systems.

10) Foreign AGRT Development. Foreign test track demonstrations performed during the 1970's have indicated that an AGRT-type concept is technically feasible, but, with one exception, further work has not occurred. However, the development and deployment of foreign AGT systems is being actively pursued. It can be expected that foreign AGT technology will be actively marketed in the U.S. and, therefore, compete with domestic technology.

Recommendations

The following recommendations are made:

1) Use an Incremental Approach. A series of graduated interim goals/requirements for AGRT should be identified and structured. They should allow for incremental progress towards an AGRT capability and reduce instances where some goals/requirements complicate the realization of others. Increased emphasis should be focused on cost and maintainability.

2) Test Selected AGRT-Type Technology. AGRT-type technology, developed by both AGRT prime contractors and traditional transit system suppliers, should be thoroughly tested before implementation at transit systems. The tests should be conducted, first at the Transportation Test Center in Pueblo, Colorado, and later, as appropriate, in an operating urban transit environment.

3) Focus on Cost Reduction. In order to make AGRT an attractive option, efforts should focus on reducing overall system capital and operating and maintenance costs.

4) Test Advanced Command and Control Subsystems. Future command and control subsystem testing plans should concentrate upon the development of greater flexibility for functional verification testing and demonstration. In order to achieve this, it may be beneficial to test these systems at existing facilities in Pueblo, Colorado.

5) Continue MAGLEV Development. Development of MAGLEV technology should be continued in order to substantiate its advantages and disadvantages, and to establish the optimum configuration for urban deployment.

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INTRODUCTION

This document summarizes the report "Advanced Group Rapid Transit (AGRT) Program Review". The report itself is a separate document and is in statement/outline form with source references. The report provides support for the conclusions and recommendations which are presented in this summary.

This review addressed the status of the two AGRT systems and the MAGLEV technology currently under development. The expected performance capabilities and costs of AGRT systems are related to those of existing Automated Guideway Transit (AGT) systems and to conventional public transit. The role of AGRT in meeting the needs of projected transit applications was examined as were the expected benefits of using this technology.

This report is based in part on a study sponsored by the Urban Mass Transportation Administration's Office of Systems Engineering/URT-12 and conducted by a team consisting of Battelle's Columbus Laboratories, N.D. Lea & Associates, Inc., The MITRE Corporation - Metrek Division, and Transportation Systems Center/U.S. Department of Transportation. All of these organizations provided inputs to the study. UMTA personnel took an active role in the conduct of the work and provided inputs to selected study areas. Battelle coordinated the overall effort and compiled the various inputs into the resulting reports.

The study was conducted during the period June 1 through December 30, 1982, with the bulk of the research being completed by November 15th. The study made considerable use of work which had previously been performed in the AGT/AGRT area; however, new work and/or analysis of existing work was conducted as appropriate.

This introduction is followed by:

- Purpose of the Review
- Background/History of AGRT

- Present Status of the AGRT Program
- Conclusions, and
- Recommendations.

PURPOSE OF THE REVIEW

The purpose of the work reported here was to compile and analyze available information on the AGRT development program. Conclusions have been drawn relative to the present status and recommendations formulated concerning the future conduct of the AGRT development program. The review effort was directed toward determining the following:

- The technical status of the two AGRT systems now under development by Boeing and by Otis
- The technical and economic feasibility of AGRT systems as presently defined and being developed
- The potential for applying technology developed on the AGRT program to other transit systems and applications, and
- The potential for applying magnetic levitation (MAGLEV) and propulsion technology to AGT and AGRT systems.

BACKGROUND/HISTORY OF AGRT

Background

Automated Guideway Transit (AGT) is a broad class of transportation systems in which driverless vehicles operate on fixed guideways along an exclusive right-of-way. This classification covers systems having a wide range of characteristics and utilizing many types of technology; AGRT is one type of AGT. AGT has five sub-classes according to their specific characteristics and basic applications; these are:

- Shuttle-Loop Transit (SLT) -- Simplest AGT configuration. Single vehicles (20 to 100 passengers) or trains operate at headways of 60 seconds or more. Stations are on-line; there is little or no switching and routes are simple.
- Group Rapid Transit (GRT) -- Single vehicles (6 to 50 passengers) or trains operate at headways of 3 to 60 seconds. Stations may be on-line or off-line; there is extensive switching and routes may be complex.

- Advanced Group Rapid Transit (AGRT) -- Single vehicles with as few as 12 passengers operate at headways as small as 3 seconds. Stations are off-line; there is extensive switching and origin-to-destination service can be provided.

- Personal Rapid Transit (PRT) -- Single vehicles (1 to 6 passengers) operate at headways as small as 0.5 second. Stations are off-line; there is extensive switching and origin-to-destination service is provided.

- Dual-Mode Transit (DMT) -- Single vehicles (1 to 50 passengers) are capable of operating in both a manual mode on regular highways and in an automatic mode on exclusive guideways.

Of these five, only systems of the first two sub-classes are presently in revenue service. No AGRT systems are in operation. Both PRT (in West Germany) and DMT (in Japan) systems have been operated on test tracks.

The development of AGRT has been in progress since 1974 under sponsorship of the U.S. Department of Transportation/Urban Mass Transportation Administration (DOT/UMTA). AGRT development began after the DOT-sponsored demonstration of four AGT systems as part of Transpo '72 which served as a showcase for new transportation technologies in which the general public was allowed to ride the four systems. Results of the post-Transpo test program indicated that, with design, improvements in key subsystem areas such as command and control, AGT systems would be capable of providing service and capacities applicable to many urban areas.

