Chapter 6

# THE PLANNING AND DEVELOPMENT PROCESS

# INTRODUCTION

The main purpose of a rail rapid transit system is to transport passengers with speed, safety, and dependability. The train control system provides the protection (ATP), operational control (ATO), supervision (ATS), and communications necessary to accomplish this purpose.

The older rapid transit systems, such as CTA, MBTA, and NYCTA, were designed to perform many train control functions manually. Until recently, the major uses of automation have been for train protection functions (ATP) and certain supervisory functions, such as dispatching. The development of new technology within the last decade or so has made it possible to automate other train control functions, and so the older rapid transit systems are now in the process of converting to higher levels of automation, especially in the areas of train operation and supervision.

Rail rapid transit systems built in recent years (PATCO and BART) and those now under construction are tending to make use of more extensive automation and more sophisticated train control than the older existing systems. Various forms of advanced ATC technology seem to figure in the plans of system designers from the very outset. Thus, it appears that the general trend in both existing and future rail rapid transit is toward increased automation. In light of this, the process by which train control systems are conceived, planned, procured, and tested assumes great significance; and it is important to investigate the way in which the ATC design evolves within the context of overall rapid transit system development.

The evolutionary cycle of ATC, like the total transit system of which it is part, has three major phases: planning, development, and testing. These phases are generally sequential but there are numerous interactions and iterative steps. For simplicity of discussion, however, the features and issues of each phase will be treated separately. At the end of this chapter is an examination of the subject of research activities that support the overall planning, development, and testing process.

The evolution of an ATC system can be lengthy, often as long as the evolution of the transit system itself. Table 31 identifies the significant dates for 16 systems—the five existing and three developmental systems considered in detail in this report and eight other systems for general reference. The CTA, MBTA, CTS (Cleveland), and NYCTA programs involve addition of new ATC equipment or extension of an existing line. For the others, the program spans the conception and development of the entire system. The times listed include the evolution of general train control system concepts and the detailed engineering development.

The major issues associated with planning and development are examined in the order in which they generally occur in the system evolution process.

### Planning (Concept Formulation and Preliminary Design)

The concept of the ATC system is usually formulated early in the overall transit system planning process, The major issues are concerned with the origin of the ATC concept, the influences which shape it, the selection of a desired level of automation, and the criteria and techniques used to evaluate the concept and translate it into a preliminary engineering design.

### Development (Final Design and Procurement)

The final engineering design and procurement process may cover several years, during which the original concept may undergo substantial change, The most significant issues relate to how the engineering design specifications are written, how contractors are selected, how the development process is supervised and managed, and how emerging differences between concept and implementation are dealt with in the development process.

### Testing

Testing is a continual process that begins as soon as specific items of ATC equipment are engineered and, manufactured and ends when the entire system is ready for revenue service. The issues in this area have to do with the types of tests conducted, the timing of the tests in relation to the development cycle, and the methods by which the ATC system is evaluated for serviceability and conformance to specifications.

### Research and Development (R&D)

R&D is a supportive activity that runs concurrently with planning, development, and testing. The issues to be examined include the types of R&D being conducted, its application to the design of

## TABLE 31.—Significant Dates in the Engineering Planning, Procurement, and Testing of ATC for Various Transit Systems

| Activities[a] | Baltimore | BART | CTA (Lake St Line) | CTS (Airport Extension) | Dade Co. | D/FW | MARTA | MBTA (Red Line) | NFTA | NYCTA (System Improvements) | PAAC | PATCO | RTD | SEA.TAC | Twin Cities Area MTC | WMATA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planning[b] | 1962 | 1951 | 1962 | Before 1965 | 1964 | 1965 | 1962 | Before 1966 | 1967 | (f) | 1959 | 1958 | 1969 | 1967 | 1967 | 1960 |
| ATC Preliminary Design Started | 1967 | 1953 | 1962 | | 1969 | 1969 | 1966 | 1966 | 1973 | | Before 1963 | 1963 | 1970 | 1967 | 1969 | 1962 |
| ATC Preliminary Design Completed | 1973 | 1966 | 1965 | | (1975) | | 1970 | | 1974 | | 1970 | | 1973 | | 1972 | 1967 |
| ATC Procurement Specifications Issued | (1977) | 1966 | | 1966 | (1978) | 1971 | (d) | | | | 1974 | 1966 | | 1969 | | 1971 |
| ATC Procurement Contract Awarded | | 1967 | | 1966 | | 1971 | | | (1976) | | (1975) | 1966 | | 1969 | | 1971 |
| ATC Bebugging Started | | | | | | 1973 | | 1971 | | | (1978) | 1968 | | 1972 | | |
| ATC First Used In Passenger Service | (1981) | 1972 | 1967 | 1966 | (1984) | 1974 | (1977) | 1971 | (1981) | | (1978) | 1969 | | 1973 | (1981) | 1976 |
| Initial Planing (Years) | 5 | 2 | | | 5 | 4 | 4 | 1 | 6 | (f) | 4 | 5 | 1 | 1 | 2 | 2 |
| ATC Evolution (Years) | (14) | 19 | 5 | 3+ | (15) | 5 | (11) | 5 | (8) | (f) | (14+) | 6 | | 5+ | (12) | 14 |
| Total Time Span (Years) | (19) | 21 | 5 | 3+ | (20) | 9 | (15) | 5+ | (14) | (f) | (18) | 11 | | 6 | (14) | 16 |

[a] Unless otherwise noted, the dates listed are for the start of the activity. Dates enclosed in parentheses ( ) are planned dates. All activities are for new systems except as noted.
[b] ATC planning is generally influenced by a number of system decisions so this date is the start of the overall system planning.
[c] Preliminary design is considered to include some conceptual work as well as demonstration projects where applicable.
[d] Activity is currently in progress.
[e] Most transit systems are constructed in phases. The program duration listed is for a single phase or the first phase of the programs. Because early planning of multiple programs is usually comprehensive the time required for such planning will generally be longer than required for a smaller single-phase effort.
[f] At NYCTA the process of equipment replacement and updating is virtually continuous.

new systems, the use of test tracks, and major R&D needs in the area of ATC technology.

## ISSUE D–1: DESIGN CONCEPTS

How do ATC design concepts originate, and by what criteria is the level of automation selected?

For new systems, ATC design concepts emerge from policy and planning decisions about the general transit system concept. Initial selection of the level of automation tends to be influenced more by social, economic, and political considerations than by engineering concerns. In already operating systems, where ATC is installed to upgrade or extend service, engineering concerns–especially evolutionary compatibility with existing equipment-are predominant. For both new and old systems, the experience of others (particularly their mistakes) has an important influence.

Some preliminary notion of the type of train control system desired is usually included in the statement of the basic transit system concept prepared by the policymaking body responsible for planning the system. For all of the transit agencies investigated in this study, the policy and planning authority is a commission or board of directors created by legislative act. The size and composition vary. Some are elected; others are appointed. The members are usually not engineers and seldom have technological backgrounds in the area of transit operation and train control, but there is always either a technical staff or an engineering consultant firm to assist the board in planning activities. Some, particularly transit systems already in operation, have staffs of considerable technical competence. For example, the CTA and NYCTA staffs do all the engineering planning for new developments and oversee procurement and testing. In general, however, the local policy and planning agency augments the technical capability of its staff by hiring consultants who conduct studies to support planning decisions and flesh out the basic design concept. In some cases, the consultant firm may also be responsible for the subsequent engineering development of the system.

The activities of the planning agency are influenced by many factors: State and Federal legislation, regulatory agency rules and decisions, UMTA policy, economics, public opinion, local social concerns, labor relations, and political interests, to name a few. Technical, considerations often play only a small part and may be overridden by these other concerns. Specific examples from among the systems investigated will help to illustrate the nature and diversity of the ways in which ATC design first takes shape.

The PATCO Lindenwold Line was planned and constructed over an n-year period. It is not clear when the basic ATC design concept was formulated; but an engineering consultant report published in 1963, about midway between the time of the initial decision to build the system and the time the line was opened for service, recommended the use of ATP and ATO. The tone of the report makes it plain that the nature of the train control system was still an open question 5 years after the planning process started. The primary justification advanced by the consultant for ATP was safety, and for ATO efficiency of operation.

In contrast, an ATC design concept for BART was established very early in the planning process and took over 20 years to evolve. Original planning studies conducted by engineering consultants to BART in 1953 to 1956 advanced the general concept of completely automatic operation at high speed and short headways. An onboard “attendant” was envisaged, not as an operator but as an aide to passengers, much like an airline stewardess. The idea of building a glamorous “space age” system employing the most advanced technology seems to have been a dominant concern in BART from the very beginning, This approach was clearly manifested in the ATC concept. The justification most often given was that advanced train control technology was necessary for the, high-speed, short-headway operation needed to attract patrons,

CTA, in planning the conversion to cab signaling, appears to have been most strongly influenced by operational and engineering factors, Cab signals were seen by CTA as an improved method of assuring train separation and preventing overspeed, i.e., as a way of enhancing safety. Compatibility with existing signal equipment and other elements of the system was also a factor (as it is in MBTA where cab signal conversion is now being implemented and in NYCTA where it is in the planning stage). Engineering and equipment concerns are also a dominant concern in the planned expansion of PATCO, where the existing ATC system dictates that the new lines have the same operational characteristics and level of automation in order to be integrated with the present line.

