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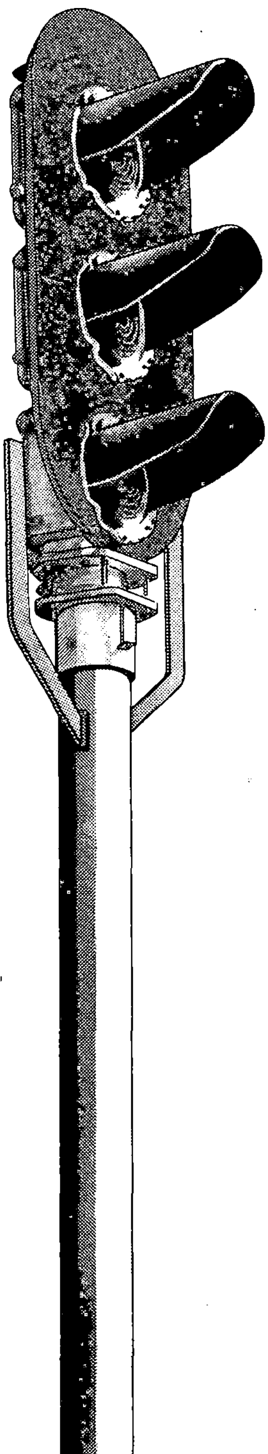
Evaluation of Signal/Control System Equipment and Technology



TASK 2
Status of Present Signal/Control Equipment

January 1979

FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION

Federal Railroad Administration

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06 – Signals, Control and Communications

PREFACE

This report results from research supported by the Department of Transportation, Federal Railroad Administration, Office of Research and Development, for the following seven separate but interrelated tasks under Contract DOT-FR-773-4236: "Evaluation and Assessment of Signal/Train Control System Equipment and Technology".

That contract covers the first phase of a multiphased program directed at the upgrading of signal and control systems on Amtrak intercity rail routes for high speed 255 kmph (160 mph) passenger train travel.

The study contract includes the following seven separate but interrelated tasks:

Task 1 - "Assessment of Signal/Control Technology and Literature Review"

Survey and assessment of the technologies incorporated in current signal and control practice; literature review and reference.

Task 2 - "Status of Present Signal/Control Equipment"

Review and analysis by major domestic and foreign railroads of the signaling systems now in use; discussion of candidate systems for adaptation by Amtrak; recommendations for further activity.

Task 3 - "Standardization, Signal Types, Titles"

Analysis with emphasis on standardization of domestic and foreign operating rules and equipment, including signal types, aspects, titles and standards; analysis of impact of FRA Rules, Standards and Instructions (RSI) on development of improved systems; recommendations for standardization.

Task 4 - "Electrical Noise Disturbance"

Study of causes of electrical noise disturbance or EMI (Electro-Magnetic Interference) as it relates to signaling; recommendations on both rolling stock and wayside signaling equipment to reduce and contain EMI radiation to acceptable levels.

Task 5 - "Economic Studies"

Economic aspects of potential improved signaling systems including capital and operational costs, reliability and maintainability, effects of standards, costs savings and benefits.

Task 6 - "Specification Development"

Functional specification for an improved signal/control system to be used by Amtrak in inter-city passenger rail operation at speeds up to 255 kmph (160 mph).

Task 7 - "Final Report"

Final report incorporating findings of Tasks 1 through 6 of this study and including recommendations for further work that may be usefully pursued in support of improved signaling systems, their application and utilization.

This particular document reports the findings of Task 2 -- Status of Present Signal/Control Equipment. This task was accomplished through interviews with technical and managerial personnel of railroads, a review of technical reports and papers and on-site visits to domestic and foreign railroads.

The authors wish to acknowledge with appreciation the efforts and cooperation given by the many individuals in governments, railroads and elsewhere who contributed so greatly to the overall effort. To single out individuals who were especially helpful would risk overlooking others who also provided valuable assistance. Therefore, our sincere gratitude is extended to all who were contacted and assisted on the project.

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SECTION 1.0

INTRODUCTION

This task report presents the results of Task 2 of the DOT contract DOT-FR-7734236; entitled "Evaluation and Assessment of Signal/Control System Equipment and Technology". Whereas the Task 1 report (NTIS) assessed the specific technologies available for use in the design of signal and control systems; this report provides a description and assessment of the systems actually in use in the U.S. and Europe.

1.1 Purpose and Scope

The purpose of this report is to convey the status of present equipment and systems used on passenger rail routes throughout the world and to compare the features of selected domestic and foreign signal/control systems. A review of all signaling on the routes over which Amtrak operates was made in order to avoid a recommendation of a final signal system that would be incompatible with existing railroads' signal systems or future electrification. In addition, comparative cost figures for signal/control systems were determined.

1.2 Procedure

As in Task 1, the initial activity was concentrated on a review of existing literature. The Railroad Research Information Service (RRIS) bulletins were utilized to identify applicable documents in the time period 1973 to 1977. Since these bulletins are issued biannually, a separate search was conducted by RRIS to identify documents released during the last six months of Calendar Year 1977. Other sources of data were also identified and utilized such as the National Technical Information Service (NTIS), various public, private, and university libraries, but the majority of the information was identified by RRIS. The document copies were received from several sources with the principle contibutors being the Northwestern University Transportation Center Library and the International Union of Railways (UIC), Office of Research and Experiment (ORE) library. Over 250 documents were accumulated and reviewed in the conduct of the overall program. Additionally, 14 transportation periodicals subscribed to by the program library were reviewed continuously to obtain current data.

Based on these data, detailed questionaires were developed and sent to railroads and transit properties to obtain specific information for each signal system. Responses were obtained from all of the domestic railroads queried and several European rail systems. The transit properties queried all sent back responses. Based on these responses, survey trips were made to obtain additional data and to physically inspect the systems. In the U.S., the Chicago Transit Authority and the Bay Area Rapid Transit system in San Francisco were surveyed. Only those railroads over which Amtrak operates were included in the U.S. portion of the railroad survey which involved visits to the Union Pacific, Chessie System, Burlington Northern and Southern Pacific railroads. The European properties visited included: British Rail (BR), London Transport, French

National Railroads (SNCF), German Federal Railroad (DB), Munich S-Bahn and U-Bahn systems, and the Italian State Railways (FS). Also, the British Columbia Railway (BC) in Canada was visited.

1.3 Background

Present day signal/control systems vary in complexity from fixed signs, written train orders, etc. to the more sophisticated Traffic Control Systems (TCS), consolidated control centers and route selection type interlocking systems which may be computer aided.

In all of these systems, the basic signal equipment is generally quite similar in appearance; however, the design philosophy of control circuitry and the technology employed for the application of the design can vary greatly.

Since the major differences between signaling and control systems implemented in the U.S. and Europe are due, in large part, to the design philosophy involved, it is important that the reader have knowledge of the philosophical background involved.

In the United States, railroad signal and control systems began to evolve in the last decade of the 19th century. Each railroad worked with the available suppliers to improve operational safety and efficiency through the use of innovative designs. As a result of this relatively uncontrolled development a somewhat chaotic evolution took place during the period from 1900 to about 1930. As early as 1906, steps were being taken to introduce federal regulation, but real controls were not established until the enactment of the Transportation Act in 1920. This act gave the Interstate Commerce Commission (ICC) authority to establish and enforce specifications for signaling equipment and to establish requirements for operation and maintenance of these equipments.

During this period an organization evolved within the railroad industry which fostered a cooperative effort in signal technology. Initially a coalition of railroad signal engineers, it was subsequently expanded to include supplier representation. This organization, known today as the Communication and Signal Section of the Association of American Railroads (AAR), was largely responsible for preparation of current standards for design, installation and maintenance. In 1922 the ICC, after conducting hearings on the subject, ordered 40 railroads to install automatic train stops or train control devices on at least one of their passenger service divisions. A revision to this order was issued in 1924 to expand the total number of railroads to 91. Given this impetus, suppliers and railroads developed both continuous and intermittent cab signaling systems. Prior to World War II the use of coded continuous ac track circuits at rates of 75, 120 and 180 pulses per minute had become the most common cab signaling system.

The Signal Inspection Act of 1937 gave the ICC additional authority to control these systems. The constraints on cab signaling and train stops were expanded to be mandatory for operation above 130 kmph (80 mph) and to require all trains running in cab signal (or train stop) territory to be so equipped. After World War II the character of railroad operations changed dramatically. The impact of the increased availability of automobiles and improved highways resulted in a decreased demand for passenger railroad service. This trend was accelerated by the rapid development of air transport and cross country bus systems. Meanwhile the railroads, faced with ever mounting maintenance costs, concentrated on freight traffic with fewer but much longer and heavier tonnage trains. One result of this activity was a decrease in train speeds, and since train stops or cab signaling were not required below 130 kmph (80 mph) most automatic train control equipment was removed. The end result is that the residual cab signaling equipment in use on U.S. railroads is based on 30 to 40 year old technology.

On the other hand, the need to move freight efficiently and economically has led to a rapid development of highly sophisticated centralized traffic control systems. These systems came into being in the mid 1930's as pure hardware implementations, and because of the recent availability of minicomputers and microprocessors they have become commonplace throughout the industry. TCS implementation has eliminated many manned signal towers and provided information in real time to the operating center for traffic management and maintenance operations.

In Europe and Japan the development pattern of railroads was somewhat similar to the U.S. prior to World War II. The principle difference was that priority was placed on passenger train operation, and the traffic density in these countries was somewhat higher than in the U.S. After World War II, the development patterns markedly diverged. Because of wartime devastation in Europe and Japan, the top priority was placed on redevelopment of the rail transportation systems. This resulted in a continued passenger train market and the need for much higher train densities (shorter headways) than were utilized prior to World War II. These requirements forced a rapid growth in cab signaling and ultimately full automatic train control.

The UIC through its ORE developed standards for new signaling systems for the European countries and a similar effort took place in Japan. Since the purpose of such systems is to provide increased safety, the development program was appropriately directed and the design standards were rewritten to reflect the new technologies as they became available. In both Europe and Japan, the use of redundancy to achieve fail-safe operation is common and implementation of redundant voting computers or microprocessors is becoming a standard means of achieving fail-safe, fail-operational system capability.

The first use of a fully computerized train control system took place in Japan on the Shinkansen line which became operational in 1964. This high speed system operates up to 250 kmph (155 mph) on 15 minute headways and has proven so successful that the Japanese National Railways (JNR) have implemented the basic design of the signal, control and communication system as the standard for all JNR. In Europe, the intermittent cab signaling system which was standard prior to World War II has been upgraded to reflect current technology and is widely used for medium density operation. High density operation, which requires continuous cab signaling, is achieved most commonly by the use of ac coded systems with the running rails as the transmitting media or by use of digitally modulated audio frequency carriers using inductive loops as the transmitting elements. The latter of these is standard for the German railways.