The AGRT program was established with an objective of developing an advanced AGT system with performance and operating characteristics that would (1) accommodate peak-hour passenger demands of medium-density urban areas, and (2) provide dispersed origin-destination service over that urban area. A large-network route configuration that would encourage people to use the system for work trips, short business trips, and social and recreational trips was envisioned. It was felt at that time that the resulting area-wide coverage, in conjunction with a requirement for no transfers and few intermediate stops, would allow the transit system to compete with the automobile. At the beginning of the program, only broad dynamic performance goals, such as a system capacity of at least 14,000 seats per lane per hour and a vehicle capacity of 12 seated passengers or fewer with no standees, were established. These specifications were consistent with the desired overall system performance and operating goals. They were also later used as the basis for the generation of more detailed system characteristics such as minimum safe headway.

The two AGRT system designs currently under partial development reflect different approaches for satisfying the broad performance goals established by UMTA in early 1974. Both Boeing and Otis have elected to develop systems that will meet the minimum system capacity goals of 14,000 seats per lane per hour through the use of the largest vehicle size preferred--12 passengers. The decision to use this combination of vehicle

and system capacities has dictated the design of a command and control system that will permit safe vehicle operation at a minimum safe headway of approximately 3 seconds at 15 mph. The goal of area-wide, origin-destination service is being met through the development of a high speed merge/diverge capability to allow for vehicle operation on complex networks with off-line stations. The Boeing and Otis AGRT systems are being designed to automatically handle those operating and management tasks typically handled by vehicle drivers, station attendants, dispatchers, schedulers, and central management and operations personnel.

Boeing is developing an AGRT system concept that revolves around the use of a software based, hierarchical command and control system and includes a moving-block collision avoidance system. The Boeing AGRT system design is in many respects, an extrapolation of its Morgantown People Mover system. Highlights of the Boeing AGRT system design include: quasi-synchronous vehicle control, rubber-tired vehicles with no-flat core radial tires, a dual redundant, microprocessor-based vehicle control unit, and a wayside-based collision-avoidance system.

The Otis AGRT system concept is also built around a hierarchical command and control system that is also software-based and provides for moving-block collision avoidance. The AGRT system Otis is developing incorporates some of the design features of their Duke University system, e.g., air cushion vehicle suspension, linear induction motor (LIM) propulsion, and lateral docking at off-line stations. Other highlights of the Otis AGRT system design include: a triple redundant, microprocessor-based wayside command and control system; and the extensive use of redundancy to ensure high reliability and safety.

Program History

The AGRT development program was initiated in February, 1974, and, at that time, was called High Performance Personal Rapid Transit (HPPRT). Subsequently, in 1976, the program was redirected and, thereafter, denoted as AGRT.

The original HPPRT program had three prime contractors (Boeing, Otis, and Rohr) which worked on separate and independent system designs. This program consisted of two phases (Phase I - Preliminary Design and Phase II - Prototype Development/Test Track) and was scheduled for completion in late 1978. It was intended that, upon the completion of Phase I, one of the three prime contractors would be selected for further work on Phase II. However, in 1975 when Phase I was completed, the program was restructured in response to recommendations contained in an UMTA AGT Program Review Paper, an Office of the Secretary of Transportation (OST) evaluation and the FY '76 DOT Appropriations Conference Report; the program name was changed to AGRT. The original Phase II program then was split into two parts, Phase IIA and Phase IIB.

Phase IIA was initiated in June, 1976 with all three prime contractors directed to continue design refinements and laboratory testing for

18 months. In Phase IIB, a single design was to have been chosen for full-scale prototype testing at the DOT Transportation Center near Pueblo, Colorado. Completion of both phases was scheduled for 1981. In the autumn of 1977, as Phase IIA was nearing completion, a task force was formed within DOT's Office of the Secretary to review the AGRT program and plan future activities. While the work of the Task Force was in progress, Phase IIA was completed. Rohr withdrew from the program at that time and signed a licensing agreement with Boeing granting the latter rights to Rohr's ROMAG (integrated magnetic levitation and propulsion) technology; this concept is now denoted as Mag-Transit. As the result of the Task Force's recommendations, the program was restructured and the period of performance for Phase IIB was extended from 36 months to 69 months. The objective for Phase IIB was to "continue system designs at the implementation level (hardware and software)".

In early 1979 UMTA reduced the scope of Phase IIB. The major change was that testing of the engineering prototype systems (EPS) be carried out at each contractor's plant rather than at the DOT facility as originally planned. It had been originally desired that a prototype AGRT system be available for site-specific installation by 1985. However, due to the slow down in related activities, this was revised to the 1990's time frame. The development of the integrated magnetic levitation/propulsion technology was to be continued, but at a lower rate of effort. Contracts for Phase IIB were signed with Boeing and Otis in June, 1979.

As a result of funding constraints, the scope of the engineering prototype system (EPS) development and fabrication effort was reduced to the point where full scale, prototype systems will not be built for demonstration at the Boeing or Otis plants. Rather, Boeing and Otis are each developing an engineering development system (EDS) that will allow them to verify the feasibility of the AGRT concept and their command and control system designs through a series of demonstrations, tests, and analyses of test data. The emphasis of the EDS effort is on function, whereas the emphasis of the EPS effort was on both function and form. The EDS effort calls for the development of only those elements of an AGRT system that are necessary for verification of performance and operating capabilities inherent to the AGRT concept and program goals. The development of complete AGRT type vehicles, stations, and other facilities, or of all command and control system software is not being undertaken.

Previous Studies of AGRT

Since the initiation of the AGRT program, there have been studies, and associated reports, which examined the program itself, the nature and capabilities of the systems being developed, and the expected market/applications for such systems. Several of these reports served as inputs to this review. Foremost among these were reports sponsored and/or generated by UMTA and OST and those prepared by the Congress of the United States Office of Technology Assessment.

In general, these studies concluded that the AGRT system development program should be continued. However, in some instances changes in emphasis were recommended; the most significant change was the emphasis on the command and control system. Also, some studies were primarily cost-benefit analyses and, therefore, did not contain conclusions or recommendations relative to the development program itself.