Operational transit systems for airports (such as Sea-Tac and AIRTRANS) feature automatic, crewless train operation. These systems were planned and built in a rather short time span (6 years for Sea-Tac, 9 for AIRTRANS). The concept of unmanned vehicles was inherent in the nature of these systems from the beginning. It was felt by the planning agencies and their consultants that fully automatic operation offered significant savings in labor costs and was the only way to make the system economically viable.

There are sometimes general engineering decisions made during the planning process that may limit the technology that can be employed for ATC equipment. For example, a number of transit planning agencies have decided to employ only equipment already proven in use by other operating transit systems. For WMATA, the schedule set by the policy makers did not permit extensive R&D and engineering studies before selecting a train control concept. Therefore, WMATA engineers decided to specify an ATC system that could be realized with proven, existing hardware.

The formulation of the ATC system concept is also strongly influenced by events in other transit systems. The community of rail rapid transit agencies, consultants, and suppliers is a small fraternity. There is a continual exchange of information among the members and a high degree of mutual awareness of plans, problems, and operation experience. Because the supply of qualified transit consultants and engineers is limited, there also tends to be a steady interchange of personnel among transit properties, consultant firms, and equipment manufacturers. These forms of interaction assure that the experience of others will be reviewed during concept selection and preliminary design,

However, the review of others' experience is often rather narrowly focused. There is a tendency to be swayed more by specific problems and incidents than by overall statistics and the general pattern of operations. "Avoiding others' mistakes" seems to be a more dominant concern than emulating their success. For instance, the problems encountered by BART were in part responsible for the more conservative approach adopted by WMATA and Baltimore MTA. Atlanta's planners also have chosen a train control system less sophisticated than that originally proposed by their consultants (PBTB, who were responsible for BART), partly as a reaction to the experience in San Francisco. Caution is a prudent course, but the rapid transit industry could also benefit if there were a more comprehensive body of comparative performance data to help make decisions on an analytical, rather than a reactive, basis.

The salient points that emerge from an examination of the initial planning process are that ATC design concepts originate (sometimes early, sometimes late) in policy-level decisions about the general nature of the system. The methodology employed to arrive at concept definition is often informal and influenced strongly by engineering consultant firms engaged to assist in planning the system. Except in the case of modernizing an existing system, technical considerations of train control system design seldom predominate. Route structure, service characteristics, vehicle design, right-of-way acquisition, cost, and local sociopolitical concerns tend to be given greater importance at the early stage of planning. The engineering aspects of train control are most often deferred to a latter stage of planning, when design specifications are to be written, As a result, the embryonic ATC design is usually not defined in detail until other parts of the system have taken shape, The preliminary ATC concept thus tends to develop a life and permanence without being subjected to engineering scrutiny and cost-benefit analysis to determine its appropriateness for, and compatibility with, the rest of the system,

There seems to be a crucial difference between existing and new systems. The former give greater weight to engineering concerns and specific operational needs in defining an ATC concept. New systems tend to take a broader, more informal, and less technical approach, The engineering-oriented approach offers the advantage of assuring a workable ATC system tailored, although perhaps not optimally, to specific local needs. But there is a disadvantage. The scope of the ATC concept in upgrading an existing system tends to be limited and constrained by what already exists. The bolder, "clean sheet of paper" approach employed by many new systems results in a more technologically advanced concept and greater coherence between ATC and the system as a whole, but the practical problems of development and engineering may not always be given sufficient attention,

## ISSUED–2: SYSTEM DEVELOPMENT

How is the ATC system concept translated into preliminary and final functional design ?

Most system development work is done by engineering consultants, except for large established rapid transit systems where it is done by the in-house staff. The methodology varies, but there is a trend toward a more systematic and sophisticated approach using simulation, system analysis, system assurance studies, and test tracks.

The first step in the development process for ATC systems is preparation of a preliminary functional design, expressing the basic concept and its underlying policy decisions in engineering terms. The preliminary design defines performance requirements and organizes the ATC system with respect to functional relationships among system components. At this stage, the ATC system is separated into its major subsystems (ATP, ATO, ATS, and communications), and the functions required of each are specified. Further analysis may separate the system into carborne and wayside elements. The preliminary design also defines the interfaces between ATC and other parts of the transit system.

For most of the transit agencies investigated, the technical staff plays some role as engineering planner in preliminary design. However, the extent of staff involvement varies widely. In established operating agencies, such as CTA, CTS, and NYCTA, the engineering staff does almost all of the preliminary design work. In new systems, where the technical staff may be quite small, especially in the early planning phases, engineering consultants are generally and extensively used. Heavy participation by consultants is also characteristic in established systems undergoing a major program of new construction or modernization. While the proportion of staff to consultant participation varies, there appears to be wide agreement among transit system managers that staff involvement should not fall below a certain minimum level, roughly 15 to 20 percent of the design work. In this way, the authority can maintain technical involvement in the preliminary design process and exercise proper control over system evolution.

Several kinds of methodology may be employed in preliminary design. The specific methods differ widely from authority to authority, and it is difficult to discern any common thread, beyond the general belief that technical studies are needed to gather and analyze information about the performance expected of the system. In the new systems now under development, there seems to be an increasing reliance on the so-called "systems approach"[79] and the use of techniques such as simulation, ridership analysis, function/task analysis, and cost/benefit studies. Several agencies (BART, CTA, NYCTA, Sea-Tac, and PAAC) have also conducted studies at test tracks on their properties to gather information needed for preliminary design.

The application of system analysis techniques does not appear, however, to extend very deeply into the design of the ATC system itself. There is a tendency, for instance in cost/benefit studies, to treat ATC as a whole, without examining the choices that may exist within the train control system as to degree of automation or alternative methods of achieving a given level of automation. One reason is the general lack of empirical data on the performance of ATC systems, which precludes a precise formulation of potential benefits, A second reason is the overriding nature of the safety factor which strongly influences designers to automate the train protection function, without regard for the cost/benefit relationship of ATP to other functional elements of ATO or ATS. Also, since the entire ATC package typically amounts to only 5 percent or less of the total capital cost of the transit system, there is a belief that cost/benefit analysis should be concentrated in areas where the payoff will be greater.

Thus, the process of developing a preliminary functional design of the ATC system still tends to be more art than science, but there is a trend toward use of more objective, quantitative, and systematic techniques. This is particularly evident at the points

[79]The "systems approach, " which derives mainly from aerospace technology, is a collective designation for techniques used to solve complex problems in a methodical, objective, and often quantitative way. The systems approach involves a logical and reiterative analysis of the system into its constituent parts, each repetition leading to a greater degree of specificity, Other characteristics of the system approach include measurability of parameters, constant recognition of subsystem interdependence, and parallel analysis of elements. The heart of the systems approach is the *'System Engineering Cycle" which involves four steps: (1) convert system requirements to functional requirements, (2) convert functional requirements to specific detail requirements, (3) conduct analysis to optimize parameters, and (4) convert specific detail requirements into end products, (Grose. 1970)

of interface between ATC and other subsystems, where mutual influence and interdependence can be reduced to quantitative expression and the parameters of performance can be manipulated. Even here, however, ATC system characteristics tend to be treated as dependent variables, i.e., the driving concerns are other system characteristics, to which the ATC system design must be accommodated.

System design is a continual and reiterative process, preliminary functional design merging into final engineering design without any clear line of demarcation, The process culminates in the statement of specific equipment and performance requirements, suitable for incorporation in procurement specifications. Often, final design coincides with the preparation of procurement specifications, and it is difficult to separate the two activities. However, for the purpose of this discussion, final design is considered to include all activities needed to define the detailed technical requirements of the ATC system, up to but not including the actual writing of procurement specifications.

As in preliminary design, the final design is executed either by the technical staff of the transit agency or by engineering consultants. Here, too, the older and established agencies tend to rely more on their own personnel, and new agencies more on consultants. Usually, a single consultant is hired for final design of the complete ATC system –carborne, wayside, and central control elements. This consultant is often, but not always, the same firm that carried out the preliminary functional design of the ATC system. Once reason for selecting a single consultant for the entire process is to assure continuity and coherence of the ATC design as it develops, It is also considered advisable to have a single consultant for all parts of the ATC system to ensure integration of the design of vehicle and wayside equipment and their all-important interface.

Many of the factors that shape the preliminary design of the ATC system continue to have significant influence during the final design process. Nontechnical factors still play a strong, but perhaps diminishing, role as the system moves from planning to engineering. The continuing influence of nontechnical factors is not surprising since they are usually built into the design criteria and guidelines that emerge from preliminary design and are applied to the final design. Still, as the system approaches the hardware stage, it is to be expected that purely engineering considerations should come to the fore. Generally speaking, however, the process of generating detailed engineering requirements from preliminary design criteria is basically an interpretive effort, with the experience and judgment of the designer playing the dominant part. However, there are two more formal design methods that are being used increasingly in new transit systems. They are system safety methodology and quantitative reliability, maintainability, and availability analysis.

