APPENDICES

Appendix A

TRAIN CONTROL SYSTEM FUNCTIONS[94]

Train control is the process by which the movement of rail rapid transit vehicles is regulated and supervised to assure safety and efficient operation of the system. Such control can be effected by manual means, by automatic devices, or by some combination thereof. The description of train control system operation presented below is cast in functional terms that apply equally to manual or automatic forms of control. Because automation is the central issue of this report, the discussion also includes an examination of the relative merits of man and machine components. A discussion of the technology of automatic train control is presented later, in appendix B.

The train control system is comprised of elements that perform four major types of functions:

- Train protection
- Train Operation
- Train Supervision
- Communications

TRAIN PROTECTION

The sole purpose of the train protection system is to assure the safety of vehicle movement by preventing collisions and derailments. Traditionally, the train protection system is functionally separate and distinct from other elements of the train control system; and it is designed so as to protect not only against failure of other system elements but against failure of its own elements as well.

Before taking up specific train protection functions, it is necessary to consider the general concept of train protection and its role in the overall scheme of system operation.

Figure A-1 is a conceptual representation of train protection functions in a typical rail rapid transit system. The indicated functions might be performed by men, machine, or both; and they might be performed by elements in locations other than those shown in the diagram, Since the purpose of the illustration is simply to indicate functional relationships, these different forms of implementation can be ignored for the moment.

The train supervision system may generate a request for the movement of trains or switches. Some of the requested moves may be unsafe. It is the responsibility of train protection system to insure that only safe moves are carried out. In order to do this, it is necessary to know the status of switches, the location of trains, and the allowable speeds for trains as affected by track limitations and the presence of other trains in the system.

Wayside logic typically performs the route interlocking function by processing information on the desired action, the location of trains, the status of switches, and the allowable speed of trains. Output of this logic consists of safe commands to move switches and safe speed commands issued to trains.

Excluding certain track and train surveillance functions, the primary concern of the onboard train protection system is the restrictive control of the propulsion and braking system. Essentially, train protection enables or inhibits the performance of certain propulsion or braking actions. Train protection determines actual train speed and compares it to the commanded safe speed. If the train is exceeding the commanded speed by a predefine amount, action to override all other less restrictive propulsion and braking functions is initiated. Similarly, the status of critical elements on board the train as well as certain conditions on the track are used to determine what action should be taken regarding the propulsion and braking system.

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[94] This appendix is based on material originally prepared by Battelle Columbus Laboratories in support of the OTA study. The editors gratefully acknowledge the contribution of Battelle Columbus Laboratories but accept full responsibilit y for the version presented here and for any alteration of content that may have been introduced in condensing and editing the material for publication,