The development of transit systems in the U.S. and Europe has followed patterns similar to those of the railroads. The European transit systems utilize essentially the same signaling design as the railroads except that full automatic train operation is standard. The U.S. transit properties, with one exception, utilize standard railroad signaling equipment with cab signaling or automatic train operation on the newer systems or the upgraded existing systems. The exception to these technologies is the Bay Area Rapid Transit System (BART) in the San Francisco-Oakland area. This system, which became operational in 1968, utilizes a highly sophisticated computer based signal and control system with digitally modulated audio frequency carriers.

There are two basic functions in a signal system: one is train detection and the second is to convey information to the train engineer or operator. The train detection function can be accomplished in different ways. In the United States and througout much of the world the track circuit is employed to detect the presence or absence of a train and to provide broken rail protection. A track circuit is defined as an electrical circuit of which the rails form a path. Basically, three types of track circuits are employed:

- dc track circuits
- ac track circuits
- af track circuits.

The dc track circuit can be further classified as a neutral, polarized or coded circuit and the ac can be further classified by its frequency (normally below 200 Hz) and the code rate. AF track circuits use audio frequencies usually above 500 Hz and are normally coded.

In most foreign countries, the track circuit is used for train detection; however, in some instances, train detection is accomplished by axle counters in conjunction with inductive loops. This type of detection does not use the rails as part of the circuit.

The other function of signaling is to convey visual information which is carried out by color light, searchlight or position light signals. The aspect of the signal conveys to the engineer the condition of the track ahead, and in turn he controls the train in accordance with the indications. Additionally the wayside signal can also indicate to the engineer the route his train will take and/or the speed at which the train can proceed. In the U.S. signal aspects are normally used to provide indications of authorized speed (speed signaling), while in Europe wayside signal aspects at interlockings normally provide route information (route signaling).

For higher speed operation on domestic and foreign railroads some form of cab signaling with or without enforced overspeed control is employed. Such systems are commonly used in conjunction with wayside block signals but may be used without them.

1.4 Definitions

For the purpose of this report, the following definitions of words, terms and phrases used in railway signal and train control systems apply. These definitions are intended only as an aid to the material contained herein.

Aspect, False Restrictive - The aspect of a signal that conveys an indication more restrictive than intended.

Aspect, Signal - The appearance of a fixed signal conveying an indication as viewed from the direction of an approaching train; the appearance of a cab signal conveying an indication as viewed by an observer in the cab. (Standard Code)

Automatic Block Signal System (ABS) - A block signal system wherein the use of each block is governed by an automatic block signal, cab signal, or both (FRA).

Absolute Permissive Block (APB) - A block signal system between sidings, consisting of two or more blocks, which when occupied, cause the opposing fixed entering signal to display an aspect indicating Stop.

Following movements are governed by intermediate fixed signals, cab signals or both whose most restrictive aspects indicate Stop; then Proceed at Restricted Speed or Proceed at Restricted Speed, respectively.

Automatic Train Control (ATC) - The system for automatically controlling train movement, enforcing train safety and directing train operations. ATC includes subsystems for

Automatic Train Protection, Automatic Train Supervision, and Automatic Train Operation.

Automatic Train Operation (ATO) - The subsystem within Automatic Train Control which performs the on-train functions of speed regulation, program stopping and performance adjustment.

Automatic Train Protection (ATP) - The subsystem within Automatic Train Control which maintains safe train operation. ATP subsystems include train detection, train separation, interlocking, and speed-limit enforcement.

Automatic Train Supervision (ATS) - The subsystem within Automatic Train Control which monitors and provides controls necessary to direct the operation of a system of trains in order to maintain intended traffic patterns and minimize the effects of train delays on the operating schedule.

Block - A length of track of defined limits, which may consist of one or more track circuit.

Block, Absolute - A block in which no train is permitted to enter while it is occupied by another train.

Cab - The compartment of a locomotive from which the propelling power and power brakes of the train are manually controlled.

Cab Signal - A signal located in the engineman's compartment or cab, indicating a condition affecting the movement of a train or engine and used in conjunction with interlocking signals and in conjunction with or in lieu of block signals (FRA).

Cab Signal System - A signal system so arranged that wayside conditions are indicated in the cab or compartment of an engine.

Circuit, Acknowledgment - A circuit consisting of wire or other conducting material installed between the track rails at each signal in territory where an automatic train stop system or cab signal system of the continuous inductive type with two-indication cab signals is in service, to enforce acknowledgment by the engineman at each signal displaying an aspect requiring a lower speed or stop.

Circuit, Control - An electrical circuit between a source of electric energy and a device which it operates.

Circuit, Cut-in - A roadway circuit at the entrance to automatic train stop, train control or cab signal territory by means of which locomotive equipment of the continuous inductive type is actuated so as to be in operative condition.

Circuit, Line - A term applied to a signal circuit on an overhead or underground line.

Circuit, Non-vital - Any circuit the function of which does not affect the safety of train operation.

Circuit, Track - An electrical circuit of which the rails of the track form a part.

Circuit, Track; Coded - A track circuit in which the energy is varied or interrupted periodically.

Circuit, Track; High Level ac dc - A track circuit which employs relatively high alternating circuit voltage on rails, low impedance energy source, and transformer-rectifier unit between rails and direct current track relay.

Circuit, Track; Impulse - A track circuit whose track relay is activated by controlled high energy pulses of short duration.

Circuit, Track; Phase Selective - An ac track circuit consisting of code transmitters, code following relays and a phase selective detector unit. Local and operating coils of the relay must be in proper phase relationship.

Circuit, Vital - Any circuit the function of which affects the safety of train operation.

Code, Transmitter - A device to vary periodically an electrical circuit at a definite predetermined code frequency.

Contact - A conducting part which co-acts with another conducting part to open or close an electric circuit.

Contact, Back - A part of a relay against which, when the relay is de-energized, the current-carrying portion of the movable neutral member rests so as to form a continuous path for current.

Contact, Front - A part of a relay against which, when the relay is energized, the current carrying portions of the movable neutral member is held so as to form a continuous path for current.

Contact, Open - A current-carrying member which is open when the operating unit is in the normal position.

Contact, Polar - A part of a relay against which the current-carrying portion of the movable polar member is held so as to form a continuous path for current.

Contact, Reverse - A term used to designate a current-carrying member when the operated unit is in the reverse position.

Continuous Control - A type of control in which the locomotive apparatus is constantly in operative relation with the track elements and is immediately responsive to a change of conditions in the controlling section which affects train movement.

Cut-section - A location other than a signal location where two adjoining track circuits end within a block.

Device, Acknowledging - A manually operated electric switch or pneumatic valve by means of which, on a locomotive equipped with automatic train stop or train control device, an automatic brake application can be forestalled, or by means of which, on a locomotive equipped with an automatic cab signal device, the sounding of the cab indicator can be silenced.

Distance, Stopping - The maximum distance on any portion of any railroad which any train operating on such portion of railroad at its maximum authorized speed, will travel during a full service application of the brakes, between the point where such application is initiated and the point where the train comes to a stop under its most inefficient braking mode.

Element, Roadway - That portion of the roadway apparatus of automatic train stop, train control or cab signal system, such as electric circuit, inductor, magnet, ramp or trip arm to which the locomotive apparatus of such system is directly responsive.

Enforced Cab Signaling - A signaling system so arranged that its operation will automatically result in the application of the brakes to bring the train to an allowable speed or to stop.

Fail Safe - A term used to designate a railway signaling design principle, the objective of which is to eliminate the hazardous effects of a failure of a component or system.

False Restrictive (FR) - A failure of a system device or appliance to indicate or function as intended which results in greater restriction than is required.

False Proceed (FP) - A failure of a system device or appliance to indicate or function as intended which results in less restriction than is required.

Filter, Electric Wave - A wave filter designed to separate electric waves of different frequencies.

Filter, High Pass - A wave filter having a single transmission band extending from some critical or cut-off frequency, not zero, up to infinite frequency.

Filter, Low Pass - A wave filter having a single transmission band extending from zero frequency up to some critical or cut-off frequency, not infinite.

Filter, Low Pass Code - A low pass filter connected between coding equipment and line to pass direct current code impulses and prevent code equipment from shunting carrier and communication circuits. It prevents line coding contacts from introducing undesired high frequency currents into the line.

Filter, Receiving - A band pass filter associated with the input circuit of a carrier receiver or repeater.

Filter, Transmitting - A band pass filter associated with the output circuit of a carrier transmitter or repeater.

Filter, Voice and Carrier Pass - A high pass filter that passes voice frequencies and carrier frequencies and attenuates frequencies below the voice range.

Filter, Voice Pass - A band pass filter that passes voice frequencies and attenuates frequencies above and below the voice range.

Forestall - As applied to an automatic train stop or train control device, to prevent an automatic brake application by operation of an acknowledging device or by manual control of the speed of the train.

Frequency - The number of cycles through which an alternating current passes per second.

Impedance - The apparent resistance in an electric circuit to the flow of an alternating current, analogous to the actual electrical resistance to a direct current, being the ratio of electromotive force to the current.

Indicator, Cab; Audible - A device (usually air whistle) located in cab equipped with cab signals designed to sound when cab signal changes and continues to sound until acknowledged.

Insulated Joint - A rail joint in which electrical insulation is provided between adjoining rails.

Interlocking - An arrangement of signals and signal appliances operated from an interlocking machine and so interconnected by means of electric locking that their movements must succeed each other in proper sequence, train movements over all routes being governed by signal indication.

Interlocking, Automatic - An arrangement of signals, with or without other signal appliances, which function in response to relay operation and circuit logic as distinguished from those whose functions are controlled manually, and which are so interconnected by means of electric circuits that their movements must succeed each other in proper sequence; train movements over all routes being governed by signal indication.

Interlocking, Manual - An arrangement of signals and signal appliances operated from an interlocking machine and so interconnected by means of mechanical and/or electric locking that their movements must succeed each other in proper sequence, train movements over all routes being governed by signal indication.

Interlocking, Relay Type - An arrangement of signals, with or without other signal appliances, operated either from a control machine or automatically, and interconnected by means of electric circuits employing relays so that their movements must succeed each other in proper sequence, train movements over all routes being governed by signal indication.

Intermittent Control - A type of control in which the locomotive apparatus is affected only at certain designated points, usually at signal locations.

Line of Light Indication - A visual display, used in conjunction with a control system, wherein the route called for and train occupancy is displayed on the console or model board by a series of lights.

Meet - A pre-programmed or pre-determined point where one train meets another as prescribed by train orders, time-table or signal indications.

Optical Isolator - An electronic device consisting of a light source (usually an infrared light emitting diode) as an input coupled optically to an output consisting of a photo diode, photo transistor or photo silicon controlled rectifier.

Relay - A device that is operative by a variation in the conditions of one electric circuit to affect the operation of other devices in the same or another electric circuit.

Relay, Biased - A relay which will operate to its energized position by current of one polarity only, and will return to its de-energized position when current is removed.

Relay, Centrifugal - An alternating current frequency selective relay in which the contacts are operated by a fly ball governor or centrifuge driven by an induction motor.

Relay, Code Following - A relay which will follow or reproduce a code without distortion within practical limits.

Relay, Magnetic Stick - A relay, the armature of which remains at full stroke in its last energized position when its control circuit is opened.

Relay, Two-Element - A relay, usually alternating current, having two separate windings, both of which must be properly energized to cause the relay to operate.