Most of the systems now being planned are including a formal system safety study, involving definition of safety criteria, analysis of potential safety problems, and identification of ways to eliminate or minimize hazards, Some designers consider this approach to safety superior to the traditional methods of "fail-safe" design. Others disagree sharply.[80] It appears, however, that much of the controversy over the "fail-safe" and "system safety" methods is semantic; and it is premature to determine whether the results of the two approaches will differ, The important point is that designers are turning, at least in the area of safety, to more systematic and quantitative methods of analysis,

Until recently, it has not been the practice in the transit industry to specify safety requirements in quantitative form, i.e., as a numerical statement of risk or probability of occurrence. Many believe that the levels of safety which must be achieved are so high that it is difficult, if not impossible, to state meaningful quantitative standards and to devise an acceptable and practical method of verifying that they have been met. This view is not universally held, and the topic is highly controversial. However, it does appear that future ATC specifications will place strong emphasis on formal procedures by which potential safety hazards can be identified, evaluated, and reduced to "acceptable" levels. An effort is being made to put hazard analysis on a quantitative basis, but much of the work is likely to remain qualitative and judgmental. (Again, this view is not shared by all in the transit industry, ) Along with the emphasis on quantitative methods, there is also a trend to define safety in a sense that is broader than just train protection and to deal with the safety aspects of the total system.

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1111%111 chapter 5, page 86 for a discussion of this topic.

The second formal design method that is coming into wider use in the transit industry is quantitative reliability, maintainability, and availability (RMA) analysis. A discussion of this design technique is postponed to Issue D–4, where it is considered as part of the general question of how these aspects of system performance are written into procurement specifications.

## ISSUE D—3: PROCUREMENT SPECIFICATIONS

How are ATC design requirements specified, and is there a "best" way to write such specifications ?

There are two basic approaches to writing specifications— the design (equipment-specific) approach and the functional (performance) approach. Each has advantages and disadvantages. The only generalization to be made about the "best" way is that, whichever approach is used, it is of crucial importance to specify equipment performance standards and to define explicitly the means of testing.

The final design of the ATC system is documented in procurement specifications in terms of required performance for ATC functions and/or equipment components. However, the procurement specifications have a much broader scope than just a listing of required ATC system performance. Requirements for documentation, scheduling, installation, management visibility and control, and various types of testing may be specified together with numerous contractual and legal provisions. The procurement specifications include all of the detailed information required for a prospective supplier to prepare a bid.

As a general rule, the organization that does the final design of the ATC system also prepares the technical portions of the procurement specification for that system. At times, another consultant writes the procurement specifications in cooperation with the final designers. In this way some additional expert knowledge is incorporated into the specifications.

The most common method of preparing procurement specifications is by drawing on available specifications for similar equipment, from preliminary proposals submitted by equipment suppliers, or from experience gained through testing or use of similar equipment. Often, a general incorporation of test and use experience is achieved by requiring the use of "proven technology," which means that the same or similar equipment must have been used or tested successfully on an operating transit property in the United States.

There are two basic approaches to writing procurement specifications. Requirements can be stated in functional terms (performance specifications) or in equipment-specific terms (design specifications). The two are not mutually exclusive, and in practice something of each approach is used. Thus, implicit in even the most design-oriented specification is the expectation that the equipment should perform in a certain way,

The design type of specification indicates, to a greater or lesser degree, the equipment or system components needed to perform individual functions. In the extreme case, design specifications call for particular items, for which only a narrow range of substitutes, or none at all, are acceptable. Such specifications are often issued by transit agencies that have similar, satisfactory systems in operation and wish to assure compatibility of the new equipment with that already in place. Recent procurements of cab signaling equipment by CTA typify this approach. Somewhat less restrictive is the design specification that calls for a type of equipment with stated characteristics but leaves the supplier some room for choice. The WMATA train control system specification is an example of the modified design-oriented approach, which has some of the features of a functional specification.

Functional (or performance) specifications define what functions are to be accomplished but not the way in which they are to be accomplished. For ATC systems, the BART specification comes closest to the purely functional approach, The Diablo test track was operated for the purpose of determining the feasibility of new ATC concepts (not to select a system). At the end of the testing period a functional specification was written to accommodate any of the concepts successfully demonstrated (and many others). For example, the basic train separation system could have used radar, track circuits, or any other device that met the stated functional requirements,

Table 32 below is a rough classification of the type of specification used by seven transit systems in recent procurements. The development of the six newest systems (Baltimore, Dade County, MARTA, NFTA, RTD, and Twin Cities) has not yet advanced to the point where ATC system specifications have been written.

**TABLE 32.—Type of Specification Used in Recent ATC Procurements**

| SYSTEM | TYPE OF SPECIFICATION | | |
|---|---|---|---|
| | Design | Functional | Combined |
| AIRTRANS | | x | |
| BART | | x | |
| CTA | x | | |
| NYCTA | x | | |
| PATCO | | | x |
| SEA-TAC | | x | |
| WMATA | | | x |

The use of a design specification permits the buyer to exercise a high degree of control over the equipment purchased. At the same time, however, it requires considerable experience and technical competence on the part of the buyer to be sure that what he specifies will perform as intended. There is always the risk that individually procured subsystems will not prove compatible, with the buyer having no recourse but to go through a process of redesign or retrofit. If a testing procedure has been established in the specification, product evaluation and acceptance is usually easier for the buyer who has followed the design approach. To the extent that design specifications are equipment-specific, they lock the buyer into a given technology and do not allow taking advantage of innovation, economy, or other improvements that the seller might otherwise be able to effect.

One of the major advantages of a functional specification is its independence from particular means of implementation. It gives the supplier great latitude when innovation is desired or when a wide range of hardware is acceptable. This approach is most compatible with a new system being built from the ground up or with an independent part of an existing system. In effect, the functional specifications transfer some of the responsibility for system design from the procuring agency to the equipment supplier.

Functional specifications, because they are less detailed, may be somewhat easier to prepare than design specifications. On the other hand, it is somewhat harder to define the desired end product with precision. The functional specification allows the supplier to be creative, but it can also provide the opportunity for cutting corners. Litigation, as in the case of the BART train control system contract, is always a possibility if differing interpretations are taken or if the method of testing system performance is not well defineed. From the buyer's standpoint, one difficulty with functional specifications is that it may not be possible to determine if the product will meet performance requirements until the complete system is assembled,

There is no universal agreement on the superiority of either type of specification, Either can be employed successfully so long as the buyer recognizes the shortcomings of the selected approach and so long as the standards for an acceptable . product are clearly and fully defined. The results of the WMATA specifications, which combine a functional and a design approach, will be awaited with great interest to see if they offer a compromise solution to the problem of specifying equipment requirements and characteristics.

It is of crucial importance that both the criteria and methods of testing the equipment be made explicit in the procurement specification, From a practical standpoint, the design type of specification may offer some advantages over the functional specification in terms of the ability to define and measure reliability and maintainability-a problem that lies at the heart of the difficulties encountered by most new systems. Because of its importance, the topic of how RMA requirements are specified is treated as a separate issue immediately following.

## ISSUE D--4: SPECIFICATION OF RELIABILITY, MAINTAINABILITY, AND AVAILABILITY

Are the methods of specifying reliability, maintainability, and availability (RMA) adequate to assure that ATC systems will give good service ?

This has been one of the most troublesome areas of ATC system design and development. Transit agencies are becoming increasingly concerned with RMA problems, and an effort is being made to write specifications in more precise and quantitative terms. In their present state, however, RMA specifications still fall short of what the transit industry (both buyers and manufacturers) consider satisfactory.

RMA specifications can be divided into two classes—those that state quantitative requirements and those that do not. Before issuance of the BART specifications, most transit agencies followed a nonquantitative approach to RMA specifications, and some still do. The BART specifications were a pioneering effort to introduce in the transit industry the quantitative methods used in the aerospace industry for specifying RMA. This was a major innovation at the time and, like nearly everything else associated with BART, controversial. However, all the agencies planning new systems are now incorporating some form of quantitative RMA requirements in their specifications.

Historically, reliability and maintainability have been treated only in general terms in procurement specifications by transit agencies. Some form of warranty was called for, but specific requirements as to reliability (mean time between failure, or MTBF) or ease of repair (mean time to restore, or MTTR) were not stated. Certain transit agencies continue to follow this practice for a number of reasons. In some cases, the procurement consists of additional equipment similar or identical to past purchases. Thus, the expected performance of the equipment is understood by buyer and seller to be like that already in use. Another reason has to do with the size and nature of the transit industry. There are only a few buyers and even fewer sellers, all of whom have been in business for many years. Hence, the needs of the former and the capability and reputation of the latter are well known. In such circumstances, it is considered unnecessary to draw up elaborate and detailed statements of RMA requirements. The seller is familiar with the kind of equipment now in use by a transit system, and the transit agency knows that the seller must stand behind the product in order to remain in consideration as a source of supply. A third reason for taking the nonquantitative approach, especially in small transit systems, is that the managing authority may not feel it is cost-effective (or they may not be able to get the funds) to prepare specifications that involve extensive engineering analysis, and perhaps testing.