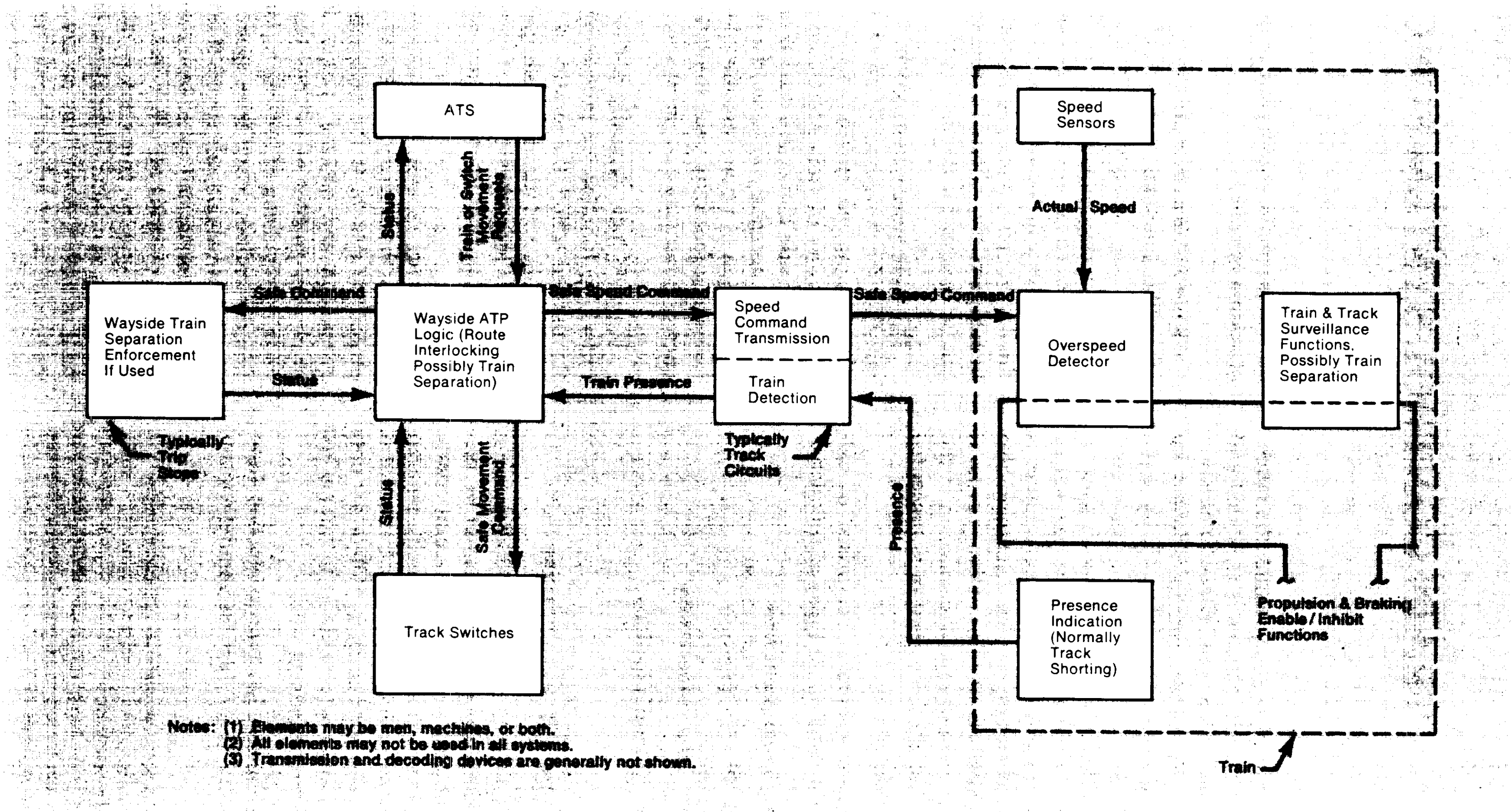

FIGURE A-1.—Conceptual Diagram of an ATP System

Train and Track Surveillance

Train and track surveillance involves monitoring the train, the track, and areas immediately adjacent to the track for safety-related conditions. It can also involve monitoring adjacent tracks and trains operating on them. passenger security, though clearly a safety-related matter, is not usually considered a part of the train and track surveillance function, Door monitoring and control, another safety-related function, is considered here to be a train operation function.[95] Train and track surveillance are essentially human roles in all operating rail transit systems today, but the amount of human involvement varies widely.

Train surveillance is concerned with monitoring the status of the train and its passengers. Onboard operators (motormen and conductors) traditionally perform this role. The primary advantage of the human in such a role is his ability to comprehend and interpret many diverse types of inputs. Except at PATCO and on the MBTA Green Line, the operator of a train is typically confined in a space that is physically removed from the passengers. His primary role in train surveillance is monitoring the status of the equipment. Conductors, if present, have more freedom of movement and can sometimes go to the scene of a possible problem to determine its nature and severity.

Passengers may provide some train surveillance functions. In systems where they can communicate with employees, they may report onboard conditions. Two-way communications systems are provided at Sea-Tac and AIRTRANS, where the vehicles are unmanned. It is likely that passengers could become more involved in train surveillance in automated small-vehicle systems.

Onboard operators provide the track surveillance function at all operating rail transit properties. In the closed environment of Sea-Tac, essentially no track surveillance is performed. At AIRTRANS, another special environment, only minimal track surveillance by roving employees is provided.

Under ideal conditions, little, if any, track surveillance would be required. Humans external to the system cause most of the problems requiring track surveillance. Trespassing, vandalism, and suicide attempts are three of the most commonly cited factors which make some form of track surveillance necessary. Here again, the human is unsurpassed in the ability to identify and deal with a very broad range of track surveillance problems.

While a human can act to prevent some accidents, he cannot prevent all of them, partly because he simply cannot stop the train in time. If one were to assure an instantaneous response and brake application along with a rather high braking rate of 3 mphps, it can be calculated that the minimum stopping distance from **60** mph for a typical train is **880** feet, and 220 feet at 30 mph. Clearly, there are many situations in which the potential hazard is either not visible at this distance or is created within the stopping distance of the train, (Suicide attempts are the classic example here.)

Damage assessment is a track and train surveillance function which can be performed by humans. When something has happened, a human can assess the damage to track or train and determine if it is safe to proceed.

Train Separation

The function of train separation is to maintain physical separation between following trains so that they are not in danger of colliding with each other. In the simplest manual system, train separation can be provided by the operator who drives the train much as a person drives an automobile. He must know the maximum safe speed with which he can approach curves and other places of limited visibility, and he relies upon seeing the train ahead and taking appropriate action to prevent a rear-end collision.

Figure A-2 illustrates the basic principles involved in automating the train separation function, The dashed line indicates the theoretical speed-distance relationship that a following train could maintain and still be able to come to a stop before reaching the end of the train stopped ahead.

When a block-type detection and speed command system is used, the location of the train within a block is not known accurately, Therefore, the train must be assumed to be in the most hazardous location, i.e., at the rear of the block. In the exampIe shown, the train is almost out of block BC but must be assumed to be at the location shown in dotted lines. The shift of the theoretical speed-distance profile can be seen to be essentially one block long. In general, the shorter the blocks, the closer the attainable spacing between trains.

[95] Some transit engineers consider door control to be a train protection function because of its relationship to safety.