Relay, Vane Type - A type of alternating current relay in which a light metal disc or vane moves in response to a change of the current in the controlling circuit.

Resistance, Ballast - The resistance offered by the ballast, ties, etc., to the flow of leakage current from one rail of a track circuit to the other.

Resistance, Train Shunt - The actual resistance in ohms from rail to rail through wheels and axles of a train, engine or car. This resistance will vary with rail and wheel surface conditions and with weight of equipment.

Shunting Sensitivity - Shunting sensitivity of a track circuit is:

1. Non-Coded track circuit - The maximum resistance in ohms which will cause the relay contacts to open when this resistance is placed between the rails at the most adverse shunting location.

2. Coded track circuit - The maximum resistance in ohms which will prevent the code responsive track relay from following the code when this resistance is placed between the rails at the most adverse shunting location.

Signal, Approach - A fixed signal used in connection with one or more signals to govern the approach thereto.

Signal - An appliance which conveys information governing train movements.

Signal, Cab - A signal located in engineman's compartment or cab, indicating a condition affecting the movement of a train or engine and used in conjunction with interlocking signals and in conjunction with or in lieu of block signals (FRA).

Signal, Color Light - A fixed signal in which the indications are given by the color of a light only.

Signal, Color Position Light - A fixed signal in which the indications are given by color and the position of two or more lights.

Signal, Distant - a term synonymous with approach signal.

Signal, Dwarf - A low home signal.

Signal, Home - A fixed signal at the entrance of a route or block to govern trains or engines entering and using that route or block.

Signal, Position Light - A fixed signal in which the indications are given by the position of two or more lights.

Signal, Semaphore - A signal in which the day indications are given by the position of a semaphore arm.

System, Absolute Permissive Block - A block signal system under which the block is usually from siding to siding for opposing movements and the fixed signals governing entrance into the block display an aspect indicating Stop when the block is occupied by an opposing train. For following movements the section between sidings is divided into two or more blocks and train movements into these blocks, except the first one, are governed by intermediate fixed signals, cab signals, or both. The intermediate fixed signals usually display an aspect indicating Stop then Proceed at Restricted Speed, and the cab signal displays an aspect indicating Proceed at Restricted Speed, as their most restrictive indications.

System, Automatic Block Signal - A series of consecutive blocks governed by block signals, cab signals, or both, actuated by a train, or engine, or by certain conditions affecting the use of a block.

System, Automatic Cab Signal - A system which provides for the automatic operation of cab signals.

System, Enforced Cab Signal - A signaling system so arranged that its operation will automatically result in the application of the brakes to bring the train to an allowable speed or to stop.

System, Block Signal - A method of governing the movement of trains into or within one or more blocks by block signals or cab signals.

System, Universal Code - A signal system employing continuously coded track circuits, code following relays and decoding units.

Traffic Control System (TCS) - A block signal system under which train movements are authorized by block signals whose indications supersede the superiority of trains for both opposing and following movements on the same track (FRA).

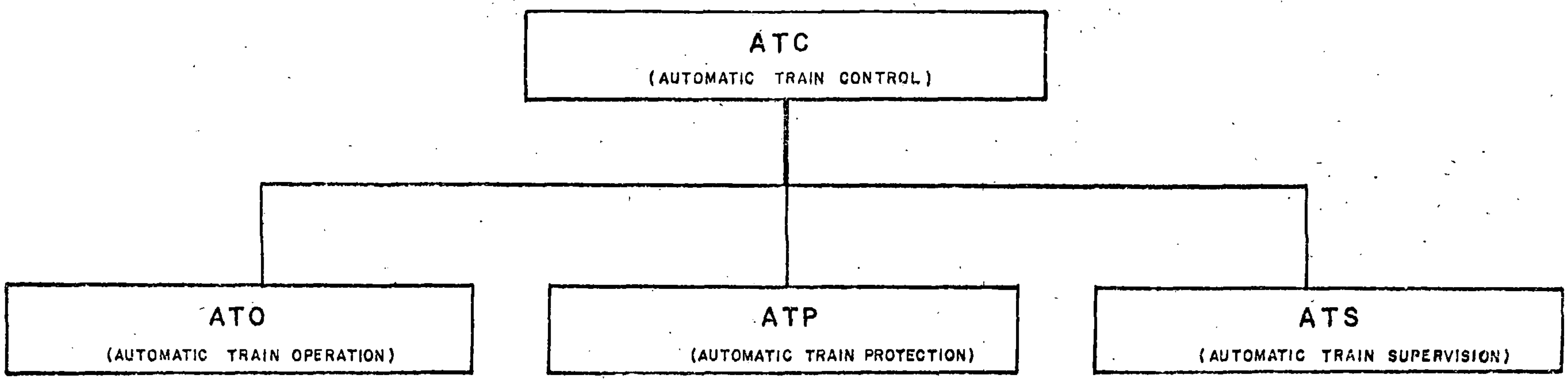
Train-to-Wayside Communication System (TWC) - A non-vital, bi-directional, digital data communications system for communication, at fixed points, between the trains and wayside.

Transponder (Wayside) - A tuned wayside device, either active or passive which, when electro-magnetically coupled to a receiving unit on a locomotive, conveys speed control, location or other information to the train. The locomotive unit, when active, is called an interrogator.

Within the signal industry considerable difference in interpretation or meaning of technical system terms exists. These different interpretations and meanings which have developed in domestic and foreign technical literature, have often caused confusion to U.S. railroad and transit signal engineers. Four terms which are important to an understanding of this report but have received varying interpretations are the following: (1) Automatic Train Control, (2) Automatic Train Operation, (3) Automatic Train Protection, and (4) Automatic Train Supervision.

Although each of these technical system terms has already been defined herein, the interrelationship of these major signal/control systems and component subsystems is further illustrated within the exhibit shown on the following page in order that the reader may identify the contemporary context as used throughout this report.

RELATIONSHIP
OF
MAJOR SIGNAL SYSTEMS & AVAILABLE FUNCTIONAL SUBSYSTEMS



ATO

- TARGET SPEED DISPLAY
- TARGET DISTANCE DISPLAY
- QUANTITATIVE SPEED DISPLAY
- SPEED REGULATION
- BRAKING REGULATION
- PROGRAM STOPS
- DOOR & DWELL OPERATION
- TWC (TRAIN TO WAYSIDE COMMUNICATION)
- ONBOARD ROUTE CONTROL

ATP

- TRACK CIRCUITS (TRAIN DETECTION)
- WAYSIDE SIGNALS
- ROUTE SECURITY (LOCKING)
- WAYSIDE SPEED LIMIT COMMANDS
- CAB INDICATION
- OVERSPEED ALARM
- OVERSPEED CONTROL

ATS

- INTERLOCKING CONTROL
- TRAFFIC CONTROL SYSTEMS
- BLOCK OCCUPANCY (TRAIN TRACKING)
- DTS (DATA TRANSMISSION SYSTEM)
- TRAIN IDENTIFICATION
- LOCOMOTIVE IDENTITY
- TWI (TRAIN TO WAYSIDE INFO)
- AUTOMATIC DISPATCHING
- TRAFFIC REGULATION
- MANAGEMENT INFORMATION SYSTEM
- CORRECTIVE STRATEGIES
- SCHEDULE CONTROL
- VOICE COMMUNICATIONS
- STATION GRAPHICS CONTROL
- HOT BOX, FLOOD, SLIDE, ABNORMAL LOAD, BROKEN FLANGE, ETC. DETECTORS.

FIG. 1-1

SECTION 2.0

SYSTEM COMPARISONS

In the interest of clarity, some of the system descriptions in the succeeding paragraphs will be limited to particular portions of the system which are of interest. Four domestic and four foreign systems will be described. Many interesting systems were identified and reviewed during the project, and eight systems have been specifically chosen for evaluation because of the unique features and applicable technologies. Although several other systems could have been chosen, these systems represent eight distinctly different technologies, all of which have been operationally proven in revenue service. The domestic systems to be described are:

Amtrak Northeast Corridor (NEC) - This is the baseline system representing a widely used U.S. cab signal technology supplemented with wayside signals and enforced braking. It is the only electrified system on a railroad with both 25 Hz and 60 Hz propulsion supply.

Southern Pacific (SP) - The Flatonia, Texas to Belen, Texas segment controlled from Houston, Texas represents U.S. state-of-the-art in traffic control systems. SP used wayside signals with dc track circuits with no cab signal control.

Bay Area Rapid Transit (BART) - Although not a railroad, this system represents the highest overall technology implementation in the U.S. Train operation is computer controlled. Information is conveyed through the rails by a new concept in track circuitry. Braking is enforced or automatic.

Airtrans D/FW Airport - Although a very small (13.5) mile system, it represents the highest level of technology implemented in the U.S. within the present constraints of AAR and FRA standards. Train operation is computer controlled. Airtrans has a block system with conventional audio frequency track circuits.

The foreign systems chosen to be described are:

British Rail (BR) - The electrified London-Glasgow mainline, which is equipped with a conventional wayside block signal system, is slated for operation of the Advanced Passenger Train (APT). Since it will perform in mixed traffic with other freight and passenger services, the APT will be equipped with an overlaid intermittent cab signal system which will provide a unique aspect for civil speed control.

Japanese National Railways - The Shinkansen Line which operates "Bullet Trains" at 250 kmph (150 mph) on 15 minute headways with fully automatic controls is the first successful computer controlled system. This was a completely new line.

German Federal Railroad (DB) - The Continuous Automatic Train Control system utilized for high speed operations also provides ATC surveillance functions and speed regulation commands. The system is used on existing lines with conventional wayside signals.

Italian State Railways (FS) - The new Florence to Rome line which utilizes on-board equipment compatible with both intermittent and continuous cab signaling, is microprocessor controlled.

2.1 Domestic Railroads

U.S. railroad signaling is regulated by the Department of Transportation, Federal Railroad Administration, Bureau of Railroad Safety. The regulations are included in a publication called "Rules, Standards and Instructions for Railroad Signal Systems".

These rules and regulations require the railroads to conform with the standards as a minimum. They do not preclude the railroads from having far more rigid standards for their signal/control systems.

The Association of American Railroads, Communication and Signal Section, is an organization consisting of personnel from the railroads, supply industry, labor and others formed into committees whose objectives are to recommend design standards, specifications and requisites for U.S. and Canadian signaling. Membership in these committees or the Association is not mandatory, nor are the standards or requisites compulsory. They are only recommended practices.

It is evident, then, that standards and practices can and do vary from railroad to railroad while still meeting the requirements of the FRA "Rules, Standards and Instructions for Railroad Signal Systems". The majority of the responses by railroads and manufacturers to the questionaires indicated changes should be made in these regulations. There appears to be a need for additions to the Rules, Standards and Instructions, especially within the cab signal/train control areas which would permit the introduction of modern technology and its associated benefits. This is not to say, however, that tried-and-true design, fail-safe philosophy should be abandoned or compromised.