The quantitative method of specifying RMA has found increasing favor in the transit industry for two basic reasons. First, the type of equipment now being purchased, especially for ATC systems, is much more complex and technologically sophisticated, creating a need for the document that governs the purchase of the equipment to become increasingly detailed and precise. Second, the number of suppliers has increased and now includes firms without a long and established record in the area of train control equipment manufacture and installation. Starting with BART and continuing with WMATA, MBTA, and a number of new systems being planned, transit agencies are turning to a quantitative approach.[81] Still, a decade after the BART initiative, the specification of RMA requirements remains a developing art,

There are significant differences in how quantitative RMA requirements are written, depending upon whether the procurement document is a design or a functional specification. In a functional specification, the buyer defines generic types of failures, their consequences, and required system performance. The seller is (in theory) free to configure the system in any way seen fit so long as the functional requirements are met and the system performs as expected. In a design specification, the buyer develops a specific equipment configuration, evaluates the consequences of failure of each component (equipment items not functions), and defines the component performance requirements. The seller must then meet the performance requirements on an item-by-item basis. Thus, the seller may well have no responsibility for the performance of the total system, but only for the parts as set forth in the procurement specification. In effect, the functional specification transfers much of the responsibility for detailed system design to the equipment supplier, whereas with a design specification this responsibility is retained by the purchaser.

With regard to RMA, the difference between design and functional specifications centers around the definition of failure. In design specifications the definition is reasonably clear-cut and precise. Failure means that a given component does not respond to a given input or fails to make a particular output within stated tolerances. In a functional specification, failure is defined not in terms of specific equipment performance, but more generally as the inability of the system (or subsystem) to perform certain functions. Some functional specifications (such as those prepared for BART and Sea-Tac) also identify the consequences of failure that are of concern.

[81] MARTA, Dade County, Denver RTD, NFTA, PAAC, and Twin Cities are all contemplating the use of quantitative RMA specifications.

A problem of interpretation can thus arise in evaluating equipment procured under a functional specification. Some failures and their consequences are defined; but others are not, even though the same piece of equipment may be involved. What then is a failure? And what particular equipment malfunctions are to be counted in determining the reliability of the purchased equipment? There is a disagreement, and litigation in progress, between BART and the ATC equipment supplier (Westinghouse Electric Corporation) as to the intent of the specification on these very points.

The WMATA train control system procurement specification, written with the BART experience in mind, attempts to deal more clearly with the definition of failure. In the WMATA specification, failure is defined as "any malfunction or fault within an equipment which prevents that equipment from performing its function in accordance with the specification. " Thus, it appears that WMATA RMA requirements pertain to all equipment failures without regard to the effect on train operation. However, the specification does not clearly indicate what modes of operation are to be counted and how equipment operating time is to be reckoned in calculating MTBF, In some systems, ATC units are located at each end of the train and actually control only half the time. If a failure occurs in a unit not involved in train operation at the time of malfunction, is this to be counted as failure? And if so, how many hours has it been operating? All the time that the car has been in revenue service, or only that part of the time that the ATC unit has been used to control the train?

Without belaboring the example, it is clear that the transit industry still has not reached a full and universally accepted understanding of how to specify and test equipment reliability. A recent statement by a representative of an equipment manufacturer (King, 1975) highlights the continuing problem.

> Success and failure of transit equipment and systems must be defined in relation to their mission. Indeed, the term "mission" itself probably requires redefinition. Many industry specifications in recent years have not agreed on such points as whether a transit vehicle completes its mission at the end of one trip or the end of a full day, or when that day ends, or whether the vehicle must be available during all peak service periods. If the function of transit equipment is carrying passengers, has a mission failed if an equipment outage occurs during nonrevenue service? These are some of the fundamental questions which must be answered to define traditiona1 reliabi1ity in a manner acceptable to transit industry application.

One of the significant problems affecting the ability of the transit industry to draw up meaningful RMA specifications is the lack of a data base describing the performance now being achieved in the industry. Individual manufacturers have some information, as do individual transit systems, but there is no uniform method of reporting and no available industry-wide data base.

This need has been recognized by transit agencies and equipment manufacturers; and, through their industry organization (the American Public Transit Association), an effort is underway to deal with the problem. APTA task group, known as RAM (for Reliability, Availability, and Maintainability), has been assigned the responsibility of developing recommendations for a standardized data collection and reporting procedure. The problem of making these data generally available, free from local transit system bias and manufacturers' proprietary concern, is still unsolved,

## ISSUE D–5: ‘ EQUIPMENT SUPPLIERS

What firms supply ATC equipment? Is there transfer of ATC technology between automated small vehicles and rail rapid transit systems?

Historically, two U.S. firms—GRS and US&S--have supplied most of the ATC equipment to the rapid transit industry. In recent years, several new firms, supplying either special product lines or control equipment for small vehicle sytems, have entered the market. The major transfer of ATC technology is from rail rapid transit to small vehicle systems, but not the reverse.

The suppliers of ATC equipment to the rail rapid transit industry fall into two distinct groups: those that provide a broad line of services and equipment and those that have limited lines or specialty products. There are many firms in the latter category, but the former includes four companies, General Railway Signal Company (GRS) and Union Switch and Signal Division of the Westinghouse Air Brake

Company (US&S)[82] are old, established firms that have a long history in the signals and communication business and have dominated the market. Recently, two new suppliers have entered the competition. Westinghouse Electric Corporation (WELCO) supplied the ATC system for BART, where they were low bidder against GRS and US&S. Transcontrol is furnishing the ATC system for the San Francisco MUNI light rail system and for the Toronto Transit Commission in Canada,

There are many more suppliers of ATC equipment for small, automated-vehicle, fixed-guideway systems. In addition to GRS, US&S, WELCO, and TransControl, the list includes Philco-Ford, TTI (now TTD) and Varo Monocab.

The number of firms supplying small-vehicle ATC systems, and the organizational relationships among them, change from year to year. Some drop out of the market, new ones enter, and others form joint ventures or acquire each other. It is a market where there are many more companies offering systems than have actually received contracts for installations, Further, the resulting contracts are usually rather small. The complete "Satellite Transit System" installation (guideway, vehicles, and controls) at the Seattle-Tacoma airport was about $7 million, while the AIRTRANS system at the Dallas-Fort Worth airport was about $3 I million. The ATC portions of these systems were about 7 to 12 percent of the total contract prices.[83]

To date, transfer of technology between conventional rapid transit systems and the new small vehicle systems has been in one direction—from the conventional to the new systems. Reverse transfer, and entry of small vehicle system developers into the conventional rail rapid transit market, has not occurred, perhaps due to the much larger size of the contracts and capital commitments required to compete in the conventional rail rapid transit market, or perhaps due to the failure of AGT suppliers to develop workable systems for rail rapid transit application.

While some foreign-made ATC equipment is utilized in the United States, the market is not really receptive to foreign incursions. There are several reasons. Some procurement specifications exclude foreign suppliers by requiring prior transit service in the United States or by including restrictions on foreign-made components. Also, U.S. transit agencies tend to doubt that foreign suppliers would be able to provide continuous long-term service. Finally, there are some major differences between U.S. and foreign ATC technology and engineering techniques.

## ISSUE D–6: CONTRACTOR SELECTION

How ore contractors for ATC design and engineering selected?

The lowest technically qualified bidder is usually selected. Competitive bidding and award to the low bidder is required by law in many States.

Usually, two or more suppliers will compete for the opportunity to design, build, and install ATC system hardware and software in response to the technical specifications describing required system characteristics. Ultimately, responsibility for selection of the supplier rests with the directors of the transit authority. Most frequently, the directors rely on their technical staff for evaluation of the proposals and for monitoring the work of the selected contractor. This procedure was followed at CTA, CTS, MBTA, NYCTA, and PATCO. However, at BART, the general engineering consultant (Parsons, Brinckerhoff-Tudor-Bechtel) was delegated authority for some of the contractor selection and management. Interviews with personnel at new systems in the planning or early construction phases (MARTA, RTD, WMATA, Baltimore, NFTA, and the Twin Cities) indicate that these agencies will also utilize consultants to assist in contractor selection and management,

The increasing involvement of consultants in contractor selection and management for new rail rapid and small vehicle systems reflects the increasing complexity of new rail rapid and small vehicle systems. The design and development of such systems is often beyond the capability of the limited staff maintained by most transit agencies. It should be noted, however, that consultants may have somewhat different motivation and may use somewhat different evaluation criteria than the transit authority,

[82] Union Switch and Signal is also referred to by the acronym of its parent firm, WABCO.

[83] In relative terms, this proportion is somewhat greater than the 3 to 5 percent of total contract price that is typical for rail rapid transit systems. The absolute dollar amounts, however, are quite small.

Contractor selection is relatively simple when "off-the-shelf" equipment is to be used and the competition reduces to a matter of price among prospective suppliers, all of proven capability. Often, however, the available equipment does not satisfy all of the specifications and requirements. Contractor selection then involves identifying qualified suppliers, publishing an invitation for bid, evaluating the bids received from the prospective suppliers, and awarding a contract. Table 33 summarizes the contractor selection approaches used by transit authorities in several recent procurements.

Several of the transit authorities require that a prospective ATC system supplier be a manufacturer of equipment proven in use on operating transit systems in the United States. If the ATC system at BART is considered to be proven, this restricts the list of qualified ATC equipment suppliers to just three companies: GRS, US&S, and WELCO. However, technical personnel at some authorities do not accept the BART ATC system as proven. Thus, only GRS and US&S are presently considered qualified by these authorities. The list could be enlarged by including Transcontrol if Canadian installations were accepted.

The opportunity for a new company to become qualified as a supplier of ATC equipment is offered by several authorities, who will permit the company to install and demonstrate ATC equipment at a test track location on the authority's property. If testing proves that the equipment has desirable performance features together with acceptable safety, quality, reliability, and maintainability, the authority's technical staff may approve this company's qualifications to bid for the next ATC equipment procurement. The prospective supplier must bear the expense of the demonstration equipment, installation, maintenance, and testing in this prequalification program.