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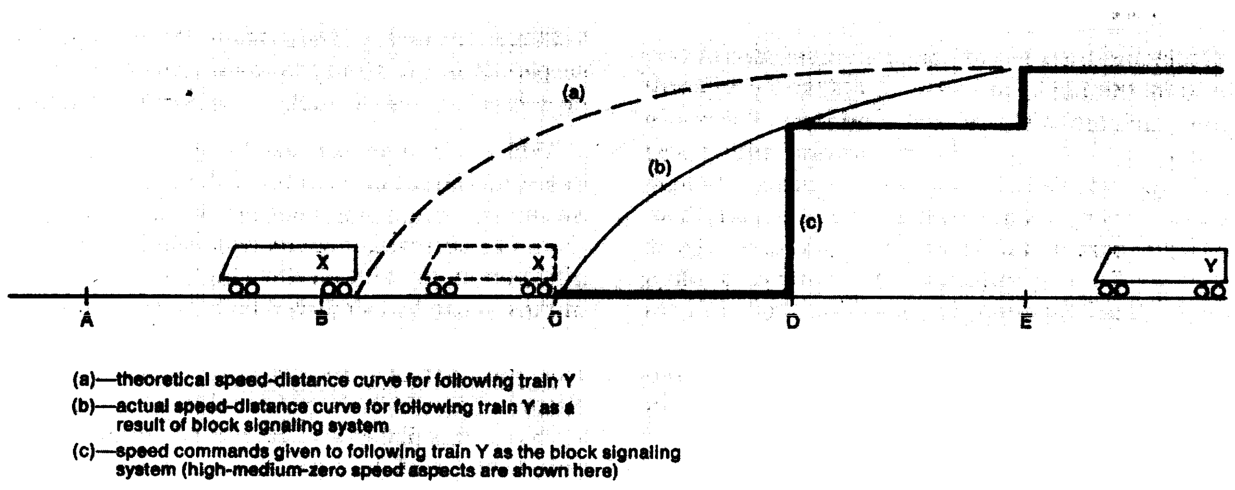

FIGURE A–2,—Train Separation in a Conventional Block Signaling System

Many arrangements of speed commands are possible. For example, if the commands were only stop or go, all signals shown (except perhaps the ones at A and E) would indicate stop. It is frequently desirable for operational reasons to have a train approach closer than the safe stopping distance from full speed. In such a case, an intermediate speed command would be provided, as shown in the block DE. A train traveling in this block would receive an intermediate speed command followed by a zero speed command from point D. One can readily see that the shorter the length of blocks and the greater the number of speed commands, the more closely a train can follow the theoretical speed-distance profile. Obviously, the system for accomplishing this becomes more complex and expensive as block length is shortened.

It should be noted that a number of factors used in the actual design of a system are not shown in this simple illustration. There is some system response time involved before braking is initiated. Grades may reduce the actual effectiveness of the brakes. No safety factors are included. Some systems provide additional blocks between trains, All these tend to further increase the spacing between trains.

The difference between intermittent and continuous speed command transmission can be seen here. Suppose the train is moving and, in a brief increment of time clears block BC. Block CD will immediately indicate the intermediate speed and block DE will go to full speed. If a following train were just a few feet into block DE when the speed command in that block changed, the operator would have no way of knowing it if the speed command were transmitted by a visual signal located at E. He would have no indication of a change in signal status until the signal at D became visible. By contrast, the continuous, or cab, signal would immediately indicate to the operator that he could increase his speed. An additional advantage of cab signals is that a train can move into block DC to stop whereas, with wayside signals and trip stops, the train would stop at D, or even farther back.

All rail transit systems to date have been designed on the assumption that a leading train is either stopped or will stop instantaneously. It can be seen that trains could follow one another much more closely if a less stringent assumption could be made about the stopping of a leading train. This is precisely what is proposed in many short-headway PRT systems where position, velocity, and acceleration of a lead vehicle would all be considered in establishing headways. Some studies of PRT headway have shown, however, that removing the brick-wall concept reduces minimum achievable headway by only a small amount.

So far as is known, there are no rail rapid transit systems planning to abandon the traditional train separation philosophy. The major differences in train separation practice are associated with the way in which train separation commands are enforced, Intermittent or wayside signaling systems provide train separation by use of trip stops.[96] Continuous or cab signaling systems enforce train separation using onboard equipment. A safe speed command is transmitted to the train and equipment on board insures that the operator initiates action to slow the train as appropriate.

Humans play a role in train separation under at least some situations. In some locations, operators are permitted to approach trains ahead of them more closely than would be permitted by the signal indication, This is always done under strict procedural controls. It maybe done at highly congested stations or in emergency situations. Practically speaking, the maneuver is identical in nature to driving one bus up behind another bus which has stopped.

Route Interlocking

Route interlocking is the process by which trains are prevented from making conflicting moves, i.e., moves that would be unsafe. Typical conflicting moves are those which would cause a train to collide with another train, to go off the end of the track, or to run through an open draw bridge. Route interlocking involves monitoring the presence and position of the trains in a system and the positions of the track switches. The information from the monitors is processed by logic, usually the front contacts of vital relays, and used to inhibit or permit the movement of the trains. As an example, when a train is dispatched from one location to another and the trip involves passage of the train through one or more track switches or crossovers, the route interlocking allows the train to proceed through the switches and crossovers only when it is safe to do so and prevents other trains from entering the route until the first train has safely passed.

Information on the presence and location of the trains is obtained from the train detection system, as described earlier. Information on the status and the position of the track switches is monitored by the route interlocking. Before a route is alined for a train, it must be determined that the proposed route will not be in conflict with an existing route for another train. If no conflict exists, then the appropriate track switches must be positioned and their positions verified. Then each switch must be immobilized and locked until the passage of the train has been verified. These precautions are necessary to insure that the switch positions are not changed after the route has been alined and to insure that a switch is not moved under a train. Either of these events would be unsafe.