PRESENT STATUS OF THE AGRT PROGRAM

The AGRT development program presently is in Phase IIB and both prime contractors (Boeing and Otis) are working toward the EDS demonstration/tests presently scheduled for post 1985. The testing and analysis to be associated with these demonstrations is intended to provide verification of the functional performance capabilities of the critical command and control technologies now under development, and to generate a data base for future system level studies. The scope-of-work modifications, expenditure limitations, and delays which have occurred throughout the program have had adverse effects. Foremost among these are: increased contractor program management costs, significant reductions in EDS demonstration capabilities, delays in EDS testing, and an increasingly tight program schedule.

The status of each of the two AGRT systems under development, as well as the work remaining to be done following EDS testing and prior to urban deployment, is discussed below. Not all of the hardware and software being developed is representative of, or traceable to, the hardware or software that would be found in an AGRT system ready for urban deployment. For instance, since no urban network has been selected, neither contractor is developing central control equipment or software that is representative of the central control equipment or software that would be found in an AGRT system in revenue service. However, both are developing vehicle command and control systems for EDS testing that could be used, with only minor packaging modifications, in an urban deployable AGRT system. Items such as the vehicle command and control system are referred to as AGRT traceable items.

Boeing

The focus of EDS development efforts is on zone and vehicle-borne command and control (C & C) subsystems. A major developmental item is the collision-avoidance system which originally was intended to use radar to provide vehicle-presence detection and range. Serious technical problems have recently been identified with this method and Boeing will change its system to use another vehicle-presence detection method. Other than this, there are no major technical and/or development problems which exist relative to Boeing's EDS program. However, this program is not intended to verify reliability, maintainability and cost goals.

A traceable AGRT vehicle is not being developed. To minimize costs, two modified Morgantown-system vehicles will be utilized. These vehicles will not have the desired top speed and would not meet the AGRT ride quality and noise requirements as originally envisioned in the Specification. In a further move to minimize costs, construction of an AGRT traceable guideway for EDS has been dropped. Boeing's existing test track facility will be modified for EDS testing. The proposed power distribution system design is based upon standard technology and equipment and, therefore, requires no new developments. The original station design and construction work has been substantially reduced as a result of program cutbacks. A single on-line station at the test track will contain only those features essential for vehicle operations.

Areas requiring additional development/study by Boeing prior to urban deployment are as follows (including examples of specific work needed):

- Command and Control (zone-to-zone handoff, failure and anomaly management, fleet management)
- Vehicles (bidirectional steering, entrainment capabilities, vehicle recovery, propulsion and power conditioning units, maximum longitudinal emergency deceleration, effects of grades on high-speed performance, and complete design including packaging)
- Guideway (aesthetics and cost)
- Stations (passenger processing-fare collections, destination selection and information management, configuration), and
- Other (reliability and environmental evaluation, noise and operating environment, system capital/development and operating/maintenance costs, failure management, maintenance facility, and procedures).

Otis

As with Boeing, the focus of Otis' EDS development work is on the zone and vehicle-borne C & C subsystems. The C & C design and development work is proceeding as planned for both of these areas. However, the AGRT-traceable central C & C level subsystem is not being developed in this phase. Both hardware and software work for the zone and vehicle levels are well advanced.

A traceable vehicle chassis is being developed; it will be a modified Duke-University-system vehicle. An open AGRT guideway will be built for EDS testing, but it will not have elevated segments. It is expected to provide for almost full performance and vehicle control verification. The proposed power distribution system design is based upon standard technology and equipment. Detailed station design work has not yet

started, but the original scope of this work has been substantially reduced due to program cut-backs. Current plans do not include any passenger processing provisions.

At this time there are no major technical and/or development problems which exist relative to Otis's EDS program. However, this program is not intended to verify reliability, maintainability and cost goals.

Areas requiring additional development/study by Otis prior to urban deployment are as follows (including examples of specific work needed):

- Command and Control (automatic fault/failure monitoring, automatic real-time routing and dispatching, failure management)
- Vehicles (cab-design, fabrication, test and evaluation, maximum longitudinal emergency deceleration, vehicle recovery, entrainment capabilities)
- Guideway (aesthetics, and cost)
- Stations (configuration, passenger processing-fare collection, information management, and destination selection), and
- Other (reliability and environmental evaluations, EMI effects, operating environment, hardware packaging, minimized production cost, vehicle control unit, system capital and operation/maintenance costs, failure management, maintenance facility, and procedures).

CONCLUSIONS

The conclusions presented on the following pages are supported in the report "Advanced Group Rapid Transit (AGRT) Program Review". Each conclusion is followed by a brief supporting discussion and a reference to the locations in the report where the conclusion is supported. Each reference is in the form of a Roman numeral and an Arabic numeral corresponding to a section and a page in the report. These conclusions are followed by "Recommendations" which result from the conclusions.

Conclusion No. 1 - Applications of AGRT Technology

Conclusion

Subsystem and component technology of the type being developed on the AGRT program may be able to improve the performance and the productivity of AGT and existing conventional transit. Examples are implementation of the moving-block concept, the use of microprocessor-based control systems, electronic power conditioning units, and diagnostic systems. Since private industry is also exploring these areas, it would be helpful if non-AGRT portions of the private sector could take greater advantage of the resources and research resulting from the AGRT program and vice versa.

Discussion

An analytical study showed that a moving-block collision avoidance system has a potential advantage over a fixed-block system because of the increased throughput capability and the operational flexibility of the overall system. The increased throughput capability is achieved by minimizing the spacing between the trains or vehicles. The operational flexibility results from the relative ease with which a microprocessor-based system can be changed to meet the changing needs of day-to-day operations.

The increase in potential throughput capability assumed that no significant bottlenecks exist in the system. However, on many existing transit systems turnbacks, crossovers, and stations, rather than the quantization limits of a fixed-block system, limit the system throughput. New systems would not necessarily have these bottlenecks. None-the-less, some rail transit operators have expressed an interest in exploring the moving-block control technology concept because of the potential flexibility it offers. Improved anomaly management could be a major by-product of advanced microprocessor-based control systems.