Prior to 1969, the Dallas/Fort Worth Airport Board conducted an investigation of possible suppliers of an automated system. As a result of this investigation a Varo/LTV/GRS team and Dashaveyor were selected as the two (and only) qualified candidates. These two submitted preliminary engineering reports in October 1969. In 1970, Varo/LTV/GRS and Dashaveyor received technical study grants for demonstration of their systems at the plant. Initial bidding for AIRTRANS took place in March 1971, with Varo/LTV/GRS and Dashaveyor being the

**TABLE 33.—Contractor Selection Approaches**

| Transit System | Bidder Qualification | Evaluation Process | Contract Award |
|---|---|---|---|
| BART | (d) | (b, c) | WELCO |
| CTA | | (b) | GRS, US&S |
| CTS | (d) | (b) | GRS |
| D/FW | (e) | (b, c) | GRS |
| MARTA | (d) | (b, c) | |
| MBTA | (d) | (b) | GRS, US&S |
| NYCTS | (a, d) | (b) | GRS, US&S(f) |
| PATCO | (d) | (b, c) | us&s |
| SEA-TAC | | (b, c) | WELCO |
| WMATA | (g) | (b) | GRS |

(a) Demonstration at test track.
(b) Low bid.
(c) Proposed performance.
(d) Manufacturer of proven equipment.
(e) Demonstration at plant was an original requirement. At a second bidding there was no such prequalification.
(f) R-44 and R-46 procurements.
(g) Preliminary proposals.

only bidders allowed. One bid was rejected as too high, and the other was rejected as not responsive to the specifications. In May 1971, a second bidding took place with four bidders: Bendix/Dashaveyor, VSD-LTV, WABCO Monorail Division, and WELCO. VSD-LTV was selected as the supplier. The subcontract for the train control system was awarded to GRS by VSD-LTV.

The "invitation to bid" requests a cost quotation for supplying the ATC system and services defined in the procurement specifications. The solicitation may also require submission of a technical proposal that describes how the bidder intends to satisfy the requirements of the procurement specifications. In addition to the technical requirements, provisions for documentation, program planning, management visibility and control, quality control, acceptance and systems assurance testing, and the many other factors specified as important to the procurement must be taken into account by the prospective supplier in preparing his bid. Experience shows that it is very difficult to add or increase a requirement once an "invitation for bid" has been published and the prospective suppliers' responses have been received.

As a general rule, competitive bidding is employed by the transit authorities; and, in most cases, competitive bidding is required by State law or local ordinance. Usually, however, the authorities reserve the right to reject all bids and have a new solicitation. This study has disclosed no instances where a sole-source solicitation had been employed.

The established transit agencies select an ATC equipment contractor from previously qualified suppliers on the basis of the lowest price. Other agencies employ a single-step process where technical capability and cost are weighed together. WMATA was unique in that they used a two-step process in which the responsiveness of prospective contractors' proposals to the procurement specifications in a prebid solicitation was used to make a selection of qualified bidders. Subsequent selection of the winning contractor from the two qualified bidders was based solely on cost.

To date, cost estimates and award to the low bidder have been based solely upon the capital costs of system development and construction. Life-cycle costing, which would require cost competition based upon both the capital and operating costs, is an alternative costing method that has not been used but may find increasing favor as energy and economic conditions cause a shift in values.

## ISSUE D–7: CONTRACT MANAGEMENT

***How is the performance of the contractor(s) monitored and how is system development controlled?***

**There are two basic methods. The transit authority may monitor development using in-house engineering staff. Alternately, a general contractor or consultants may monitor progress. Use of in-house staff, when such capability is available, is more likely to ensure that criteria important to the operating agency are applied during evaluations of progress. On the other hand, the necessary expertise may not be available in house, especially in new properties.**

Once a contract has been awarded, data on program status and control over program direction available to the transit authority management are limited to that specified by the contract. Therefore, it is important that the contract provide the means for monitoring the contractor's progress and for exerting some directive control over contractor activities.

Management control is achieved in many ways ranging from a resident engineer at the contractor's plant to formal design status reviews, RMA predictions, progress reports, and other such techniques. Traditionally, management control of an ATC system contract has been achieved by assigning signal engineers from the authority's staff the task of monitoring the work of the ATC contractor. These engineers are expected to know the status of the contractor's program at all times throughout the contract, and, in particular, to be aware of any problems and the work being done to solve them. They also direct contractor progress by exercising approval of designs proposed by the contractor,

Maintaining management control has become increasingly difficult as ATC systems have grown more complex. BART, PAAC, and WMATA ATC system procurement specifications included provisions for system assurance programs, periodic design reviews, and other modern management techniques. Several transit authorities expect to hire separate consultants to plan, specify, and monitor the system assurance programs for their ATC pro-



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curements. These consultants will report directly to the transit authority technical staff.

One important method for achieving management control is independent review of the ATC manufacturer's design. This review may be conducted by the transit authority engineering staff or by engineering consultants. The manufacturer is required to correct all the deficiencies identified. Besides providing an independent evaluation of the manufacturer's design, this procedure also educates the reviewer on the details of the design. This particularly is important in new systems where the staff may not have lengthy transit experience. A variation of this approach is being used at MARTA. Periodic reviews of the MARTA train control system design are being held under the auspices of UMTA, with the DOT Transportation Systems Center serving as a technical consultant.

Established transit properties such as CTA and NYCTA have traditionally required the manufacturer to continue to correct equipment deficiencies until the equipment performance is acceptable to the chief engineer. Management control by these authorities succeeds, in part, because of the limited market for ATC equipment. If an ATC equipment manufacturer wishes to remain in business, he must necessarily satisfy his customers, and these two are the largest in the country. The major change in methods of management control for the new ATC system procurements is the introduction of requirements for detailed program planning by the contractor. The increased management involvement permits control action to be taken immediately when a deviation from the program plan is noted. This makes it possible for management to avoid potential problems rather than waiting until they occur and require drastic action to correct.

Upon completion of the manufacturing process, the ATC equipment is delivered to the transit authority, installed, and tested. Test procedures are described in the next issue.

## ISSUE D-8: TESTING

How are ATC systems tested? What kinds of tests ***are*** conducted, for what purposes, and when in the development cycle?

There are three categories of ATC system testing, each beginning ata different stage in the system life cycle and satisfying different needs. Engineering testing occurs early in the development cycle and provides data for detailed system design and modification Assurance testing is performed to evaluate how well the equipment meets procurement specifications. Acceptance testiing is performed when the whole ATC system has been installed and debugged and may be performed on significant subsystems before their 'integration into the total system. Acceptance testing is the final demonstration that the system meets specification. There is room for improvement in several areas-test planning, documentation, and dissemination of results.

Testing serves a number of important functions in the development process. It provides the data necessary to support ATC design. It serves to identify actual or potential problems during manufacture and installation. It is the means to verify that the resulting system meets specified requirements.

There are three basic types of testing: (1) engineering testing, (z) assurance testing, and (3) acceptance testing. Each is initiated at different times in the system life cycle, and each satisfies different needs, but they are not mutually exclusive. They frequently overlap in time, and data obtained in one type of testing may be useful for the purposes of another. Although all three types of tests are initiated prior to opening of the system, they may extend well into the period of revenue service.

The results of testing are of primary interest to the transit agency installing or modifying an ATC system and to its system contractors. The test results may also be of value to other authorities who are planning a similar system. Careful planning of tests, description of test procedures, and documentation of results is essential to maximize the value of testing.

Of particular interest for this report is the adequacy of the testing process in terms of planning, procedures, and documentation of results. Also of interest is responsibility for testing and evaluation of test results. Finally, the degree to which test results for one system are utilized at others planning similar systems deserves exploration.

### Engineering Testing

Engineering testing begins early in system development and includes tests of components and subsystems to verify that they perform as expected. There are also tests undertaken to diagnose the cause of a problem and assist in its solution. This second category of tests is called "debugging."

Engineering tests are generally performed by the ATC system contractor to support equipment design and manufacture. Results are not always documented and are generally not submitted formally to the transit authority, A representative of the authority may be in residence at the supplier's plant and may monitor engineering test results. NYCTA, for example, follows this procedure.

Because engineering testing occurs early in system development and there is higher order testing later on, it is probably not necessary to have more formal documentation and wider dissemination of engineering test results than is presently the custom. Furthermore, manufacturers frequently consider the results of these tests to be proprietary.

### Assurance Testing

Assurance testing includes inspection and quality control during production and tests to ensure that the equipment meets procurement specifications.

In general, the procurement specifications include provisions for the quality control program. Unfortunately, quality control programs are not always adequate, For example, the BART ATC system procurement specifications provided for such a program, but strong and effective quality control was really not achieved. An effective quality control test program must include not only a good inspection and test program but management procedures to follow up and correct deficiencies.

Besides quality control, tests are conducted to demonstrate that equipment meets specifications for performance, safety, reliability, maintainability, and availability. Such tests are performed on individual components at the factory or as they are installed, then on subsystems, and eventually on the whole ATC system. Failure of the equipment to perform according to specifications leads to diagnostic testing to isolate faults and correct them—another type of debugging. Ideally, these tests would be completed and all deficiencies corrected before revenue operation. However, the length of time required for some kinds of assurance tests (notably reliability) and pressures to begin passenger service often dictate that operations start before the tests are completed. Some transit authorities recognize this necessity by indicating in the procurement specifications those assurance tests that must be completed before revenue service and those that will be accomplished during revenue operation.