Route interlocking is an essential part of the train protection for all but the most simple transit systems. As system complexity increases, route interlocking assumes greater importance. Early route interlocking functions were often accomplished through the use of complex mechanical devices which prevented establishing potentially hazardous switch positions. Some such equipment is still in use. New installations are all equipped with electrical or electronic logic which, may also permit remote actuation of switches and signals.

Overspeed Protection

Overspeed is the condition where the actual train speed is greater than the intended or commanded speed. Overspeed can be dangerous because the train may derail if it goes too fast around a curve or the train may have a collision because it is going too fast to stop within the available distance. It is the responsibility of other train protection system elements to determine the allowable safe speed and to assure that the commanded speed does not exceed the allowable safe speed.

Basically, overspeed protection has two inputs and one output. The inputs are commanded speed and actual speed. A signal enabling or inhibiting the propulsion and braking system is the output. A comparator, either a man or machine, compares actual speed with commanded speed and determines if propulsion power can be applied or if a brake application is required. The overspeed protection function can be accomplished on board the vehicle or through the use of wayside equipment.

All transit systems that use cab signaling also have automatic overspeed protection. In order to do this, it is essential that the onboard speed measuring and comparing device have a virtually zero prob-

[96] A trip stop is a mechanical device which is located near or between the running rails; it is associated with a wayside signal. When the wayside signal indicates that a train is to stop, the trip stop is positioned so that it will apply the brakes of any train which attempts to pass the wayside signaL When the wayside signal indicates that a train can proceed, the trip stop is mechanically positioned so that it does not affect the brakes of a passing train. Thus, the trip stop enforces a stop command presented by the wayside signal.

ability of failure in an unsafe mode, Even though single tachometers traditionally have been regarded as “fail-safe,” redundant tachometers are sometimes used. The outputs are compared, and if disagreement exists, a failure is assumed to have occurred and the overspeed protection logic treats this as an overspeed condition. A more frequently used approach, though, is a fail-safe speed measurement system not requiring redundancy that reduces reliability y.

It is not uncommon for a cab signal display to fail without failure of the overspeed protection system. Under such conditions, the operator can run the train safely but may have difficulty in maintaining the desired speed without exceeding the overspeed limit, The audible warning devices that are normally provided permit the operator to run without cab signals without receiving a penalty brake application.

OverSpeed can be detected and controlled from the wayside. Through the use of timing circuits and known lengths of track, it is possible to determine if the average speed of a train over a certain distance is equal to or less than the allowable safe speed, If the measuring distance is short, an essentially continuous overspeed protection can be provided, If the measuring interval is long (say tens or hundreds of feet), only an average measure can be obtained, so the instantaneous value could exceed the intended limit,

TRAIN OPERATION

Train operation consists of three major functions:

Velocity Regulation

Station Stopping

Door Control and Train Starting

In the traditional concept of signaling, train operation is not considered a safety-related aspect of train control. However, there are some safety aspects of train operation. If abrupt starts, stops, and changes are made, passengers may be thrown down and injured. If door control is assumed to mean the monitoring of the status of the train doors, passenger safety is also involved,

There is some disagreement among train control engineers concerning the functional relationships among train operation, train protection, propulsion, and braking systems, Some consider control of jerk, slip-slide, and flare-out as train operation functions; others consider them to be propulsion and braking functions. Some consider door control a part of train protection (because of its relation to safety); others place door control within the province of train operation. These subjects will be touched upon briefly below.

Velocity Regulation

Overspeed protection is designed to prevent a train from going too fast. Velocity regulation is concerned only with controlling the speed of the train in response to operational needs. Velocity regulation systems are “nonvital,” that is, they are not essential to the safety of the system.

Velocity regulation may be accomplished by a man or machine, When a man acts as the controller, he simply compares the actual speed with desired speed and tries to minimize the difference between the two. The desired speed may be presented in the form of wayside or onboard displays. Actual speed is determined from speedometers on board the vehicle, A human controller uses a handle of some sort to control speed much as an auto driver uses an accelerator pedal. In such a system, the hand on the handle is the interface between the train control and propulsion and braking systems.

A machine controller performs exactly the same functions as a man, but the control signal is provided in the form of an electrical signal to a controller in the propulsion and braking equipment. Most ATO systems to date have provided this signal in a combined digital and analog form. The system designed for WMATA uses a completely digital interface,

For operational reasons, it is sometimes desirable to modify the speed of the train. This is usually called performance level modification, Here, a command (verbal, visual, or electrical) is transmitted to the train telling it to run at a selected fraction of the commanded safe speed. Performance level modification is not a safety-related function.

Performance level modification is normally accomplished on board the vehicle. In manual systems, an operator may receive a verbal or visual instruction to operate the train at reduced speed. In some systems, notably NYCTA, performance level modification is not normally used, Trains are held at stations rather than operated at slower speeds between stations, Both BART and WMATA provide transmitters in stations and at other critical locations to send performance level requests to the train. Performance level modification is thus accomplished automatically without operator intervention. Baltimore is considering a performance level modification system in which a visual wayside display is provided to an onboard operator who then manually sets the desired performance level for the next segment of the trip.