2.1.1 Amtrak-Northeast Corridor

Amtrak employs a continuous ATP system on its Northeast Corridor lines (NEC) from Boston to Washington and Philadelphia to Harrisburg. The system uses a coded (0-75-120-180) 100 Hz carrier frequency transmitted through the rails to an approaching train. The coded carrier signal is inductively coupled to the train by pick-up coils mounted on the engine and located over the rails. The incoming signal is then amplified and an aspect corresponding to the code received is displayed on the cab signal indicator. A speed control system that compares train speed with the maximum speed allowed by coded carrier signal is used in conjunction with the cab signal system. This speed control system automatically applies the brakes on an overspeed condition, or if changes in cab signal aspects are not acknowledged within a pre-determined time period. Therefore, it can be seen that the engineer with this type of system is very much involved in the decision making process. If the acknowledgment to the change in the cab signal indications is not made within the allotted time, a "penalty" brake application is made, and the train is brought to complete stop. Changes to a more restrictive cab signal aspect, in addition to displaying on the visual cab indicator, are also indicated by an audible alarm within the cab.

2.1.2 Southern Pacific

The Southern Pacific (SP) has in service from Flatonia, Texas to Belen, Texas, a computer aided Traffic Control System (TCS) extending a distance of 670 miles (1078 Km). Three dispatching stations control the entire line. Two sections are operated with traditional model board type control consoles, while the third is controlled by a color CRT console.

The system utilizes microwave for transmitting signal and communications data and a computer for basic dispatching tasks. Pulse modulated track circuits that are overlaid on a standard dc track circuit provide the wayside signal information. The dc track circuit is used for train detection and broken rail protection.

The computer, in addition to performing dispatching tasks such as meet/siding decisions, advance clearing, etc., can also project train routes in order to provide for optimum track utilization. A more detailed description of this system is contained in the Task 1 report under Section 5.3. Train braking is completely controlled by the engineer.

2.1.3 Bay Area Rapid Transit

The Bay Area Rapid Transit system (BART) uses the inductively coupled multiple audio frequency track circuits in its vehicle command system. This type track circuit is basic to the overall ATP system. The system induces a 6 bit digital code providing eight speed commands into the rail for pick up by the vehicle. Train detection is accomplished by shunting of the track circuit which is connected to a wayside control unit which, in turn, is connected to other wayside control units.

Speed regulation on the BART system is provided by the on-board control equipment in conjunction with computer generated corrective speed commands. Speed commands are also displayed digitally at the operators console. No wayside signals are used.

Station stopping is achieved by a separate wayside antenna system that provides the vehicle with distance-to-go information. This information, together with the train's length that has been manually inserted into the station stop computer, allows calculation of distance-to-go and provides for center-of-platform stopping. A computer aided route selection system is also in service on BART. This system along with the train identity system provides for automatic route selection and other auxiliary functions such as platform announcements and train destination signs.

2.1.4 Airtrans D/FW Airport

The Airtrans system utilizes conventional steady dc track circuits for train detection coupled with overlaid frequency shift keyed audio frequency carriers for train control. Since Airtrans incorporates full automatic train operation, two additional audio frequency carriers are utilized for train-to-wayside and wayside-to-train digital data communications.

The three-aspect automatic vehicle protection (AVP) functions are standard in that a measured overspeed results in an emergency brake application until the train is fully stopped. Since the train is unmanned, the central control operator accomplishes the reset function via the automatic train supervision (ATS) function.

The automatic train operation (ATO) functions include speed regulation, station stopping, door opening and closing, and train routing. The train transmits periodic digital messages to wayside equipment which provide vehicle identity, malfunction status and running route. Prior to each station and diverging track switch, there are dedicated wayside receivers which decode this data to set switches and initiate station stopping sequences for each train.

The ATS system tracks train progress through the system and displays the position of all trains, as well as their malfunction status, on a hard wired display panel. This panel also displays the status of the electrical propulsion power system and of each of the stations in the guideway network. In the event of a malfunction in trains, stations or power systems, the details of the malfunction are displayed to the operator on a CRT display. The operator can then take corrective action by entering commands into a special multifunction keyboard and/or a standard teletype keyboard. All

CRT data and operator keyboard entries are permanently recorded via line printer and stored in disc memory for later recall.

The ATS system can alter train performance to reduce speed or change running routes but cannot override the Automatic Vehicle Protection (AVP) system except to reset an overspeed to restart a train after the train has come to a stop.

2.2 Foreign Railroads

European systems are designed to comply with guidelines set forth by the International Union of Railways (UIC) and documented through the Office of Research and Experiments (ORE). The standards for cab signaling and automatic train control are essentially identical throughout the countries studied. Cab signaling is widely used in Europe. An intermittent system with passive wayside inductors is most generally used. Where speeds above 200 kmph (125 mph) or high train densities (close headways) exist, continuous cab signaling is utilized. The continuous cab signaling systems use either the running rails or a transposed loop laid in the center of the tracks for wayside-to-train communications. There are significant differences between European and American technologies as applied to signaling and control.

In Europe, the technique of "checked redundancy" and "asymetrical redundancy" is accepted extensively as a means to achieve "fail-safe" system operation. The design of signaling and interlocking circuits utilizes miniature relays with all contacts back checked in a design technique to obtain "fail-safe" objectives. Extensive application of microprocessors is common in train-borne cab signal/train control equipment. Automatic train operation, train describer systems and automatic dispatchers are utilized extensively in European railroad/transit systems.

2.2.1 British Rail London-Glasgow Line

British Rail (BR), on its London-Glasgow Line, will operate both the conventional passenger trains and the Advanced Passenger Train (APT) over common trackage. Conventional passenger trains presently operate at 160 kmph (105 mph) with 4-aspect color light signals. The APT, due to its improved braking characteristics and dynamic roll control can safely operate at 250 kmph (150 mph) over the same trackage.

In order to avoid confusion between normal and APT allowable speed limits, an intermittent cab signaling system was designed and installed to be utilized by the APT's only. As long as this system is operative, the APT's can proceed at their maximum allowable speed. In the event of a failure of either the train-borne or wayside intermittent equipment, the APT's cab signals will cut out and an audible warning which must be acknowledged will sound. The train must then run at the speeds established by the wayside signals.

The APT wayside transponder units are self contained passive elements of the system. Since the transponders convey civil speed limit information only, they are not interfaced with the wayside signals and are permanently coded. The APT on-board equipment is comprised of a 147 khz transmitting system and a 73.5 khz receiving system. The transmitter is continuously operated so that when the APT passes over a wayside transponder, the transponder can detect and rectify the transmitted signal to power the transponder logic and transmitter circuitry. The transponder creates a binary coded message based on its permanent coding and repetitively transmits the message as a modulated 73.5 khz carrier as long as the receiver is energized by the APT on-board transmitter. The interface geometry between the APT and wayside transponders is such that six complete messages will be conveyed at 250 kmph (150 mph) APT speed. Once received, the message will continue to be displayed unless changed by a following transponder.

Although the wayside transponders are highly reliable, fail-safe system design is accomplished by mounting the transponders at or less than "regular intervals" of 1 km. The APT on-board logic starts a counting sequence upon receipt of each message set from a wayside counter. Tachometer pulses are counted until an equivalent distance of 1 km has been measured. If no new transponder messages are received within the count period, the cab signaling system is deactivated and the APT is forced to revert to the wayside signals only. The APT cab signal receivers, antennae and logic are dualized and the output compared for "check redundancy" purposes. The cab display and carrier transmitter are highly reliable single units since they are not required to be fail-safe. A fail-operational capability is achieved by equipping both drive units of the APT with cab signaling systems, either one of which may be utilized for APT operation.

2.2.2 Japanese National Railways - Shinkansen Line

The Japanese National Railways (JNR), in the initial design of its New Tokaido Line (Shinkansen), implemented a planned evolution from conventional gravity operated relay control circuits to a "state-of-the-art" fully automated train control system. The selected ATP configuration is enforced cab signaling utilizing audio frequency track circuits. A carrier frequency of 1000 Hz was chosen and speed limits are conveyed by means of amplitude modulation of this carrier at rates from 36 to 70 Hz. The carrier frequency and modulation rates were chosen to avoid interference from the traction supply system frequencies. When the system was put into operation in 1964, the train speed was manually controlled by the operator to speed limits of 210, 160, 70 or 30 kmph (130, 100, 45, 20 mph) as dictated by the ATP system. Exceeding the speed limit resulted in enforced braking until the train speed dropped below the speed limit.

The initial system configuration also included complete centralized monitoring of train movement and control of the relatively small number of interlockings. The entire system is dual track.

As the system expanded and traffic density increased, ATO was developed and integrated with the ATP and ATS systems.

The system in operation today is totally automatic with the use of triple redundant microprocessors in on-board ATO and central ATS equipment. Fail-safe operation is achieved through majority voting and fail operational capability is achieved through the use of three channels. The nominal running speed/distance profile is stored in the on-board ATO computing system. Prior to dispatching the train, modifications to the profile to accommodate track work restrictions, etc. are programmed into the on-board equipment by the engineer with punched cards supplied as a part of the train order. The ATS system monitors the progress of the train along its route and, based on this information, computes predicted station arrival times. The ATS system then sends commands through the audio frequency track circuits to the on-board ATO equipment which modify the stored profile as required (within the constraints of the ATP system) to achieve "on time" performance. Train acknowledgment data (and malfunction status) are also conveyed to the ATS system via amplitude modulated audio frequency track circuits.

2.2.3 German Federal Railroad - Continuous Automatic Train Control

The German Federal Railroad (DB) operates intermittent train control and continuous train control systems over its rail system. Its high speed lines utilize a continuous automatic train control (CATC) system which was initially placed in operation on the Munich-Augsburg line in 1966. This system has been expanded and continually refined to incorporate new technology. It must be understood that the CATC system is utilized exclusively for train control, and the system is overlaid on existing train detection and wayside signaling systems.

The CATC system communications link is the key to understanding system operation. The wayside communications elements are 12.5-km (7.8-mile) transposed inductive loops with the transpositions occurring at 100 m (330 ft.) intervals. Normally these loops are mounted on the track centerline between the rails. The train-borne antennae is mounted in a manner to pass continuously over them. Data is exchanged between the train and wayside on a 56 KHz carrier modulated at 600 bits per second; between the wayside and the train a 36 KHz carrier FSK modulated at a 1200 bit/sec rate is used. Each 12.5-km loop is associated with its own control unit, and the control units are interconnected so that data communication (via common buss) occurs between controllers within a group. Each group of controllers then communicates with the control center (usually by dedicated line and modems).

The data transmitted from wayside to trains includes train address (since more than one train may be controlled by one loop), loop location code, loop section (group) number, train direction and limiting velocity, target speed and distance-to-target supervisory data. The on-board train equipment determines course position within the loop by count of 100-meter transpositions from the beginning of the loop and fine position by count of tachometer pulses from the last transposition. The in-cab display then indicates, in addition to the wayside transmitted data, the actual distance to go to the next target check point. The on-board equipment also transmits data to the loop controller indicating section and target acknowledgment, velocity profile, coarse and fine location, actual speed and malfunction (or operating) status.