It is important to note that statistically significant tests to demonstrate ATP safety probably cannot be conducted, The required levels of safety are so high that a valid quantitative test for safety would take years or even decades to complete, even if accelerated testing methods were employed. As a result, assurance of ATC safety is accomplished by a combination of analysis and testing. The analytical work is done to identify possible design or engineering defects that could produce an unsafe condition. Testing then concentrates on these areas. While it may not be able to produce statistically significant results, test data of this sort can lend credibility to engineering judgments made about safety.

### Acceptance Testing

Acceptance testing is the final set of tests on the completed ATC system to demonstrate that the system meets all procurement specifications, Acceptance testing is specified in detail as part of the ATC system contract and usually consists of an' integrated series of tests which take place over months or years. Acceptance testing tends to concentrate first on safety features, then on performance, and finally reliability and maintainability, Formal tests of the personnel subsystem and man-machine integration are seldom, if ever, conducted. Problems in this area are detected and corrected as they arise in the course of other testing or operations. The ATC system is accepted by the procuring agency when it has been demonstrated that specification requirements and contractual acceptance provisions in the contract have been met.

The planning, conduct, and communication of test results are basic to all three categories of testing, The adequacy of documentation of plans, test procedures, and results was reviewed during this study in order to evaluate the testing process. The general conclusion is that documentation of test plans has been less than adequate,

From interviews with representatives of transit systems now being planned, and from examination of procurement specifications, it is apparent that there will be increased emphasis on formal documentation of test plans in the future, For example, the PAAC ATC system procurement specifications require the contractor to prepare and submit various test plans appropriate to the different categories of testing. As another example, MTA Rapid Transit Development Division (Baltimore) expects to hire a reliability, maintainability, and system safety consultant who will be required to plan a comprehensive and integrated program for the entire transit system, including the various system assurance tests pertinent to RMA and safety. This consultant will work with both the general engineering consultant and the ATC system design subcontractor.

Confidence in test results is determined to a large degree by the detail to which testing procedures are documented. Careful attention to details such as accuracy, precision of measurement, and control of the test environment is important. In some cases, it is difficult to assess the quality of testing that has been conducted in existing transit systems because documentation is lacking or inadequate.

For testing to be of maximum value, the results must be communicated to interested parties. Within a single organization, this may be accomplished informally by oral report or internal memoranda. However, in an integrated test program, more formal reporting procedures are necessary to assure that the test results are properly disseminated. As in test planning and performance, there is room for improvement in the dissemination of results, particularly outside of the transit agency.

**ISSUE D-9: R&D PROGRAMS**

***What organizations are undertaking R&D and what is the nature of their programs? Are the results of research being applied?***

**Organizations planning new systems and equipment manufacturers do some R&D, but little is devoted to ATC. Most R&D is supported by the Federal Government. Application of R&D is inhibited because the results are considered proprietary, especially by manufacturers.**

R&D may be defined as discovery of new knowledge and its development for use in practical application. R&D must be distinguished from applications engineering which refers to the solution of specific technical problems. With this distinction in mind, the following summarizes the organizations which might be expected to perform R&D in ATC and their involvement in such activity.

### R&D Programs

Operating transit agencies perform very little ATC R&D. Fiscal realities of the operating environment do not support such activity. Operating agencies do conduct ATC applications engineering.

Agencies planning new rail rapid systems and their subcontractors perform R&D in the course of system development--chiefly design and development of new hardware, test track demonstrations of new concepts, and basic analytical work. Funds may be provided for such purposes by the Federal Government as part of technical study programs and capital grants. Transit agencies sometimes use their own funds to support such work.

The American Public Transit Association (APTA) is the principal rail rapid transit industry association. Some of its committees are active in areas related to ATC, principally safety and reliability. Such work is paper-and-pencil studies and is supported by member organizations. The Transit Development Corporation is an industry-organized R & D corporation. No programs specifically related to ATC have been undertaken,

Some R&D in ATC reliability and small vehicle systems is done by manufacturers. This work is supported primarily by private investment, There has been some private investment in test track demonstration programs. (See Issue D-10, p. 151.) Most industry work in ATC for rail rapid transit is applications engineering.

Educational research organizations, such as the University of Minnesota, Northwestern University, Aerospace Corporation, and Applied Physics Laboratory, have funded contributions to the literature for small-vehicle, fixed-guideway systems. They have not made substantial private contributions to rail rapid transit R&D for ATC.

The Federal Government is the principal source of R&D funds. Major Federal support to assist testing and demonstration of ATC equipment for conventional rail rapid systems was given in the mid-1960's in conjunction with the BART and Transit Expressway test tracks. (See Issue D-10, p. 151.)

Recent Federal programs have generally been associated with support of major vehicle or system concept development rather than ATC as such. These programs include the State-of-the-Art Car (SOAC), the current Advanced Concept Train (ACT I), the TRANSPO '72 demonstrations, the Standard Light Rail Vehicle, PRT activities at Morgantown, West Virginia, and the now-canceled Dual-Mode Program,

In small vehicle technology, a new project directed toward the development of a high performance PRT (HPPRT) system has major ATC elements. Also, the Applied Physics Laboratory (APL) of Johns Hopkins University has been providing more or less continuous support to UMTA in PRT technology. Most of the APL work has focused on analytical studies of operational and reliability problems associated with PRT systems. APL has also provided general technical support to UMTA, notably as a technical monitor (with MITRE) of the TRANSPO '72 PRT demonstrations.

Recent and current work in system assurance has been closely allied with ATC technology and the question of manned versus unmanned vehicles. An UMTA-funded ongoing program in these areas is being conducted by the Transportation Systems Center (TSC). One product of this work was a report entitled "Safety and Automatic Train Control for Rail Rapid Transit Systems, " published in July 1974. It is expected that the results of the TSC investigation of system assurance and the question of manned/unmanned systems will be available in 1976.

Except for the APL work, there has been little support for the development of analytical tools needed to evaluate ATC (and other) problems associated with advanced technology systems. This situation now appears to be changing. A part of the now-canceled Dual-Mode project was to have involved development of the analytical tools necessary to evaluate such general concerns as operational strategies and reliability. Such a requirement is included in the later phases of the recently initiated HPPRT program.

There are indications that a more programmatic approach to ATC technology for small vehicles will be initiated. UMTA is currently developing an Automated Guideway Technology (AGT) program which will deal with many system and subsystem problems on a generic rather than project-specific basis. If there are any significant contributions to rail rapid transit system of these programs, they are likely to fall in the area of the development of methodology and analytical tools. Equipment requirements for AGT and rail rapid transit are so different that contributions to rail rapid transit hardware technology are unlikely. However, better analytical tools would be an important contribution.

### Application of R&D

The application of the results of R&D varies according to the sponsoring organization, Privately supported R&D, such as is done by manufacturers, is generally proprietary and not fully available to the industry. Unfortunately, this is where most of the expertise resides,

The results of federally supported research and that conducted by educational institutions generally finds its way into the literature, Much of this work is more theoretical then practical in outlook. Further, such work is often concerned with automated small-vehicle technology rather than more conventional rapid transit. The increasing involvement of the Federal Government in rail rapid transit may change the situation.

Transit agencies planning new systems or modifying old ones generally exchange information, on a personal basis, with their counterparts at other transit agencies, This helps to compensate for the lack of research literature and the withholding of proprietary data held by manufacturers.

## ISSUE D-10: TEST TRACKS

What role do test tracks play in ATC R&D? Who operates and funds test tracks?

Test tracks are not built solely for ATC studies but to serve several objectives, and their value should be judged accordingly. For development of ATC, test tracks are used for R&D, demonstration of conceptual feasibility, and hardware test and evaluation. By permitting scientific and engineering work in the absence of constraints imposed by revenue service, test tracks are vital to advances in transit technology. Some test tracks have short life spans. Others are more or less perrnanent facilities. They are operated and funded by the transit agencies, manufacturers, and the Federal Government.

As used here, a test track is a facility built expressly for the purpose of engineering and scientific studies, and not revenue trackage that may be used for test purposes. Thus, the Morgantown project is not a test track. The TRANSPO '72 exhibition, while perhaps better classed as a demonstration, is included because of the post-TRANSPO test program. Test track programs discussed below are categorized by the three types of organizations which operate them: transit agencies, manufacturers. and the Federal Government.

### Transit Agencies

BART Diablo Test Track.—The purpose of this track was to demonstrate the conceptual feasibility of alternative subsystems for BART—not, as commonly thought, to select hardware to be procured. The results of the program were used as a basis for writing functional specifications for BART equipment.

The 41/2-mile test track was located between Concord and Walnut Creek, California. It was operated in the mid- to late- 1960's, at a total program cost of about $12 million. The Federal Government supplied about two-thirds of the funds, and BART the remainder. Most suppliers participating in the program are believed to have invested substantial funds of their own.

ATC was 1 of 11 different system elements studied at the track. Because the purpose was concept demonstration using prototype hardware, reliability and maintainability studies were not part of the ATC test program. Four ATC systems were demonstrated, Suppliers were General Electric, General Railway Signal, Westinghouse Air Brake, and Westinghouse Electric.[84] The results of the formal tests were that all four systems met the general requirements for BART ATC, with no one system significantly better.