There is a general trend toward the use of automated velocity regulation. The two newest systems in operation (BART and PATCO) employ automated speed regulation, NYCTA is planning to install it (and other features) over a long period of time with the objective of eliminating the conductor, MBTA has installed velocity regulation on the new portions of the Red Line. CTA, however, opted not to use automated velocity regulation on its new cab signaling installation.

Station Stopping

Station stopping involves bringing the train to rest at a selected location along a station platform under some form of programed control. It is not technically a safety-related function. Both humans and machines perform the station stopping function.

In manually operated systems, the operator normally uses some reference mark as an indicator of the point where he should initiate braking. This mark may be any wayside object, possibly a marker placed for the specific purpose of braking reference, A skilled human can ordinarily stop a train within an accuracy of a few feet. Variability in train weight, performance characteristics, and track conditions affect the human's ability to stop a train precisely. The required deceleration rate also affects his performance. The higher the average rate, the greater the variability in result.

The degree of sophistication of automated program stop equipment is a function of the accuracy required. PATCO utilizes two "triggers" spaced some distance away from the station as reference points for programed stopping, The first trigger initiates maximum-rate deceleration. A second trigger, roughly at the end of the platform, causes the ATO package to measure the train's speed and adjust the deceleration rate accordingly, A manually set switch in the train cab is used to define train length so that the braking action will cause the train to be centered on the platform regardless of its length. Under adverse weather conditions, the operator makes the stop manually, initiating deceleration at a point marked by a yellow pole on the wayside.

Where both station and train doors are used, it is necessary to aline the train with the doors within an accuracy of a few inches. Both Sea-Tac and AIRTRANS have such a system. Information on train weight, instantaneous position, speed, and deceleration may be processed by an onboard computer to achieve precision stopping. At BART, a long wayside antenna provides the position signals necessary for the onboard program stop computer. Other needed information is derived and processed on board.

Door Control and Starting

Some engineers do not consider door control and starting to be train protection functions since the opening and closing of doors present no hazards to the train. Clearly, however, the safety of passengers is affected by door operation, so it is common to interlock door functions with train protection, a practice that leads some engineers to regard door control as a part of train protection.

Three basic pieces of information are required for the control of door opening, It is necessary to determine that the train is in a proper location for doors to be opened. If there are doors on both sides of the train, the proper side must be identified at each station, Assurance that the train is stopped and will not move is required. (Clearly some of these requirements must be overridden in emergency situations.)

On starting, four conditions should exist before a train leaves a station. The doors should be closed and locked. No passengers should be caught in the doors. It should be time for the train to depart. The train protection system should indicate that it is safe to move the train.

In manual systems, most of the door control, monitoring, and starting functions are performed by humans. When a conductor is on board, control and monitoring of doors is ordinarily his most important assignment. Lights are usually provided to indicate the status of all doors. (It is worth noting that a 10-car train may have as many as 40 doors, each with two leaves, on each side of the train. Thus, 160 door leaves must be monitored during the movement of the train through the system.) Because there is no truly foolproof practical door, all U.S. rail rapid transit systems have onboard personnel to act as a back-up to insure that door closure is not initiated when passengers are boarding and leaving and to verify that no one is caught when the doors are closed and locked.

Where trains are unmanned, a more complex form of door control is required, In special environments such as the Sea-Tac and AIRTRANS systems, door systems much like those of elevators have been used. The platforms are enclosed and doors on both train and platform must be closed and locked before the train can move. Doors with pressure-sensitive edges are used to prevent possible entrapment of passengers in a closing door. All door functions are interlocked with the train protection system.

Jerk Limiting

Jerk is defined as the rate of change of acceleration. Control of jerk contributes to a smooth ride and from a rider standpoint, a somewhat safer one. Customarily, jerk limiting is a function of the propulsion not the train control system.

Jerk limiting applied during stopping is sometimes termed “flare-out control.” It is identical to the maneuver that a skilled automobile driver performs just as the car is coming to a stop. By easing off on the brake, the transition from deceleration to full stop is smoothed out. Because there are safety implications to releasing the brakes, flare-out control is usually designated to be either a part of the train protection system or to be interlocked with it.

In a manually operated transit system the flare-out function is performed by the operator much as it is performed by an automobile driver. The smoothness with which the function is performed depends to a great extent upon the skill of the operator. In an automatic train control system, the flare-out function can be performed automatically by sensing the speed of the time when the train velocity becomes less than some predetermined amount. It is necesary that this reduction in braking effort be allowed to persist only for a short period of time. Otherwise, the braking system of the train could be disabled. Accordingly, flare-out is controlled by a timer so that the reduction of braking effort can persist only for a few seconds. During normal operation these few seconds are sufficient to bring the train to a complete halt, and the brakes then are re-applied. It is essential that the design and the implementation of the flare-out system be such that a failure cannot permanently withhold braking action. Figure A-3 is a schematic diagram of a typical automatic flare-out control system.

Slip-Slide

Slip refers to the slipping of wheels during the application of power. Slide is concerned with wheels sliding when brakes are applied. Slip or slide occurs when the tractive effort of the train exceeds the adhesion capability of the wheels and rails. Excessive slip, which occurs during acceleration, can damage the propulsion equipment, wheels, and rails, Slide, which occurs during deceleration, can damage the wheels and rails; a wheel locked during braking can be ground flat on the bottom if it is dragged very far, with possible damage to the crown of the rail as well. In addition, one or more sliding wheels during braking can increase the distance needed to stop a train because the coefficient of friction between a sliding wheel and rail is lower than that between a rolling wheel and rail.