With these data available, the control center then regulates the operation of all trains, controls train routing and station train arrival displays and provides operational and statistical data to the operators. Control center displays are a combination of mimic boards and CRT displays.

2.2.4 Italian State Railways - Combined Train Control System

The Italian State Railways (FS) are systematically upgrading their system for operation at 270 kmph (170 mph) in several areas with portions of the Rome-Florence line presently in an operational status. Large portions of the FS railways utilize intermittent train control with passive wayside inductors. Where continuous train control is provided, it is accomplished via 50 Hz track circuits coded at 75, 120, 180 and 270 pulses per minute.

To achieve compatibility with these two systems and yet provide the additional speed regulation points for intermixed high speed passenger trains, an overlaid continuous ATP system has been implemented. This overlay is a 175 Hz carrier modulated at 75, 120 and 180 pulses per minute added to the existing continuous train control system. The high speed trains are equipped to decode the higher frequency carrier (along with the 50 Hz carrier) to obtain the applicable speed limits. The train-borne equipment provides the capability to operate with intermittent, normal continuous or two carrier continuous ATP systems and automatically switches to the system sensed. Because of extensive incorporation of solid state circuitry and redundant microprocessors, the on-board units occupy the same volume as the earlier intermittent or continuous units. This increases the practicality of a retrofit program.

2.3 System Comparisons

The salient features of the four domestic systems described in Subsection 2.1 and the four foreign systems described in Subsection 2.2 are presented in summary form in Figure 2-1. The features listed at the left of the table are those required of any system which can be considered to fulfill all of the presently identified desires of Amtrak and the railroads over which it operates. As was expected, none of the eight systems, as presently operated, fulfills all of these desires. All of the systems provide at least some

		DOMESTIC SYSTEMS				FOREIGN SYSTEMS			
	ITEM	NEC	SP	BART	AIR TRANS	BR	JNR	DB	FS
WAYSIDE EQUIPMENT	COMPATIBILITY WITH 250 KM./HR. OPERATION	NEED MORE ASPECTS	NEED MORE ASPECTS	YES	NEED MORE ASPECTS	YES	YES	YES	YES
	ELECTRIFICATION COMPATIBILITY 25 HZ.	YES	YES*	YES	YES	YES	YES	YES	YES**
	ELECTRIFICATION COMPATIBILITY 60 HZ.	YES	YES*	YES	YES	YES**	YES	YES	YES**
	CAPABLE OF HIGH AND LOW SPEED MIXED TRAFFIC	NEED MORE ASPECTS	NEED MORE ASPECTS	NO	NEED MORE ASPECTS	YES	NO	YES	YES
	FIXED WAYSIDE SIGNAL INTERFACE CAPABILITY	NEED MORE ASPECTS	NO	NO	NO	YES	NO	YES	YES
	COMPATIBILITY WITH JOINTLESS TRACK CKTS.	NO	NO	YES	NO	YES	YES	YES	NO
	AAR/RS&I COMPLIANCE	YES	YES	NO	YES	YES	NO	NO	YES
TRAIN EQUIPMENT	ASPECT DISPLAY	YES	NO	YES	NO***	YES	YES	YES	NO
	SPEED DISPLAY	NO	NO	YES	NO***	NO	YES	YES	YES
	OVERSPEED CONTROL TYPE	S	NO	E	S	S	E	E	S
	OVERSPEED CONTROL REACT. TIME	6 SEC	—	6 SEC	6 SEC	5 SEC	5 SEC	3 SEC	3 SEC
	SPEED REGULATION	NO	NO	YES	YES	NO	YES	OPTIONAL	OPTIONAL
	PRECISION STOPPING	NO	NO	YES	YES	NO	YES	NO	OPTIONAL
	TRAIN TO WAYSIDE COMM.	NO	NO	YES	YES	NO	YES	YES	NO

* TRAIN CONTROL ONLY - TRAIN DETECTION IS NOT COMPATABLE

E - ENFORCED TO SPEED LIMIT . S — BRAKE TO STOP AND RESET

** CARRIER FREQUENCIES MUST BE SHIFTED

*** DRIVERLESS VEHICLE

Figure 2-1 — SYSTEM COMPARISONS

capability to satisfy the fundamental requirements of high speed operation and compatibility with electrification.

In the analysis of the questionaire responses and the conduct of the survey trips, a basic set of evaluation factors for a "universal" system evolved. The most important features dictated by high operating speeds are:

5-aspect cab signaling - mandatory

Quantitative speed limit cab display - highly desirable

Overspeed control - mandatory

Speed regulation - desirable.

In the electrification compatibility assessment, the NEC, Airtrans, and JNR systems are presently operating with 60 Hz propulsion supply, so compatibility is already established. SP presently utilizes dc track circuits, but no technology changes would be required to go to ac track circuits or to utilize the existing PCM audio signal circuits for both signals and train detection. PCM is in limited use on the Southern Pacific. BR and FS utilize carrier frequencies which are not compatible with 60 Hz propulsion, but again no change in technology is required to choose carrier frequencies which are not harmonically related to either 60 or 25 Hz.

The impact of mixed traffic operation implies an ability of the basic system design to provide signals which are unique to each type of traffic. BART and JNR were designed and programmed specifically for trains which have predictable, uniform operating characteristics. To operate mixed traffic with either of these systems would, as a minimum, require extensive software changes, while the remainder of the systems, which already operate mixed traffic, would require only the changes previously identified.

The use of CWR requires insulated joints with coded ac track circuits (NEC, SP, Airtrans and FS). Audio track circuits (BART and JNR) or systems which do not require use of the running rails for communication (BR and DB)do not require insulated joints with CWR except normally at interlockings.

Task 2 does not specifically address the subject of detail compliance with the FRA-RS&I or the AAR standards since that subject will be covered in detail in the Task 3 report. It is important, however, to identify the basic impact, or the fact that there will be an impact, on these regulatory documents. It is not believed that any of the eight systems examined actually violate the regulations, but rather the regulations must be expanded to reflect the technologies used in the BART, JNR, FS and DB systems.

In general the train-borne equipment utilized in the foreign systems is more sophisticated and computer-oriented than that in the U.S. (BART being the exception). This results in the foreign equipment packages being much smaller and lighter than their domestic equivalents. The utilization of assymetrical redundancy and majority voting to achieve fail-safe design, although common in the U.S. aerospace industry, has not yet been accepted in the U. S. rail industry.

Task 3 activity will determine the required additions to the existing regulations necessary to accommodate the use of these design techniques.

The train-borne equipment characteristics identified in Table 2-1 reflect ATP requirements (aspect display, speed display and overspeed control) and ATO requirements (speed regulation, automatic stopping, and TWC). ATP is considered mandatory for 250 kmph (150 mph) operation while the need for full ATO is questionable. ATO is almost universally utilized in foreign and many American transit systems but rather infrequently on any railroads -- foreign or domestic. From Fig. 2.1 it is apparent that ATO systems are available and operational. High reliability is achievable and demonstrated - particularly in Airtrans, which is a fully automated driverless system.

Summarizing, while none of the eight systems examined provided all of the features desired, several could be easily modified to provide them. Section 4.0 of this report will examine the feasibility of incorporating these system types as well as the specific technologies identified in Task 1 in a new system design. The design will accomodate 250 kmph (150 mph) operation, be compatible with electrification and allow mixed traffic operation to be incorporated on the railroads over which Amtrak operates.

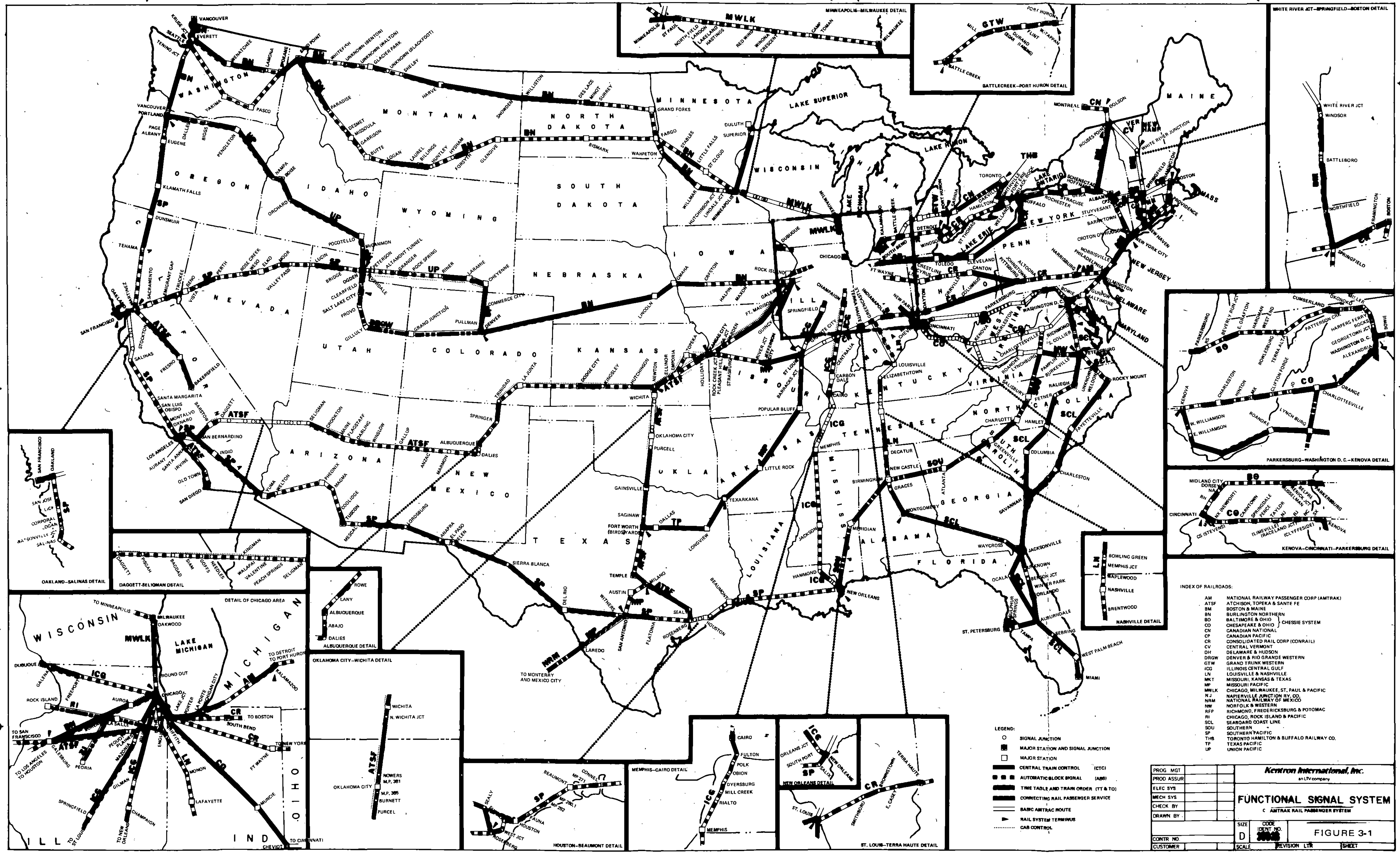
SECTION 3.0

AMTRAK DESCRIPTION

The existing National Railroad Passenger Corporation (Amtrak) can be broadly classified into two operating categories: (1) that portion of U.S. railroads which is owned, operated and maintained by Amtrak and (2) those route miles of trackage owned, operated, and maintained by private U.S. railroads over which Amtrak owned passenger trains are operated and dispatched by the owning railroad under agreements with the National Railroad Passenger Corporation. This latter category consists of eighteen (18) private carriers and one connecting line (Southern Railway). For purposes of this study, the signal/control systems for all eighteen (18) of these privately owned carriers will be considered. A System Route Map of all routes over which Amtrak presently operates is shown in Figure 3-1.