After final ATC specifications were prepared by BART, the winning contractor, Westinghouse Electric, was selected on the basis of low bid. Because the WELCO system was developed in response to new specifications and designed to be price-competitive, it is not surprising that it differed from any demonstrated. This system was not subsequently tested on the Diablo track before final systemwide installation. Whether such testing would have avoided some of the later ATC problems encountered in BART depends upon the type of tests which might have been performed and the criticality of the analysis of results, rather than the particular track used.

PAAC Transit Expressway Program Transit Expressway.—This program, conducted by the Port Authority of Allegheny County, ran from June 1963 to November 1971 at South Park, 11 miles from downtown Pittsburgh. The objective was to design and develop a new technology—namely a fully automated system of medium-size, light weight, self-propelled vehicles which could be operated singly or in trains of 10 or more vehicles. The work was done in two phases at a cost of $7.4 million. Two-thirds of the funds were provided by the Federal Government; and the remainder was provided by Allegheny County, the State of Pennsylvania, and Westinghouse Electric.

As the first fully automated transit system, significant development work was done on ATC. The ATC system underwent major changes between the first and second phases of the program. The final system is comparable to BART, with the exception of the train detection equipment which was specifically designed to detect the rubber-tired vehicles planned for the system.

The importance and value of this program lies in the many innovations demonstrated there and later incorporated into systems now operational elsewhere. The ATC technology has been used by Westinghouse Electric for the Seattle-Tacoma and Tampa airport systems, for BART, and for the Sao Paulo METRO in Brazil. PAAC used the project to develop procurement specifications for TERL, a program recently defeated by the voters.

### Manufacturers' Test Tracks

Manufacturers' test tracks have been built primarily for work on automated small-vehicle systems. These tracks are used either to develop new systems, to check equipment prior to delivery, or both. Federal funds may be used, as was the case of the Dashaveyor and Varo test tracks which were used for feasibility studies conducted by these companies for AIRTRANS at the Dallas-Fort Worth airport. Some company test tracks that have been used for ATC development or checkout are:

- Dashaveyor, Pomona, Calif.
- Varo Monocab, Garland, Tex.
- WABCO Monorail Division, Cape May, N.J.

[84] The Philco Corporation also tested portions of an ATC system later, after the completion of the formal test program.

- TTD, Denver, Colo.
- Bendix, Ann Arbor, Mich.
- Alden, Milford, Mass.

Federal Government

TRANSPO '72.—Four automated small-vehicle systems were demonstrated at TRANSPO '72 and later evaluated in a test program conducted between August and November 1972. Federal funds amounting to about $7 million were provided for the demonstration and test program. There was also substantial private investment. The exact amount is unknown, but it is thought to be of the same order as the Federal contribution. The systems demonstrated and their manufacturers were:

- Dashaveyor System—Bendix Corporation
- ACT System—Ford Motor Company
- Monocab System—Rohr Industries
- TTI System-Otis

The systems were developed under tight time constraints with limited funds. This led to some compromises in the ATC system design. The post-TRANSPO test program showed that some of the ATC equipment had undesirable control characteristics, including long delay times and speed oscillation. It was concluded that the basic cause of these problems was the prototype nature of the equipment.

Apart from its value as a public demonstration of new technology, the major benefit of the TRANSPO '72 program was the increased capability in small-vehicle technology gained by the four participating manufacturers, Because of basic differences in philosophy and operating characteristics between automated small-vehicle systems and rail rapid transit and because of the less stringent demands placed on a system in an exhibition (in comparison to a revenue operation), the TRANSPO '72 program had limited value in improving ATC systems for general transit industry application.

Pueblo Colorado Test Facility.—DOT's High Speed Ground Transportation Center at Pueblo, Colo,, became operational in 1973, Managed by the FRA, the Center can test several types of ground transportation systems. Both advanced systems and rail technology programs are conducted, The former programs include the Tracked Levitated Research Vehicle (TLRV), the Tracked Air Cushion Research Vehicle (TACRV), and the Linear Induction Motor Research Vehicle (LIMRV), For rail technology programs, the Center includes 20 miles of conventional railroad trackage, used for studying train dynamics under a variety of track and grade configurations, a 9.1-mile oval rail transit track with a third rail for testing electrically powered rolling stock, and a Rail Dynamics Laboratory for simulator testing of full-scale railroad and rail transit vehicles. As a part of the now-canceled Dual-Mode Program, it was planned to build two guideway loops at the site, each 2 miles in circumference.

Probably the most significant rail transit activity at Pueblo was the testing of the State-of-the-Art Car (SOAC) in 1973. There was little ATC related work associated with this R&D activity, and the ATC provisions at Pueblo are all but nonexistent. There are several reasons for this. DOT has been using the facility for other purposes. Limited facilities are available. (For example, there are no provisions for inserting signals into the rails,) The site is very remote from both operating properties and equipment suppliers. Most transit agencies feel it is essential to conduct final ATC development work in the actual operating environment (atmospheric, electrical, etc.) where the equipment will be run. Unless there are specific federally funded programs requiring that the work be conducted at Pueblo, it seems unlikely that significant amounts of ATC research for rail rapid transit will be conducted there.

## ISSUE D–11: RESEARCH NEEDS

***What are the major needs for research and development in ATC technology?***

**R&D to obtain new and more advanced ATC technology for rail rapid transit is not required at present. Rather, the need is to seek refinements in existing technology which will result in improved reliability, maintainability, and system performance at reduced cost.**

The MITRE Corporation (1971) conducted a survey of rail rapid transit agencies and equipment manufacturers to identify problems that should be addressed in a federally funded research program. Of the 11 top priority areas indicated by this survey, none had any direct relationship to ATC. The results must be accepted with some caution because

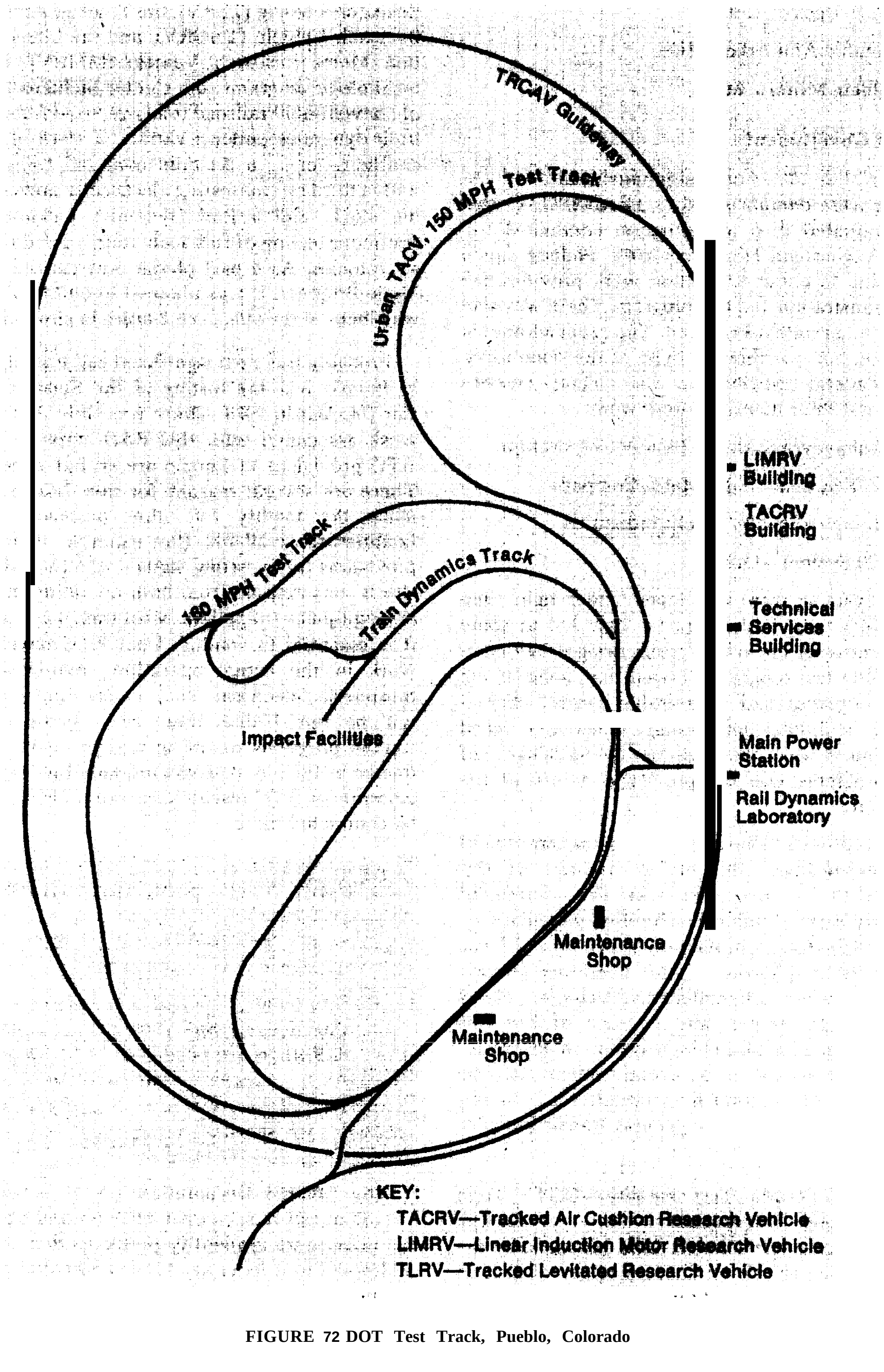


**FIGURE 72 DOT Test Track, Pueblo, Colorado**

none of the industrial firms surveyed were ATC equipment manufacturers and because the intent of the study was to identify problems for investigation at the DOT Pueblo test site. (As indicated earlier in Issue D-10, p. 151, the Pueblo test facility is not suited for investigation of ATC problems.) Still, the survey does suggest that ATC is not viewed as a major R&D problem by a significant part of the transit industry.