Slip-slide control is traditionally considered part of the propulsion and braking system, but it has important relationships with the train control system. For example, correction of sliding during braking can be obtained only by reducing the braking effort, which has obvious safety implications. Either through the design of the braking system or in conjunction with the train protection system, assurances must be provided that operation (or malfunction) of the slip-slide control does not permanently prevent application of the brakes when a brake application is required.

TRAIN SUPERVISION

In general terms, train operation functions are concerned with the movement of individual trains. Train protection acts as a restraint to prevent accidents for individual trains or between trains. By nature, these two groups of train control functions are tactical and localized, in that they deal with short-range concerns for specific elements or places in the transit system. In contrast, train supervision comprises a group of functions concerned with the overall regulation of traffic and the operation of the transit system as a whole. Thus, train supervision functions are strategic, systemwide, and more long-range.

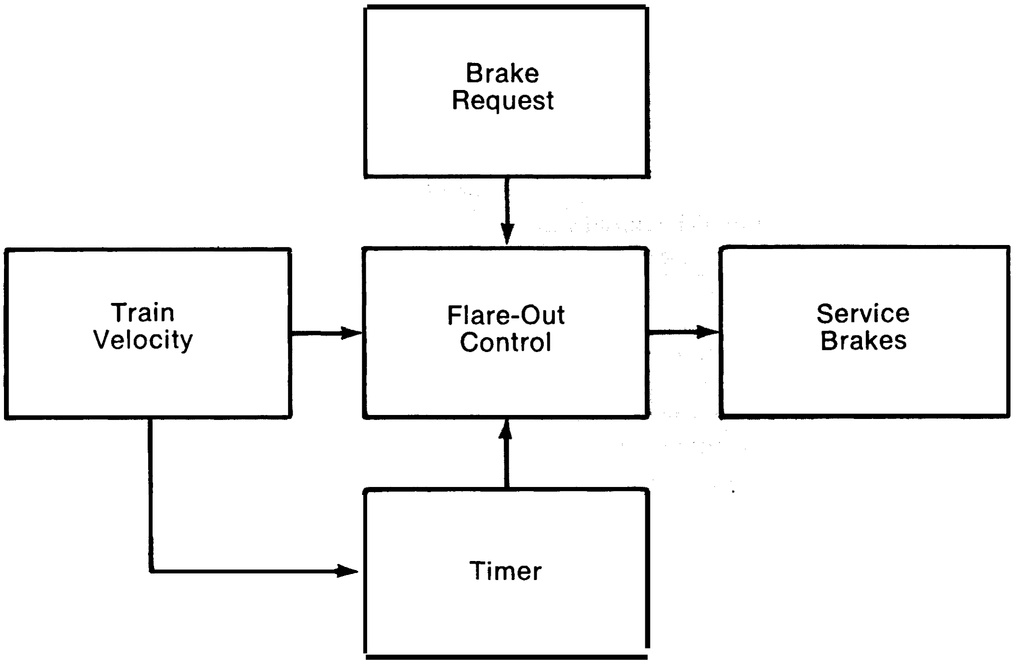

FIGURE A–3.-Conceptual Diagram of Service Brake Flare-Out Control

The functions of train supervision are:

- Schedule Design and Implementation
- Route Assignment and Control
- Dispatching
- Performance Monitoring
- Performance Modification
- Alarms and Malfunction Recording
- Recordkeeping

Schedule Design and Implementation

In most rail rapid transit systems, the functions of schedule design and implementation are not connected on a real-time basis. Train schedules are evolved to meet the transit system's objectives, whether they be minimization of operating cost, maximization of service, utilization of equipment, or whatever. Most train scheduling in such situations is performed manually, with perhaps occasional assistance from a computer,

Train schedules do not change frequently. Once a basic service pattern has been established, it may remain unchanged for months or years. The primary changes may be the addition of special trains to provide extra service to special events. This type of extra service is usually provided in off peak hours and presents no major train control problem. Providing special crews is likely to be the most difficult problem here.

Where major changes of schedule or operational procedure are contemplated, it may be necessary to utilize computer simulations. NYCTA has been using such simulations for about a decade for examining complex scheduling and routing problems. Simulations may also be used in the planning of systems. Where systems are computer controlled, provision may be made to use the computer for simulations of possible operational changes.

Operational implementation of the schedule is generally focused in some central control facility. This facility may be simple or elaborate. Hierarchical control structures may be utilized, The primary functions of the control center are (1) receipt and display of information on the status of the system, (z) decisionmaking regarding action to be taken, and (3) issuing commands for action. It should be kept in mind that supervisory functions and decisions may affect the safety of passengers, but train supervision cannot override train protection considerations.

Most control centers have functions beyond train control alone. It is common to monitor and control the electric power systems and other critical elements such as pumps and blowers in these facilities, Monitoring of station platforms, fare collection areas, or parking lots may also be carried out by central control facility, Passenger service communications may be provided, as well as some service to the news media or the general public.