3.1 Amtrak Owned/Operated System

The present Amtrak owned and/or operated trackage consists of the Northeast Corridor between Washington, D.C. and Boston, Philadelphia to Harrisburg, and New Haven, Connecticut to Springfield, Massachusetts. Certain portions of the Northeast Corridor, notably, New York to New Haven and within Massachusetts, are actually owned by State agencies but operated and maintained by Amtrak. The Washington to New Haven and Philadelphia to Harrisburg routes of the Northeast Corridor are presently electrified with 11.5 KV, 25 Hz ac traction


INDEX OF RAILROADS:
AM NATIONAL RAILWAY PASSENGER CORP (AMTRAK)
ATSF ATCHISON, TOPEKA & SANTE FE
BM BOSTON & MAINE
BN BURLINGTON NORTHERN
BO BALTIMORE & OHIO
CO CHESAPEAKE & OHIO
CHESSIE SYSTEM
CN CANADIAN NATIONAL
CP CANADIAN PACIFIC
CR CONSOLIDATED RAIL CORP (CONRAIL)
CV CENTRAL VERMONT
DH DELAWARE & HUDSON
DRGW DENVER & RIO GRANDE WESTERN
GTW GRAND TRUNK WESTERN
ICG ILLINOIS CENTRAL GULF
LN LOUISVILLE & NASHVILLE
MKT MISSOURI, KANSAS & TEXAS
MP MISSOURI PACIFIC
MWLK CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC
NJ NAPIERVILLE JUNCTION RY. CO.
NRM NATIONAL RAILWAY OF MEXICO
NW NORFOLK & WESTERN
RFP RICHMOND, FREDERICKSBURG & POTOMAC
RI CHICAGO, ROCK ISLAND & PACIFIC
SCL SEABOARD COAST LINE
SOU SOUTHERN
SP SOUTHERN PACIFIC
THB TORONTO HAMILTON & BUFFALO RAILWAY CO.
TP TEXAS PACIFIC
UP UNION PACIFIC
LEGEND:
SIGNAL JUNCTION
MAJOR STATION AND SIGNAL JUNCTION
MAJOR STATION
CENTRAL TRAIN CONTROL (CTC)
AUTOMATIC BLOCK SIGNAL (ABS)
TIME TABLE AND TRAIN ORDER (TT & TO)
CONNECTING RAIL PASSENGER SERVICE
BASIC AMTRAK ROUTE
RAIL SYSTEM TERMINUS
CAB CONTROL
MINNEAPOLIS–MILWAUKEE DETAIL
BATTLECREEK–PORT HURON DETAIL
WHITE RIVER JCT–SPRINGFIELD–BOSTON DETAIL
PARKERSBURG–WASHINGTON D.C.–KENOVA DETAIL
KENOVA–CINCINNATI–PARKERSBURG DETAIL
NASHVILLE DETAIL
OAKLAND–SALINAS DETAIL
DAGGETT–SELIGMAN DETAIL
DETAIL OF CHICAGO AREA
ALBUQUERQUE DETAIL
OKLAHOMA CITY–WICHITA DETAIL
HOUSTON–BEAUMONT DETAIL
MEMPHIS–CAIRO DETAIL
NEW ORLEANS DETAIL
ST. LOUIS–TERRA HAUTE DETAIL
PROG MGT
PROD ASSUR
ELEC SYS
MECH SYS
CHECK BY
DRAWN BY
CONTR NO.
CUSTOMER
Kentron International, Inc.
an LTV company
FUNCTIONAL SIGNAL SYSTEM
AMTRAK RAIL PASSENGER SYSTEM
SIZE D
CODE IDENT NO.
FIGURE 3-1
SCALE
REVISION LTR
SHEET

power. Under the federally sponsored Northeast Corridor High Speed Rail Passenger Improvement Program (NECIP), all of this territory, with the exception of the New Haven to Springfield line, will be electrified for 60 Hz traction power propulsion.

The existing signal/control systems throughout the corridor are now under study for eventual conversion to electrification compatibility and immunity to either 25 Hz or 60 Hz traction power frequencies. The final signal system will provide safe braking distances and operation for 250 kmph. (150 mph) maximum passenger train speeds. The existing four-aspect 100 Hz wayside continuous cab signal and train control system will be modified and expanded to include the entire area from Washington to Boston.

3.1.1 Train Detection

Train detection is accomplished by a variety of track circuits including steady dc, dc coded, steady ac and ac coded track circuits. This is further complicated by the fact that the ac track circuits utilize a variety of relays including vane, centrifugal, coded resonant and phase selective relays. Of these devices, only the two-element phase selective relays have sufficient harmonic rejection to be compatible with 60 Hz propulsion current. For the purpose of this study, it will be assumed that the interface, when 60 Hz electrification is completed, will be 100 Hz phase selective relays in ac coded track circuits.

3.1.2 Wayside Cab Signaling Equipment

At present, 100 Hz energy is code-rated at 75, 120, or 180 pulses per minute and applied to the rails to provide continuous cab signal energy and to actuate fixed wayside signals. Present cab signal aspects are displayed in the cab as follows:

Track Circuit Frequency/Code Rate	Indication	Maximum Authorized Speed
0/0	Restricting	30 kmph (15 mph)
100 Hz/75 ppm	Approach	50 kmph (30 mph)
100 Hz/120 ppm	Approach Medium	80 kmph (45 mph)
100 Hz/180 ppm	Clear	Maximum Authorized Speed

With an increase in passenger train speeds to 250 kmph (150 mph), it appears that the 100 Hz/180 ppm speed command now used for a "Clear" indication will become a definitive speed, perhaps 160 or 200 kmph (100 or 120 mph) for high speed passenger trains, and 100 or 130 kmph (60 or 80 mph) for freight and commuter equipment. For high speed passenger trains, speed indications above the 100 Hz/180 ppm will be required.

At the time of this report, design decisions for the exact additional NEC command speed/code-frequency-rates had not been firmly established. The system will, however, utilize existing cab signal technology.

3.1.3 On-Board Cab Signal Equipment

On the Northeast Corridor all Amtrak owned intercity passenger trains are presently equipped with four aspect enforced cab signaling with automatic overspeed control which forces full compliance with the speed authorized by the continuous cab signal system. Many of the commuter rail agencies operating on NEC (Massachusetts Bay Transportation Authority, Connecticut Department of Transportation, Metropolitan Transportation Authority, New Jersey Department of Transportation, Southeast Pennsylvania Transportation Authority, etc.) employ locomotives equipped only with cab signal indication; ConRail freight trains are also usually equipped with cab signal indication only.

3.1.4 Fixed Wayside Signal System

From Washington, D. C. to New York (Sunnyside) position-light type wayside signals are currently used in conjunction with the four-aspect continuous wayside cab signal system.

Between New York (Sunnyside) and New Rochelle, New York the existing signal system is a semaphore type with no cab signals. AC track circuits are centrifugal relay type.

From New Rochelle to New Haven, coded 100 Hz phase selective track circuits are being installed for operation of both fixed wayside signals and a four-aspect cab signal system. Within interlockings 200 Hz track circuits code rated at 120 ppm are being installed for train detection. The 100 Hz coded cab signal system within interlockings is overlaid by route selection and train presence detection circuits. Upon completion this territory will be compatible with 60 Hz electrification and 250 kmph (150 mph) speeds.

Between New Haven and Boston, the wayside signaling is predominantly color-light. Track circuits are dc overlaid with a four-aspect coded 100 Hz cab signal system.

Upon completion of the Northeast Corridor Improvement Project, all corridor signaling will be compatible with either 25 Hz or 60 Hz electrification and provide continuous coded cab signal control. Wayside signals will be provided at interlockings and at other locations as required.

3.2 Railroad Owned/Operated Amtrak Systems

Figure 3-2 summarizes the type and amount of signal/control systems currently in service on all lines over which Amtrak operates. It should be noted that while cab signal systems are in service on 83% of Amtrak-owned track miles, only 9.3% of the private railroad-owned track miles over which Amtrak operates are equipped with any form of cab signal control.

Approximately 5.2% of the railroad-owned track miles over which Amtrak operates are non-signaled routes. Of the railroad-owned track miles equipped with wayside signaling, 49.9% is also equipped with TCS.

The Functional Signal System map shown in Figure 3-1 geographically illustrates all routes over which Amtrak operates (both privately and Amtrak owned) and shows the composite type of signal/control systems employed.

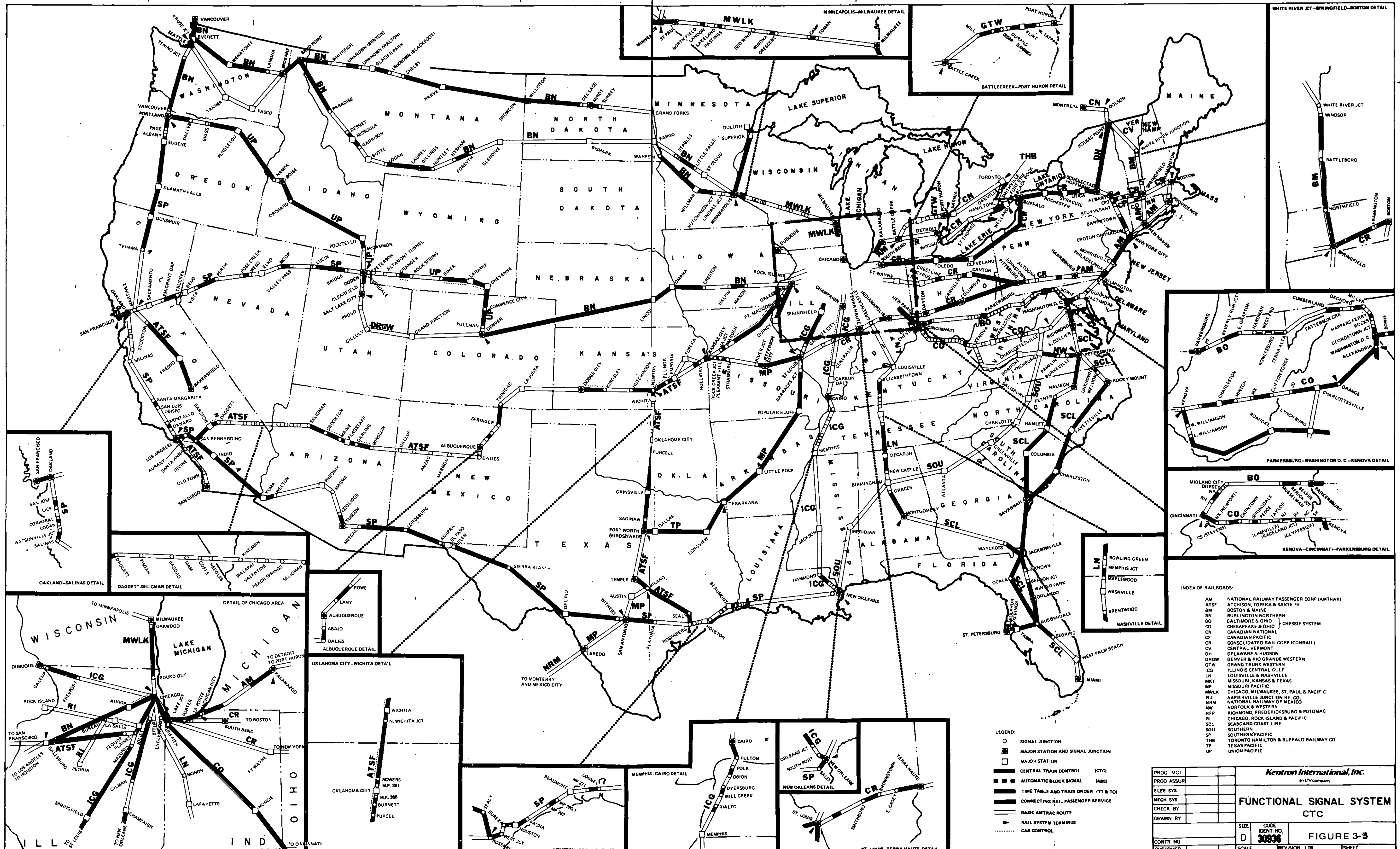
Figure 3-3 illustrates those areas of the system in which TCS is in operation. Figure 3-4 delineates the areas where