The domestic control-system suppliers consider fixed-block technology to be fully capable of meeting the operational and performance requirements of present transit systems at a lower cost than moving-block technology. As a result the suppliers are not pursuing further developments in this area, even though at least one supplier already has an issued patent on a moving-block control system and such systems are available from foreign suppliers. The Detroit Central Automated Transit System (CATS) - an AGT system - will have a moving-block control system. It should be noted that the inductive communications loops used in some moving-block systems do not provide broken-rail protection which is inherent in most fixed-block track-circuit systems.

References

References which support Conclusion No. 1 are pages II-5, 18, III-11, and IV-1 through 30 of the report.

Conclusion No. 2 - Program Costs

Conclusion

The AGRT program costs already expended through FY'82 are in excess of $36 million, and it appears that at least $53 million more will be required to carry the program, as it is presently defined, through EDS testing. The exact funding needed depends on the actual level of funding provided each fiscal year between now and completion of EDS testing.

Discussion

This conclusion is a summary statement of program cost data which now exist. The costs to date are known from the contractor awards and resulting contractor invoices. The projected costs to complete the work through the EDS testing activity are based upon estimates by the two development contractors and UMTA. Work on the program, through the completion of EDS testing, will be directed to the demonstration of the AGRT concept only and will not result in a deployable system.

References

References which support Conclusion No. 2 are pages III-31 through 36 of the report.

Conclusion No. 3 - Additional Work Required

Conclusion

Significant additional development work will be required after EDS before the urban deployment of AGRT systems will be possible. The cost of the additional development and verification of the two engineering development systems, necessary to bring them to the level where they could be considered as candidates for urban deployment, is estimated to be at least $34 million over and above the funding required to complete the current EDS program phase. This would result in two pre-production prototype sytems capable of meeting the original AGRT performance goals.

Discussion

Following the completion of the EDS activity, it will be necessary to continue the development program on through the engineering prototype system (EPS) activity as previously defined in order to have a complete AGRT system suitable for urban deployment.

The current phase of the AGRT program calls for the two prime contractors to proceed with the development, installation and testing of an EDS at their plants. Each facility will contain the minimum amount of required equipment that will allow the testing and verification, in an interactive manner, of the major subsystems in a system-level configuration. The functions to be verified in the EDS phase are:

- Multiple vehicle operation up to 15 mph continuously by Boeing and up to 40 mph by Otis.
- Merging of vehicles at 15 mph by Boeing. Merging of vehicles at 40 mph by Otis.
- Demerging of vehicles at 15 mph by Boeing. Demerging at 40 mph by Otis.
- Automatic vehicle operations in stations.
- Verification of the collision-avoidance system.

Additional efforts, beyond EDS, necessary for the development, testing, and verification of an EPS would need to be directed toward the following:

- Multiple vehicle operations at speeds up to 40 mph.
- Multiple vehicle operations at minimum safe operational headway for the entire speed range up to 40 mph.

- Merging of vehicles at speeds up to 40 mph.

- Merging of vehicles at the minimum safe operational headway for the range of operational speeds.

- Achievement of the performance, cost, safety and reliability goals.

Achievement of the EPS activities cited above will require the following:

- Additional development of vehicle-related subsystems: vehicle body, steering and braking.

- Guideway construction to accommodate the full range of vehicle and multi-vehicle operations. A new facility would be required for Boeing.

- Central control facility and zone control facility development including the capability for fully automated operation, fleet management, failure/anomaly management, and passenger processing and information management.

- Experimental determination of the reliability of the equipment and modifications of the equipment as required to achieve acceptable reliability together with documentation of the results.

- Determination of the maintainability of the equipment in actual operation. This may require repackaging and/or redesign of the equipment to obtain acceptable maintenance characteristics.

- The application of "Value Engineering" techniques to minimize overall system costs while achieving an acceptable level of performance.

- Verification and documentation of the achievable reliability, performance, cost, and safety parameters of the EPS system in operation.

References

References which support Conclusion No. 3 are pages II-7 through 17, 20 through 28, 34 through 41, and 44 through 61 of the report.

Conclusion No. 4 - AGRT Goals/Requirements

Conclusion

The goals/requirements in the AGRT Specification, taken together, represent a major advance over current capabilities. Some of these goals/requirements complicate the realization of others, and it is unclear whether all can ultimately be met without relaxing some. Recent experience in the transit industry has taught that changes of such proportion are difficult to achieve in a single step, and that instead success is more likely with a series of manageable increments.

Discussion

The goals/requirements, as originally specified in the governing Specification (AGRT Urban System Specification, Exhibit B of RFP DOT-UT-70108, dated October 31, 1977), cover a number of areas, including system performance, safety, aesthetics, cost and maintainability. Taken together the goals/requirements are very advanced compared to the performance of present transit systems. However, individually the goals/requirements are technically feasible.

The goals/requirements include a sustained line speed capability of 40 miles per hour under adverse grade and weather conditions (uphill and headwinds), a capacity of 14,000 seats per lane per hour, vehicle capacity as small as 12 persons, and all passengers to be seated. This combination of capacity and vehicle size complicates the design by requiring a very short (3-second) headway capability. Present AGT systems in revenue service operate at headways of 15 seconds or greater.

Originally, the AGRT capital cost goal was a complete system for no more than $4 million per lane mile in FY '73 dollars; this translates to about $8 million per lane mile in 1982 dollars. While this goal is responsive to present-day transit needs, it is very ambitious when compared with the costs of recent AGT installations shown below (1982 dollars per lane mile):

- Miami DPM - $29 million
- Detroit People Mover - about $20 million
- Atlanta Airport People Mover - about $14 million
- Morgantown System - about $19 million.