Route Assignment and Control

The supervisory system selects, assigns, and controls the routes to be followed by trains. Under normal circumstances, the routes of a conventional transit system are fixed, Major delays must be involved before train rerouting is done. In a linear two-track system, the most ordinary form of rerouting is concerned with operating the system over only one track until a problem on the other track is cleared. Except for the systems which use computers, alternating the direction of traffic flow is accomplished under the control of humans at a control center or tower. BART provides special computer programs which can generate the necessary commands for single-track operation. WMATA plans a similar approach, This approach presumably can lead to more efficient operation, both in terms of increased flow through the system and in the freeing of the controllers to make other decisions during such emergencies.

In a few transit systems, there are opportunities to route conventional trains from one line to another in case of major service disruptions, NYCTA, for example, can reroute trains on some of the main Manhattan lines. Additionally, the four-track (two local, two express) arrangement of portions of the system permits interchange of trains between some tracks on the same route-always at a loss in overall performance.

Dispatching

Train dispatching is concerned with the makeup of train sets and the timing of their departure from selected points in the system. In conventional rail transit systems, a written schedule is used to indicate the anticipated system needs for the day, both by train size and time of departure. Dispatching usually takes place from terminals or yards.

Most train dispatching in conventional systems is accomplished through the use of preprogrammed dispatch machines at terminals and entry points. These machines simply provide a visual indication that it is time for the train to depart. In a short system such as PATCO, there is normally no further supervisory control of the motion of the train through the system. Operators are provided with a timetable, and verbal communications are used if any problem arises.

Modification of the dispatching routine may be accomplished under computer control in systems such as BART and WMATA. Manual or verbal override is used at all operating transit properties except BART. Modification of dispatching schedules is required to compensate for various delays on the line.

Performance Monitoring

Train performance monitoring is closely allied with train dispatching and route assignment. Essentially, the purpose of this function is to smooth out irregularities in the flow of traffic. Methods of performing this function range from the very simple to the very sophisticated.

Basically, there are two approaches to performance monitoring and control, They may be accomplished on an intermittent or a continuous basis. In all conventional systems in operation and being planned, performance monitoring is done on an intermittent basis, Train running times between stations or terminals are measured and any control actions deemed necessary are taken. There is no continuous monitoring of the performance of the train while it is running. (Verbal communications can ordinarily be used to provide an indication of serious performance problems as soon as they occur.)

If it is desirable to modify the performance (speed, running time, acceleration) of a train, commands for the performance modification are usually transmitted at selected wayside locations (typically stations). Continuous performance modification commands are not provided. Again, verbal communications may be used to transmit a command at any time.

Performance Modification

There are two basic ways of modifying train performance. Trains may be held at specific stations to provide more uniform spacing. Either in conjunction with this or as an alternative, the actual running time of the train speed or acceleration rate can be changed.

In the systems which have the least amount of automation, performance monitoring and control is essentially accomplished by humans. Supervisory and onboard personnel monitor the state of the system. Information on significant perturbations may come in through model board displays or voice communications. Required performance modifications may be indicated by voice transmission or reductions in speed commands.

One step upward in automation is the addition of dispatching lights at certain stations. By use of such lights, trains can be held in these stations to attempt to smooth out the flow of traffic.

At the highest levels of automation are the systems which use computers to adjust performance requirements continually so as to provide schedule adherence and/or uniform flow of trains through the system. Both BART and WMATA have facilities to monitor the performance of all trains in the system and to compare the actual and desired status of the system, Through rather elaborate control procedures, computers then issue commands to modify individual train performance in a way such that the system objectives are met.

Views vary on the value of automating the function of train performance modification. At BART and WMATA not only are the desired performance levels calculated automatically, they are transmitted and implemented automatically as well. Baltimore is considering an evolutionary system which could eventually incorporate a computer. Initial thoughts are that performance level commands would be displayed in stations and onboard operators would set switches to establish performance levels for the ATO equipment. NYCTA, which plans eventual conversion to automatic train operation, does not now contemplate the use of performance level controls as such. It is planned to control train spacing by dispatching at terminals and selected stations as well as by verbal control.

Alarms and Malfunction Recording

Aside from the annunciation of delays in train motion, supervisory systems can be used to indicate other problems in carborne equipment. Fire, low air pressure, lights out, air-conditioner failure, motor failure, and many other things are potential candidates for malfunction alarm. In traditional manned systems, information on the status of onboard equipment is not transmitted to the wayside automatically. Annunciation of malfunctions is provided by displays in the operator's cab. The information may be relayed immediately by voice transmission if the problem is serious. Minor problems may be reported at the end of a run or the end of the day.

In unmanned systems, there is a greater need for annunciation of malfunctions. Both the Sea-Tac and AIRTRANS systems have malfunction annunciation systems with displays in the central control facility. A hierarchy of malfunction conditions is defined, and each group is treated in accordance with the seriousness of the event involved.

It should be noted that the annunciation system for train supervision may be a subset of a larger system which deals with the status of many types of equipment throughout the system. This may include pumps, blowers, electrical power distribution equipment, and so forth.

Recordkeeping

Supervisory equipment or personnel keep records for individual vehicles and the overall transit system. By means of train and car identification equipment, information is provided on the accumulation of car miles and used to schedule maintenance activity. If computational capabilities are a part of the supervisory system, additional functions may be performed. The computer may be used to generate work orders or schedules for routine maintenance. Spare parts ordering may be handled. Manpower utilization and payroll data may be processed. Reliability and maintainability data may be derived. Special management reports also may be generated.