RAILROAD	ROAD MILES SIGNALED	TRACK MILES SIGNALED	TRACK MILES ABSS	TRACK MILES TCS	TRACK MILES CS/TC	ROAD MILES ELECTRIFIED	ROAD MILES AMTRAK OPS.	ROAD MILES COMMUTER OPS	TRAIN DETECTION SYSTEMS
AMTRAK	587·4	1,614	1,164.2	449·8	1,344	339	587·4	530·6	AC/DC TRACK CIRCUITS
ATSF	5,388	7,029	2,904	4,125	0	0	4,029	0	DC TRACK CIRCUITS
B&M	571·07	814·37	409·48	404·89	53·83	0	153·94	206·8	AC/DC TRACK CIRCUITS
BN	8,792	10,213	5,422	4,791	38	0	5,494	38	AC/DC TRACK CIRCUITS
CHESSIE	4,953	6,712	3,120	3,592	89·9	0	1,603	159	DC TRACK CIRCUITS
C.M.S.P.&P.	2,803	3,364	2,221	1,143	0	0	416	111	AC/DC TRACK CIRCUITS
CONRAIL	13,039·78	19,920·93	9,668·42	5,971.52	2,282.3	597	3,202	1,067	AC/DC TRACK CIRCUITS
D&H	460	590	38·5	551·5	0	0	197	0	DC TRACK CIRCUITS
DREW	1,004	1,071	80	991	0	0	570	0	DC TRACK CIRCUITS
STW	395·5	660.4	515·6	144·8	0	0	157·6	26	DC TRACK CIRCUITS
ICG	2,922	3,768	2,798	957	339	99.2	1,370	76·6	AC/DC TRACK CIRCUITS
L&N	3,222	3,592	965	2,527	0	0	810	0	DC TRACK CIRCUITS
MO PAC	5,215	5,709	2,820	2,889	0	0	1323.3	0	DC TRACK CIRCUITS
N&W	4,336	5,509	1,736	3,773	0	0	443	15	DC TRACK CIRCUITS
RF&P	113	234	0	234	227	1.1	113	0	AC/DC TRACK CIRCUITS
CRI&P	2,760	3,112	2,234	877	333·3	0	0	46·9	DC TRACK CIRCUITS
SCL	3,327	3,957	244	3,713	0	0	2,271	0	DC TRACK CIRCUITS
SP	6,799	7,448	3,767	3,681	0	0	4,022.6	46·9	DC TRACK CIRCUITS
UP	4,089	5,326	2,576	2,750	2,127	0	1,468	0	DC TRACK CIRCUITS
TOTALS	70,756.75	90,643.7	42683.2	43,565.51	9,241.33	1,036.33	28,230.84	2,323.8	

INCLUDES 4,394.99 MILES OF MBS, ETC.

ABSS= AUTOMATIC BLOCK SIGNAL SYSTEM.
TCS = TRAFFIC CONTROL SYSTEM.
CS/TC = CAB SIGNALS/TRAIN CONTROL

Figure 3-2 - AMTRAK MILEAGE SUMMARY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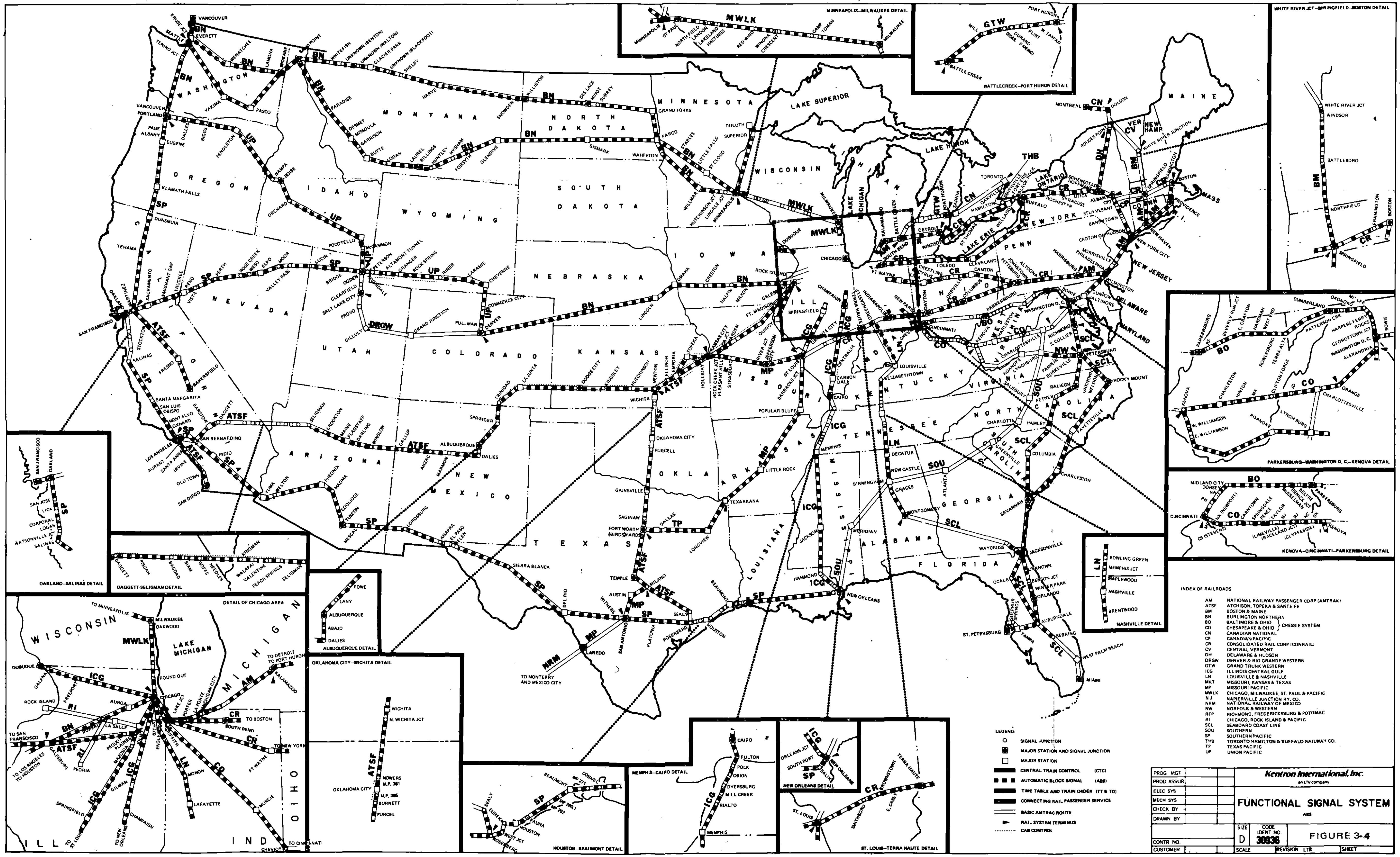
BATTLECREEK–PORT HURON DETAIL
WHITE RIVER JCT–SPRINGFIELD–BOSTON DETAIL
PARKERSBURG–WASHINGTON D.C.–KENOVA DETAIL
KENOVA–CINCINNATI–PARKERSBURG DETAIL
NASHVILLE DETAIL
OAKLAND–SALINAS DETAIL
DAGGETT–SELIGMAN DETAIL
ALBUQUERQUE DETAIL
DETAIL OF CHICAGO AREA
OKLAHOMA CITY–WICHITA DETAIL
HOUSTON–BEAUMONT DETAIL
MEMPHIS–CAIRO DETAIL
NEW ORLEANS DETAIL
ST. LOUIS–TERRA HAUTE DETAIL
TO MONTERREY AND MEXICO CITY
LEGEND:
SIGNAL JUNCTION
MAJOR STATION AND SIGNAL JUNCTION
MAJOR STATION
CENTRAL TRAIN CONTROL (CTC)
AUTOMATIC BLOCK SIGNAL (ABS)
TIME TABLE AND TRAIN ORDER (TT & TO)
CONNECTING RAIL PASSENGER SERVICE
BASIC AMTRAC ROUTE
RAIL SYSTEM TERMINUS
CAB CONTROL
INDEX OF RAILROADS:
AM NATIONAL RAILWAY PASSENGER CORP (AMTRAK)
ATSF ATCHISON, TOPEKA & SANTE FE
BM BOSTON & MAINE
BN BURLINGTON NORTHERN
BO BALTIMORE & OHIO } CHESSIE SYSTEM
CO CHESAPEAKE & OHIO
CN CANADIAN NATIONAL
CP CANADIAN PACIFIC
CR CONSOLIDATED RAIL CORP (CONRAIL)
CV CENTRAL VERMONT
DH DELAWARE & HUDSON
DRGW DENVER & RIO GRANDE WESTERN
GTW GRAND TRUNK WESTERN
ICG ILLINOIS CENTRAL GULF
LN LOUISVILLE & NASHVILLE
MKT MISSOURI, KANSAS & TEXAS
MP MISSOURI PACIFIC
MWLK CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC
NJ NAPIERVILLE JUNCTION RY. CO.
NRM NATIONAL RAILWAY OF MEXICO
NW NORFOLK & WESTERN
RFP RICHMOND, FREDERICKSBURG & POTOMAC
RI CHICAGO, ROCK ISLAND & PACIFIC
SCL SEABOARD COAST LINE
SOU SOUTHERN
SP SOUTHERN PACIFIC
THB TORONTO HAMILTON & BUFFALO RAILWAY CO.
TP TEXAS PACIFIC
UP UNION PACIFIC
PROG MGT
PROD ASSUR
ELEC SYS
MECH SYS
CHECK BY
DRAWN BY
CONTR NO.
CUSTOMER
Kentron International, Inc.
an LTV company
FUNCTIONAL SIGNAL SYSTEM
CTC
SIZE D
CODE IDENT NO. 30936
FIGURE 3-3
SCALE
REVISION LTR
SHEET