There is some question as to whether the capital cost goal can in fact be achieved. It is believed, however, that a relaxation or restructuring of some of the other goals adversely affecting costs, in conjunction with a concerted effort directed specifically to cost reduction,

could result in system costs substantially below those of present AGT systems. An UMTA-funded study on guideways, for example, indicated the possibility of significant cost savings for certain guideway designs.

Another ambitious jump is represented by the maintainability goal: a maintenance staff of 0.1 person per vehicle. This represents more than an order of magnitude reduction from the size of present AGT maintenance staffs, and may not be achievable. For example, Atlanta Airport requires 3.5 persons per vehicle, Duke Univesity requires 4 persons, and Morgantown has 1.0 person. The Miami people-mover maintenance staff has been estimated at 1.7 persons per vehicle.

Many of the goals/requirements complicate the achievement of others. For example, as noted above, a very short (3-second) headway capability is required by the combination of system capacity and vehicle size. This in turn may necessitate an emergency deceleration rate in excess of the allowable rate.

Experiences from previous UMTA programs have clearly shown that it is desirable to make changes in transit technology in an evolutionary, rather than a revolutionary manner; large scale changes are fraught with peril. This is well evidenced by the outcome of such programs as the Transbus and the State-of-the-Art Car (SOAC). Many problems of cost, schedule and technology were also experienced initially with the Morgantown People Mover (MPM) system development program. However, there were "lessons learned" from each of these programs and they are being applied throughout the transit industry. Such problems also appear to be typical of large-scale system development programs in the transit industry.

References

References which support Conclusion No. 4 are pages III-15 through 25, and VI-10 and 11 of the report.

Conclusion No. 5 - Level of Service

Conclusion

Studies have shown that AGRT may provide a higher level of service (i.e., shorter average trip time) than existing automated guideway systems.

Discussion

This conclusion is based upon studies, conducted by various independent groups, which compared the performance of AGRT-type systems (i.e., short headways and small vehicles) with other automated guideway systems (i.e., longer headways and larger vehicles). This assessment study did not include bus and heavy rail systems because data were not available. These studies considered several network deployment scenarios and passenger demand distributions. The results indicated that a higher level of service was provided by the AGRT-type systems. Level of service was measured by the average trip time, the number of intermediate stops, and the percentage of trips requiring a transfer. The primary measure was trip time which is the total time a passenger is in the system from the time of arriving on the platform of the origin station to the time of arriving at the destination station.

The conclusions relative to the level of service provided by AGRT compared with other AGT systems are:

- AGRT will provide direct origin-to-destination or scheduled service with fewer intermediate stops and transfers than SLT or GRT.
- Average trip time could be reduced up to approximately 30%.
- Average wait time is often longer, but the total trip time is reduced because of one or more of the following:
  - Fewer intermediate stops
  - Reduced number of transfers, and
  - Higher cruise speeds.

References

References which support Conclusion No. 5 are pages III-85 through 93 of the report.

Conclusion No. 6 - Verification of Command and Control Subsystems

Conclusion

Performance of key aspects of their respective zone and vehicle level command and control subsystems for AGRT will be verified by the EDS testing programs of Boeing and Otis. However, based on current funding, such verification is not expected to occur before the end of 1985.

Discussion

Program redirections and long-term spending limitations have resulted in slippage of the initial EDS testing schedule and reductions in the EDS demonstration capabilities of the two AGRT contractors. However, both contractors will be able to verify and demonstrate, to different degrees, the performance capabilities of their respective command and control systems.

Boeing's demonstration capabilities have been more heavily affected by program-related events than those of Otis. Boeing will be able to verify the capabilities of their AGRT command and control system through analytical means. However, use of modified Morgantown vehicles and the test track constructed for testing of those vehicles will preclude demonstration of some AGRT requirements (e.g., 40 mph maximum speed, speed and headway regulation, and exterior noise levels).

Otis is building an AGRT traceable vehicle chassis/bogie and test track. Because of this they will be able to demonstrate an ability to meet most of the AGRT performance and control requirements.

Future levels of AGRT funding are uncertain and because of this, the completion date for EDS testing is likewise uncertain. However, based on current funding, such verification is not expected to occur before the end of 1985.

References

References which support Conclusion No. 6 are pages I-16 through 18, II-3, 6, 8, 9, 16, 17, 21, 22, 29, 30, III-31 through 36 of the report.

Conclusion No. 7 - Similarity of Boeing and Otis Command and Control Subsystems

Conclusion

Both AGRT prime contractors have developed moving-block command and control (C & C) systems using different design concepts for implementation. Although each design has distinct advantages and disadvantages, the two have evolved to the point where they are functionally quite similar.

Discussion

Boeing and Otis have each developed software-based C & C systems that will allow them to meet AGRT functional and operational requirements. Each is satisfying the requirements for a fail-safe/fail-operational system through the use of microprocessors, microcomputers, redundancy, and a hierarchical C & C system that allocates responsibilities to the lowest level possible.

Because of difficulties encountered in the development of its radar/reflectometer based collision-avoidance system (CAS), Boeing is now pursuing the development of a CAS that will result in a Boeing C & C system that is functionally quite similar to that of the Otis C & C system. Both systems then would rely upon inductively-coupled, digital communication systems for transmitting individual vehicle speed and location information to the wayside for the determination of vehicle separation and control commands. Each design, however, has features that are unique and that may provide some advantages over the other design. For instance, the Boeing system uses dual similar hardware and dual dissimilar software to achieve a fail-operational/fail-safe capability. Otis uses only hardware redundancy to achieve this.

References

References which support Conclusion No. 7 are pages II-5, 6, 8, 9, 15, 18, 19, 21, 22, IV-5, 6, 12, 13 and 14 of the report.