Where malfunction communication equipment is used, it speeds diagnosis of system faults. In general, it appears that in-service diagnosis and repair of individual failures is significantly less important than maintaining operation of the system as a whole. Where practical, attempts are made to continue to operate trains w th failed equipment long enough to get them out of service. If this is not possible, pushing a train or modular replacement of elements is attempted, The use of significant amounts of diagnostic equipment appears more appropriate in maintenance shops than on in-service equipment,

COMMUNICATIONS

Communication functions are implicit in all other types of train control system activity, and various forms of communications (both verbal and data) have been mentioned in connection with the description of train protection, operation, and supervision functions. Table A–1 is a summary of the major types of communication performed by and within the train control system. Each is discussed below, with emphasis on those that have not been treated previously.

Train Protection

Train protection communications are traditionally separate from all others. Special precautions are taken to insure that signals from other circuits or systems do not mix with train protection signals.

It appears that future ATP systems will all rely heavily on electrical or electronic transmission systems. Voice communications are a part of ATP but, in general, play a minor role. Voice communications are largely used to transmit information regarding visual verification of a safety situation or procedural instructions related to emergency operation.

Operational Control and System Status

These two functions are discussed together because system status provides the feedback information for operational control. Essentially, these are the communications involved in the train supervision function. Most routine status information is transmitted by electrical means and displayed visually. In automated systems, much of the status information is processed directly by computers. Visual displays may be provided routinely or on a call-up basis.

Status information includes more than just the motion of vehicles. It also concerns conditions on platforms, availability of trains in yards, track conditions, and any of a hundred other things. Malfunction alarms transmitted from carborne or wayside equipment provide status information on certain equipment. The more highly automated the system, the greater the need for equipment status information, but this does not necessarily mean increased automation of the means for transmitting equipment status information. If additional information is to be communicated, it can also be given over a voice channel by the onboard attendant.

Operational commands may be transmitted by almost any means, ranging from a printed timetable to electronic devices. There is a trend toward use of electrical or electronic devices for signal transmission in the new systems being planned, but there are some specific exceptions. NYCTA, for example, plans to operate a hierarchical supervisory system in which major decisions will be made in a command center and relayed by voice or teletypewriter to dispersed towers for execution, Baltimore is considering visual transmission of performance level

TABLE A–1.—Primary Means of Communicating Information Related to Train Control

Function	Primary Means of Transmission (T') and Display (D)			
	Visual	Voice	Electric Signal	Written
Train Protection	T, D	—	T, D	—
Operational Control	D	T	T, D	—
System Status	D	T	T, D	—
Emergency Communication	—	T	—	—
Passenger Service	—	T	—	—
Maintenance Information	—	T	T	T, D
Business Operations	—	—	T	T, D

adjustments using displays on the wayside in stations. Voice communication with all trains appears to be an essential element in all new systems and in upgrading old ones, Emergency operational commands may thus be relayed by voice communication.

Emergency Communications

Emergency communications are the only type that may involve contact with outside agencies or employees not on trains or reachable by telephone. For this and other reasons, at least one space radio system is provided in all transit systems to allow communication with roving employees.

It is felt by most transit system managers that the ability to communicate with passengers, preferably two-way but at least one-way, is extremely important in controlling emergency situations. Assuring the passenger that his plight is known and help is on the way is believed to have considerable psychological value.

Emergency communications may also involve dealing with police and fire departments as well as other organizations of the civil government, These communications may be handled either by radio or telephone.

The human role in emergency communications is very important for the simple reason that the nature of emergencies is such that unexpected events occur. Because humans respond to a very wide range of situations, it seems unlikely that the emergency communication role of the human can be replaced.

Passenger Service

Train control equipment or personnel act to provide information to the passengers. In most systems, onboard operators or station personnel provide information on station identity and train destination. ATS equipment is used to perform some of these functions in highly automated systems. At BART, for example, special destination signs indicate the imminent arrival of trains, the approximate location at which the trains will stop, and the destination of the trains. These particular signs are also used to display commercial messages and thereby produce revenue for the system, Both AIRTRANS and Sea-Tac utilize prerecorded messages in the trains to provide information to passengers. AIRTRANS has both TV displays and lighted signs to display route information at the stations,

Maintenance Information

Elements of the train control system maybe used to provide information needed for scheduled or unscheduled maintenance. Train and car identification systems can be used to provide information on accumulated car miles. In highly automated systems, malfunction detectors and annunciators transmit malfunction information either directly to the maintenance facility or through central control to the maintenance facility. Voice communications relating to maintenance problems may be channeled through central control or handled directly.

Communication of maintenance information related to inventory control may also be handled over the ATC communication system, especially if a central computer is used. This maybe accomplished over commercial telephone lines, or special data transmission links. Except for fully automated systems, there does not appear to be a trend toward significant increases in ATC communications for maintenance information transmission.

Business Operations

Basic data available from the train control system may be used in planning business operations regarding workforce allocation, expansion plans, procurement policies, vehicle utilization, and so on, This information is generally presented in the form of tabulated reports which may be computer printouts or periodic manual summaries of system performance parameters.