During visits to transit agencies made by Battelle Columbus Laboratories as technical consultants in this assessment, comments and suggestions were solicited on R&D needs in rail rapid transit technology, particularly those associated with ATC. Here again, the results indicate that ATC is clearly not a major concern.

Operating transit agencies felt that the major R&D needs were:

- Improvement of chopper control, multiplexing of train lines,[85] and a.c. traction motors;
- Documentation of slip-slide tests for use in official and expert testimony in damage and injury suits;
- Clarification of the trade-off values associated with such technical matters as analog vs. digital signals, control signal frequencies and modulation rates, types of station stops, choppers vs. cam controllers, and the use of p-wire;
- Review of the availability and allocation of radio frequencies for both voice and data transmission by transit systems;
- Development of a data base and clearinghouse for reliability and maintainability information for the benefit of transit systems and manufacturers.

Transit systems in the planning and construction stages had a differing set of priorities:

- Investigation of electromagnetic interference problems;
- Improvement in the reliability of ATC systems and related equipment;
- Study of techniques for, and the value of, regenerative braking;
- Establishment of a data bank on the safety, reliability, and maintainability experience of operating transit systems;
- Maintenance training programs to ensure that new and sophisticated transit equipment (including but not limited to ATC) can be properly cared for;
- Studies of collisions and crash resistance, particularly for small-vehicle systems.

Since one of the main purposes of this technology assessment was to weigh the need for R&D in the area of automatic train control, this topic was given special attention. In addition to review of the literature and collection of opinion within the transit industry through the interviews cited above, the matter of research needs and priorities was made the subject of a separate investigation by the OTA Transportation Program staff and the OTA Urban Mass Transit Advisory Panel. This investigation drew especially on the experience of individual panel members and of various transit system managers, equipment manufacturers, technical consultants, and DOT officials. The findings of this investigation, as they apply to rail rapid transit, are presented below.[86]

At the outset, it should be noted that there is no need for a significant R&D effort to make major advances or innovations in ATC technology for rail rapid transit systems. The basic technology is sufficiently developed for present and near-term future purposes. What is needed now is research and development to refine the existing technology and to improve performance at reduced cost. The major elements of such a program are discussed below. Figure 73 is a matrix, categorizing the importance of these R&D efforts against the estimated relative cost to carry them out.

## Reliability and Maintainability

There are several aspects of reliability and maintainability in which further work is needed.

### Equipment Reliability and Maintainability

There is a major need to develop more reliable and maintainable equipment. This applies not just to ATC but other types of rail rapid transit equipment.

[85] The underlined items are those directly or indirectly related to ATC.

[86] R&D needs for automated small-vehicle systems are explored in a separate OTA report, Automated Guideway Transit: An Assessment of PRT and Other New Systems, June 1975.

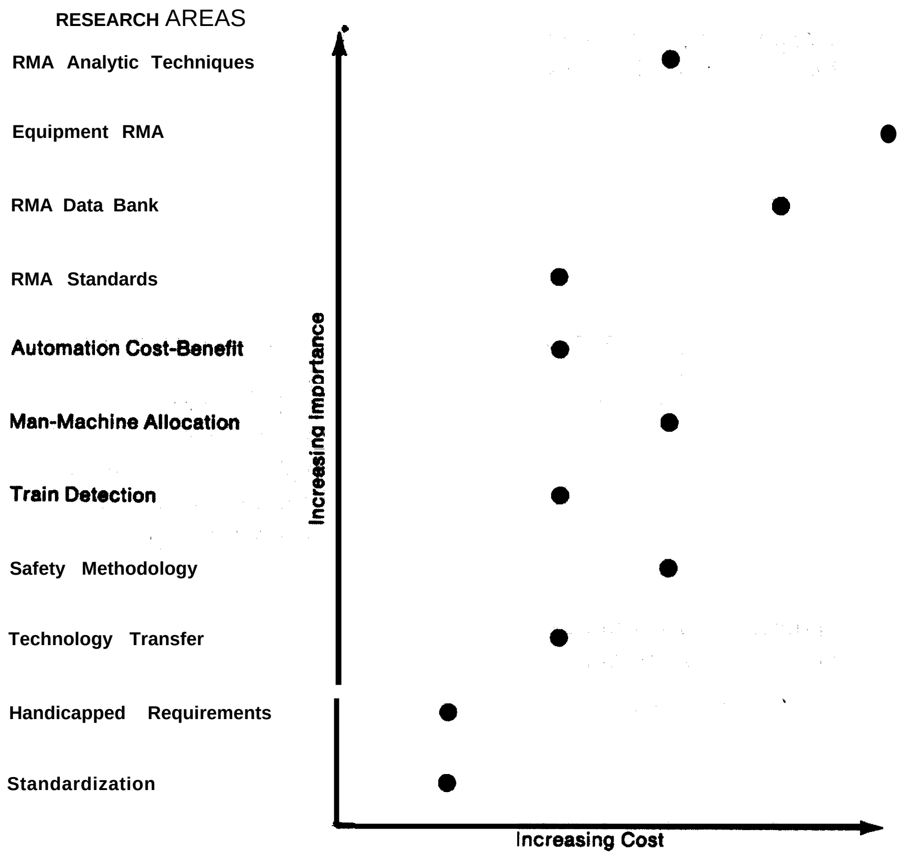


**FIGURE 73. ATC Research and Development Priorities and Relative Cost**

Techniques for RMA Analysis

Improved and more quantitative methods are needed to evaluate total system performance in terms of reliability, maintainability, and availability. Component performance measures exist. Total system performance measures do not. Total system measures would permit better allocation of reliability requirements among subsystems, better understanding of reliability trade-offs, and better utilization of the maintenance work force.

RMA Standards and Guidelines

An effort is needed to establish realistic equipment standards and to clarify manufacturers' responsibilities in the area of RMA. The standards must be high enough to assure reasonable availability of equipment but not so high as to make the equipment unnecessarily costly.

Reliability and Maintainability Data

A pool of data from testing and operational experience pertaining to equipment reliability and maintainability y would be of great value to transit system planners, research groups, and manufacturers. At present, there is no uniform way of recording and reporting such information, and no clearinghouse for collecting and disseminating it within the transit industry.

Safety

The safety levels of the rail rapid transit industry are high and exceed nearly all other forms of public and private transportation. Still, there is a need for research in two aspects of safety.

Train Detection

The much publicized train detection problems of BART (which are probably no more severe than those experienced in other transit systems) have underscored the need for clarification of the standard for train detection and the need for a uniform method to test the performance of train detection systems.

### Safety Methodology

Controversy over system safety versus fail-safe principles abounds in the transit industry, There is also debate over how safety is to be measured and how safe is safe enough. Research is needed to develop an objective and quantified method for evaluating the safety aspects of rail rapid transit system performance.

## Man-Machine Relationships

### Function Allocation

There is great variability among transit systems in the duties assigned to the human operator. Significant errors were made in the original design of the BART system because of the highly passive role assigned to the train attendant. The man-machine interface needs to be carefully studied to determine the optimum role of the human operator in automated systems and to ensure that provision is made for the operator to interact effectively with the system in abnormal or emergency situations. The role of personnel assigned in a supervisory capacity needs to be similarly examined.

### Cost-Benefit of Automation

Research is needed to determine the relative advantages of manual and automated methods of operation with respect to energy savings, variability of trip time, equipment utilization, system capacity, and manpower costs. Such data would be of value not only in the design of new systems but also in the .modernization of old ones.

## Application of Technology

Even though ATC is a rather mature and well developed technology, there remain some problems of practical application. Three areas are in need of special attention.

### Standardization

There are a number of technical and economic benefits to be gained from reducing the diversity of ATC equipment now in use or planned for installation in rail rapid systems. These advantages must be scrutinized and evaluated against the disadvantages of inhibiting innovation and impeding improvement that standardization might bring.

### Technology Transfer Within the Industry

There is a general shortage of persons with experience in ATC system design, manufacture, and operation at all levels in the industry. This shortage is most keenly felt by agencies planning and building' new systems. Research is needed to devise more effective methods for sharing information, exchange of experienced personnel, and training of new personnel.

### Requirements for the Handicapped

Under the stimulus of the Federal Government, there is an increasing concern in the transit industry with the transportation needs of the handicapped. As a part of the investigation of the general social costs and benefits of providing rail rapid transit service for the physically, visually, and auditorily impaired, there is a need to consider the specific influence of ATC. Among the matters of interest are acceleration and deceleration limits and their effects on system capacity and trip time, passenger assistance on trains or in stations with a low level of manning, and the safety of the handicapped and others in emergency situations.