Conclusion No. 8 - MAGLEV

Conclusion

High speed magnetic levitation (MAGLEV) and propulsion technology has advanced substantially in recent years, especially in Germany and Japan. Some of the advantages of high speed MAGLEV technology may be transferrable to low and medium speed applications. In order to establish the extent to which this technology is applicable to conventional transit and AGT/AGRT systems, more MAGLEV development as it applies to these systems is needed. Specific developments include guideways, switches, and vehicle control and communications. Also, system level studies are needed to establish the AGT/AGRT operating scenarios which most effectively utilize these advantages.

Discussion

Some of the advantages of high speed MAGLEV are propulsion and braking independent of friction, low noise, increased reliability, and improved ride quality. These advantages are potentially beneficial for low or medium speed application. They are supported by measurements performed on existing MAGLEV configurations; others are deduced from intrinsic system characteristics. For example, the noise demonstrated by the HSST-01 system in Japan was lower than that from conventional trolley coaches. Under normal operating conditions, MAGLEV vehicles do not contact the guideway; therefore, there is no ground vibration transmitted to the vehicle and ride quality is enhanced.

These potential benefits are especially relevant in urban environments. They have been heavily considered by transit people in their decision to deploy two different low speed MAGLEV configurations--one in England (Birmingham Airport) and the other in the Federal Republic of Germany (Berlin DPM). These are examples of simple AGT applications. In contrast, for the Toronto case (Transurban system), the project was abandoned because the technology was found to be too complex for its intended application. The Transurban system used LIM propulsion with electromagnets to provide both lift and guidance.

During the past 10 to 15 years, high-speed MAGLEV technologies--particularly linear motors--have advanced substantially. Research and development activities around the world have resulted in test track demonstrations of both attractive and repulsive MAGLEV transportation systems. A record speed of 320 mph for repulsive MAGLEV has been obtained in Japan. Also, a record speed of 248 mph for attractive MAGLEV has been obtained in Germany.

A beneficial by-product of high speed MAGLEV efforts has been the demonstration of the concepts and the performance characteristics of MAGLEV subsystems in the medium and low speed range (below 60 mph). These

subsystems include linear machines, power conditioning units (PCU), gap sensors and controllers.

Such subsystems have been operated for extended periods of time. The German TR05 vehicle was operated extensively at a maximum speed of 46 mph at the 1979 International Transport Exhibition IVA, Hamburg. The Japanese HSST-02 vehicle was operated at a maximum speed of 62 mph. These passenger-carrying demonstration vehicles used variations of attractive MAGLEV concepts.

References

References which support Conclusion No. 8 are pages V-17 through 24 of the report.

Conclusion No. 9 - Mag-Transit Study

Conclusion

As part of the overall AGRT program, Boeing is developing the Mag-Transit concept which is one of several MAGLEV technologies. Significant progress has been achieved by this study in the further development of the power conditioning unit (PCU) and vehicle controller. However, the study is presently too limited in scope to establish the viability of using the Mag-Transit concept in low and medium speed urban transportation systems, and substantiate the apparent advantages of the Mag-Transit concept over other MAGLEV technologies, or other forms of contacting and non-contacting suspension technologies.

Discussion

The Mag-Transit concept (originally called ROMAG by Rohr) is a subset of MAGLEV and involves the use of a single-sided linear induction motor (SLIM) to provide both propulsion and suspension/guidance. It is only one of several attractive-type MAGLEV technologies.

The Mag-Transit concept was intended for low speed applications, but has the potential advantages attributed to high speed MAGLEV systems such as reduced noise, less sensitivity to weather, improved reliability and lower operation and maintenance costs. It was also anticipated that by producing propulsion and suspension/guidance forces in one subsystem the use of the Mag-Transit concept would result in reductions in weight, space and energy expenditure.

A clear basis for decision making about the Mag-Transit concept was not established when Boeing took over Rohr's work. This was due to a lack of detailed supporting data necessary to make meaningful comparisons between separate and integrated MAGLEV systems. In addition, questions relative to the feasibility of the Mag-Transit concept for urban applications remained unanswered. These included energy consumption, weight, controller complexity, guideway and switch configurations, safety-related issues and system performance capabilities for speeds below approximately 60 mph.

The original UMTA Mag-Transit program was intended to resolve these issues. However, as a result of budget cuts, the program will not provide sufficient data to allow for reasonable comparisons with other MAGLEV technologies, nor will it permit development of a system that optimizes weight, size, energy and operational factors.

References

References which support Conclusion No. 9 are pages V-3 through 16 of the report.

Conclusion No. 10 - Foreign AGRT Development

Conclusion

Foreign test track demonstrations performed during the 1970's indicated that an AGRT-type concept was technically feasible. Although AGRT efforts are not being pursued at this time, the development and deployment of foreign automated fixed guideway (AGT) systems is being actively pursued. AGT is viewed as an alternative for bus and heavy rail in medium-sized cities, and as rapid rail feeders or extensions to rail lines. It can be expected that foreign AGT technology will be actively marketed in the U.S. and, therefore, compete with domestic technology.

Discussion

During the years around 1970, significant automated guideway system development efforts in France, Germany, and Japan were directed toward PRT-type systems. These systems were characterized by small vehicles running on elevated guideways with short headways, and were to provide demand-responsive origin-destination service. During the mid-seventies, the PRT technology developments either underwent modifications or were terminated. In Japan, the PRT development was terminated. In France, the small vehicle PRT concept was abandoned in favor of a system with some AGRT-type attributes, such as a small 10-passenger vehicle and trips without transfers, but with longer headways (40 seconds and more) and on-line stations. In Germany, the PRT technology was modified by adding system features comparable to the U.S. AGRT systems. It is interesting to note that innovative transit system development activities abroad followed closely the pattern in the U.S. with efforts directed toward PRT around 1970 and then redirected toward AGRT-type technologies in the mid-seventies.

Presently, none of the foreign PRT and AGRT-type system development efforts are active. Such systems are considered technically feasible and have been demonstrated on test tracks. However, systems which had matured to the level of possible urban demonstration are not being considered for urban implementation at this time.

Although PRT and AGRT technology development has ceased, programs for the development and installation of other AGT systems are still very active. In France, the VAL system and the POMA 2000 system are scheduled to start revenue service in 1983 and 1984, respectively. Operation of the first ARAMIS system is expected for Paris in 1989. In Germany, the first deployed H-Bahn system is nearing completion and an M-Bahn system was started in late 1982 in Berlin. In Japan, ten systems exist in various stages of development; three guideway transit systems are operational, two of which are automated. The above systems all employ large vehicles with the exception of the 10-passenger ARAMIS vehicle.

Further, there is general agreement that other foreign markets exist for intermediate capacity (approx. 3,000 to 15,000 pph), automated, fixed guideway systems in cities with populations of 100,000 to 500,000. Such systems are expected to provide better service than light rail systems and to have significant cost advantages. They are seen to be less capital intensive than rail and to have lower O&M costs than bus systems. Higher levels of service are expected from high service frequency during peak and off-peak hours and shorter trip times on segregated guideways.

French, German, and Japanese AGT system developers/suppliers have undertaken significant marketing efforts in the U.S. It can be expected that these marketing efforts will intensify as operating experiences are accummulated with the new foreign systems. Competition may then exist between foreign products and products from the U.S. AGRT Program. It should be noted that most foreign domestic markets are too small to amortize the large development cost for new and advanced transit technologies and, consequently, penetration of foreign markets is pursued aggressively.

References

References which support Conclusion No. 10 are pages VI-15 through 27 of the report.

RECOMMENDATIONS

The above conclusions, together with the supporting data contained in the report proper, represent the results of the program review. Based upon this information, it will be possible to formulate decisions relative to the future course of the AGRT system development program.

The recommendations resulting from this review are presented on the following pages. Each is followed by supporting discussion and is referenced ("Justification") to those conclusions which served as the primary basis for the recommendation. It is recognized that the implementation of some of these recommendations will impact not only the overall program, but may result in the modification of ongoing work by the prime contractors.

Recommendation No. 1 - Use an Incremental Approach

Recommendation

It is recommended that a series of graduated interim goals/requirements be identified that will allow incremental progress towards an AGRT capability. These interim goals/requirements should be structured so as to reduce instances where any of them complicate the realization of others. This process should focus increased emphasis on cost and maintainability.

Discussion

There are three elements driving this recommendation. One is the realization that the current set of AGRT goals/requirements represents a major advance with respect to present transit characteristics. Recent experiences such as Transbus, SOAC and MPM programs have taught that changes of this magnitude are difficult to achieve in a single jump. Attempting to satisfy them completely, all at once, presents significant technological and developmental hurdles that may measurably delay progress, and make the realization and acceptance of a successful system much more difficult. There is instead the need to approach the situation in a series of manageable steps.

The second element is the fact that many of the current goals/requirements adversely affect the achievement of others. In identifying interim goals/requirements, care should be taken to avoid levels of specified parameters that unduly pose such complications. This does not say that the original specifications are unworkable, unrealistic or obsolete. It merely recognizes the necessity to structure the program in a sequence of steps such that the effort is directed to progressing toward the desired capabilities, rather than attempting to compromise among them.

Finally, the third element driving this recommendation is the importance of costs and maintainability to system viability. Significant reduction of capital costs would do more to increase the attractiveness of AGRT than perhaps any other single effort, because the market is so heavily tied to costs. Such a cost reduction could greatly increase the number of potential applications where these systems would be viable. Work to date has provided some understanding of the directions along which to proceed in order to achieve lower costs.

Maintainability is a significant problem with current AGT systems. Major causes of automated transit system failure include car doors, power collectors, and guideway switches. Since AGRT systems are contemplated to potentially have large fleets of vehicles, they will have many doors, power collectors, and other components with failure potential and requiring maintenance. Efforts need to be focussed upon achieving better reliability and maintainability, and upon reducing maintenance

requirements. As with the case of capital costs, there are indications of profitable paths to follow. The sophisticated application of modern reliability techniques and technology offers potential in this regard.

The importance of this point cannot be overemphasized. The major potential benefit of automation is higher labor productivity, and this cannot be achieved unless maintenance costs are minimized.

Justification

The justification for Recommendation No. 1 is Conclusion No. 4.

Recommendation No. 2 - Test Selected AGRT-Type Technology

Recommendations

Before implementation at transit systems, appropriate AGRT-type technology should be thoroughly tested, first at existing facilities at the Transportation Test Center in Pueblo, Colorado, and later, as appropriate, in an operating urban transit environment. These tests should include selected technology developed by the AGRT prime contractors and technology developed by the traditional transit-system suppliers.

Discussion

Some of the technology being developed for the AGRT program may be able to improve the performance and the productivity of AGT and other conventional transit systems such as light and heavy rail. This technology is under development by the AGRT prime contractors and, in some cases, similar systems are being developed independently by one or more of the traditional transit-system suppliers.

The purpose of this proposed work would be to (1) select technology which offer the possibility of improved performance and/or productivity of existing transit systems, (2) thoroughly test the resulting hardware and software in the laboratory-type environment of the Transportation Test Center and determine its operating characteristics, reliability, maintainability, and cost, (3) continue testing of successful candidate technology in an operating urban transit system by "overlaying" the function/hardware so that normal operation of the transit system is not affected by the test, and (4) make the results of the tests available to transit-system operators.

Candidate technology for such implementation includes the following:

- Moving-block collision avoidance systems
- Microprocessor or computer-based control systems
- Improved anomaly management
- Power conditioning units
- Diagnostic systems
- Digital communications systems.

Moving block control systems, as discussed in Conclusion No. 1, offer potential advantages over fixed-block systems in two areas. One area is increased throughput capability; this would apply more to new transit systems rather than existing ones where the turnbacks, crossovers, and stations are already established. A second area of interest to both new and existing transit systems is the operating flexibility which is inherent in a moving-block control system. This flexibility is obtained by the operating

characteristics of the software used in the computer(s) inherent in a moving-block system. The ability to change the operation of a transit system in response to changes in daily and seasonal traffic patterns, weather conditions, and special events could significantly improve both the performance and the productivity of a transit system.

Microprocessor or computer-based control systems, as also discussed in Conclusion No. 1, can provide low cost, reliable systems having great flexibility in their operation. Since the use of a microprocessor or computer is inherent in a moving-block control system, the work on moving-block control systems and computer-based control systems could be combined. Modern computer technology, which is advancing at a rapid pace, can (1) allow optimum or near-optimum operation of a transit system under changing operating conditions, (2) minimize energy consumption, (3) optimize passenger service, and (4) perform bookkeeping functions associated with the operation and maintenance of the system.

Power conditioning units being developed by the AGRT contractors modify and control the primary electric power supplied to a transit vehicle or train. These control units, using modern components and technology, can operate more efficiently than the older control units presently in service on some transit systems. In addition, they can be smaller, lighter in weight and more reliable than the older units.

Diagnostics are an important factor in minimizing the maintenance costs of a transit system and are included to some extent in the AGRT systems currently under development. A computer, which may already be on board a transit vehicle or train as part of the control system, coupled with modern sensors, could be used to identify failures or perhaps even incipient failures.

Digital communications systems, such as those being developed on the AGRT program, can be used to communicate between transit vehicles and the wayside and the central control facility. These communications systems can be used to transmit information such as speed commands and route instructions to a vehicle or train in motion. They can also be used to transmit information from a vehicle or train to a wayside location or a central control facility giving the position, speed, and operating condition of the vehicle. This information, in turn, can be used by a central control facility to optimize the operation of the system in real time.

Justification

The justification for Recommendation No. 2 is Conclusion Nos. 1, 6, 8 and 9.

Recommendation No. 3 - Focus on Cost Reduction

Recommendation

In order to make AGRT an attractive option it is necessary to reduce overall system capital and operating and maintenance costs. Therefore, effort should be devoted to these areas.

Discussion

The priorities of the AGRT program need to be directed to the market needs. Therefore, effort should be devoted to reducing capital costs and operating and maintenance (O&M) costs so that AGRT will be a competitive transit option.

Additional goals should be to reduce the amount of guideway required and the intrusiveness associated with the use of elevated guideway structures. Program efforts need to be specifically directed to activities which can achieve these goals. Novel operational techniques should be explored as a means to reduce capital costs.

The central control of automated systems makes concepts such as bi-directional operations over portions of the guideway feasible. However, research into failure management and recovery techniques is required because of the vulnerability of such "single thread" designs to vehicle breakdowns. Other areas with significant cost pay-offs are identifiable. For example, major savings in right-of-way acquisition costs would be possible if vehicle turn radius could be minimized. In some cases the difference would be not simply money saved, but whether or not the right-of-way would be acquired at all. Other examples include programmable headway controls, simplified automatic coupling, vehicle entrainment and track sharing.

Another approach to reducing costs is to focus upon lower cost guideways. A recent study showed that a concrete box beam is less expensive than the cheapest U-shaped guideway and less expensive than the type guideway described by Otis at a recent AGRT briefing for APTA.

This effort will be of direct benefit in providing the less costly intermediate-capacity fixed-guideway transit needed by cities today. Light and rapid rail systems, and AGRT will also benefit from this effort.

Justification

The justification for Recommendation No. 3 is Conclusion No. 4.

Recommendation No. 4 - Test Advanced Command and Control Subsystems

Recommendation

Future command and control (C & C) subsystem testing plans should concentrate upon the development of greater flexibility for functional verification testing and demonstration. In order to achieve this, it may be beneficial to test these systems at the Pueblo, Colorado, Transportation Test Center using existing facilities.

Discussion

Use of the Test Center at Pueblo to test C & C systems developed for AGRT in the context of conventional (non-AGRT) vehicles will demonstrate those features which may be readily transferred for use by AGT, light rail, and heavy rail transit systems. It would also be possible to test those C & C systems developed in the private sector. By so expanding the horizon of the AGRT program relative to C & C systems, the participation of the nation's private-sector transit equipment developers could be provided for and encouraged. Along with this participation would be the opportunity for the direct and ready transfer of technology from the AGRT program to these developers. It must be recognized that the systems developed by the private-sector developers are proprietary and it will be necessary to maintain their proprietary rights.

Justification

The justification for Recommendation No. 4 is Conclusion Nos. 1, and 8.

Recommendation No. 5 - Continue MAGLEV Development

Recommendation

Development of MAGLEV technology should be continued in order to substantiate its advantages and disadvantages in urban applications, and to establish the optimum configuration for urban deployment.

Discussion

Although considerable effort has been devoted to the determination of the advantages and disadvantages of MAGLEV technologies under high speed applications, its low speed applicability has not been as thoroughly examined. The current UMTA MAGLEV program is considering the Mag-Transit concept as part of a low speed, urban, high performance AGRT system and the focus has been restricted to the vehicle level only. The questions of what is the best MAGLEV approach and where MAGLEV technology can best be applied in the complete AGT spectrum are difficult to answer at this time because of the range of possible alternate designs and the lack of any detailed test or operational data for making comparisons.

The actions necessary to resolve these questions in a timely manner would require an enhanced level of UMTA support. These actions would include:

- The clarification of the nature in which MAGLEV cost and performance capabilities satisfy the operation/utilization requirements for urban mass transit.
- The evaluation of MAGLEV developments abroad such that developed technologies may be considered for integration with U.S. developed subsystems and components.
- Continued hardware development to provide a more reliable information base.

Justification

The justification for Recommendation No. 5 is Conclusion Nos. 8 and 9.