MINNEAPOLIS–MILWAUKEE DETAIL
BATTLECREEK–PORT HURON DETAIL
WHITE RIVER JCT–SPRINGFIELD–BOSTON DETAIL
PARKERSBURG–WASHINGTON D.C.–KENOVA DETAIL
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OKLAHOMA CITY–WICHITA DETAIL
DETAIL OF CHICAGO AREA
HOUSTON–BEAUMONT DETAIL
MEMPHIS–CAIRO DETAIL
NEW ORLEANS DETAIL
ST. LOUIS–TERRA HAUTE DETAIL
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLA
TEXAS
MINNESOTA
IOWA
WISCONSIN
ILL
MISSOURI
ARKANSAS
LOUISIANA
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
TENNESSEE
KENTUCKY
OHIO
PENN
NEW YORK
VIRGINIA
WEST VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
MAINE
NEW JERSEY
DELAWARE
MARYLAND
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
TO MONTERRY AND MEXICO CITY
LEGEND:
SIGNAL JUNCTION
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MKT MISSOURI, KANSAS & TEXAS
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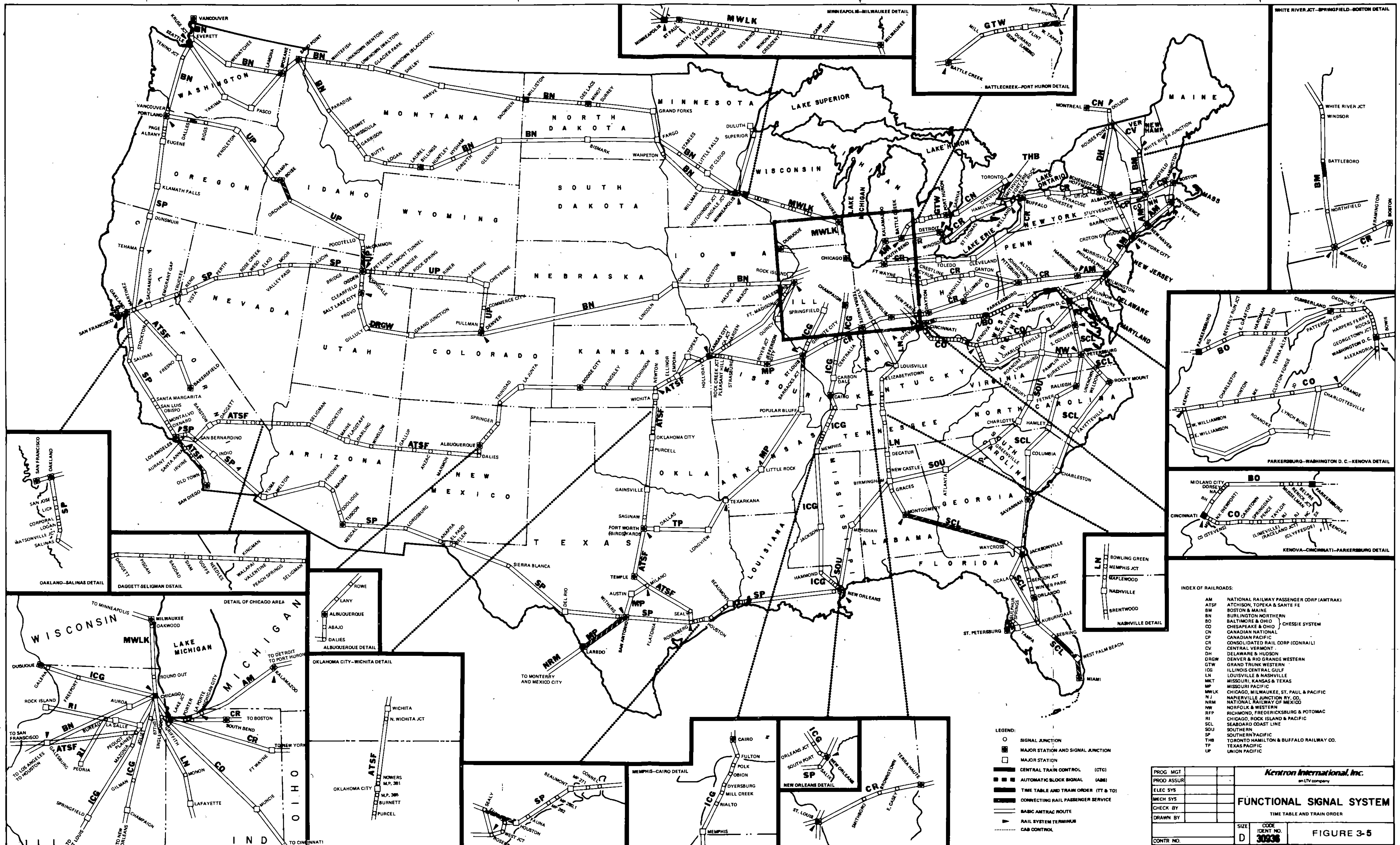
NW NORFOLK & WESTERN
RFP RICHMOND, FREDERICKSBURG & POTOMAC
RI CHICAGO, ROCK ISLAND & PACIFIC
SCL SEABOARD COAST LINE
SOU SOUTHERN
SP SOUTHERN PACIFIC
THB TORONTO HAMILTON & BUFFALO RAILWAY CO.
TP TEXAS PACIFIC
UP UNION PACIFIC
PROG MGT
PROD ASSUR
ELEC SYS
MECH SYS
CHECK BY
DRAWN BY
CONTR NO.
CUSTOMER
Kentron International, Inc.
an LTV company
FUNCTIONAL SIGNAL SYSTEM
ABS
SIZE D
CODE IDENT NO. 30936
FIGURE 3-4
SCALE
REVISION LTR
SHEET


MINNEAPOLIS–MILWAUKEE DETAIL
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CENTRAL TRAIN CONTROL (CTC)
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CAB CONTROL
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ELEC SYS
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CONTR NO.
CUSTOMER
Kentron International, Inc.
an LTV company
FUNCTIONAL SIGNAL SYSTEM
TIME TABLE AND TRAIN ORDER
SIZE D
CODE IDENT NO.
FIGURE 3-5
SCALE
REVISION LTR
SHEET

ABS systems are installed (including TCS territory), and Figure 3-5 shows those areas where no signaling is present, and traffic is controlled by timetables and train orders. These three figures show the geography of the Amtrak routes and the location of the three basic interfaces to be considered in the implementation of an overlay signal system.

3.3 Potential System Interfaces

Potential signal/control system interfaces for Amtrak high speed passenger operation over privately owned rail lines may be divided into two general classes: those concerned with overlaying and tie-in to existing railroad wayside signal/control systems for the ATP function, and those concerned with ATS, centralized control, train location, status, and management information functions.

3.3.1 ATP Interface

A system route map showing the amount and location of automatic block signal systems over which Amtrak operates is shown in Figure 3-3. Exclusive of the Amtrak-owned Northeast Corridor, approximately 90% of the railroad road miles over which Amtrak operates is presently equipped with wayside automatic block signaling. The remaining 10% is operated by timetable and train order. The objective of an overlay system should be to control the speed of Amtrak high speed passenger trains over all speed restrictions in the range of 40 kmph to 250 kmph (25 to 150 mph). Most of the existing automatic block signal systems do not provide sufficient braking distance for 250 kmph (150 mph) high speed operation but some can accommodate 200 kmph (125 mph) operation based on the Metroliner braking performance. Task 1 examined the alternatives available, short of complete block realignment, to allow 250 kmph (150 mph) operation under these circumstances. The most attractive solution, and the one implemented by British Rail on their London-Glasgow line, is to add an aspect which is only available to high speed passenger trains. This can be accomplished by several methods, but care must be taken to assure that geographical as well as headway imposed speed limits are conveyed with whatever system is implemented.

The Task 1 analyses have confirmed that the present RS&I requirement for cab signaling at speeds above 120 kmph (80 mph) is realistic. This establishes the ATP interface to the extent that a potential overlay system must provide, as a mimimum, cab signals. Based on the physical descriptions provided in Subsections 3.1 and 3.2, a number of specific interfaces may be identified. Since all of the Amtrak system and the more than 90% of the other road miles over which Amtrak operates have ABS, this is the major interface to be considered. Cab signaling constitutes approximately 8% of all signaling on Amtrak lines; cab signaling with train control less than 5%. In the 8% of the road miles already incorporating cab signaling, the option exists to interface with the existing cab signaling or with the ABS system. The majority of the cab signaling is 4-aspect code rate modulated 60 or 100 Hz carriers. Figure 3-2 summarizes the track circuit types utilized for ABS on each of the Amtrak operating railroads. The dc track circuits are comprised of steady state and rate coded designs, and the ac track circuits are also a combination of steady and rate coded 60 and 100 Hz carriers. The only audio frequency system in use is on the Houston to El Paso line of the Southern Pacific. This system is a pulse code modulated 10 Khz carrier overlaid on the dc track circuits.

3.3.2 ATS Interface

Figure 3-3 illustrates the road miles over which Amtrak operates which are TCS governed. The systems used vary from all relay operation to full computerization. The majority of the computerized systems utilize 8-bit machines such as the Data General or Digital Equipment Corporation microprocessors. The Southern Pacific on the Houston-El Paso line uses a Modcomp III 16-bit computer, and similar 16-bit machines will become more popular due to their added versatility. If the overlay system incorporates an ATS function, the interface could be at the various control centers to these computers. The other likely interface for the overlay ATS system would be with the overlay ATP system since this would avoid having to mechanize several software interfaces. The data communications interface will be a function of the basic ATS interface. Based on the existing data links, the most probable interface will be with the existing telephone lines or microwave repeater systems.

SECTION 4.0

AMTRAK COMPATIBILITY

4.1 Potential Overlay Systems

From the data gathered as a result of the literature search, questionaire responses and survey trips, several candidate signal/control and communication overlay systems can be identified. These systems fall into three broad categories:

Category A - The minimum system which fulfills the basic requirement of 250 kmph (150 mph) operation of passenger trains intermixed with slower freight traffic in electrified territory is a 5-aspect cab signaling system with enforced overspeed control.

Category B - The minimum desired system is one which fulfills the Category A requirements plus providing passenger train identity and tracking data to a central monitor point.

Category C - The "optimum" system is one satisfying the Category A and B criteria which also allows the central control point to exercise limited control of the passenger train speeds to enforce timetable schedules and possibly to provide time of arrival data to the passenger train stations.

The ATP system candidates which are capable of satisfying the Category A requirements are:

a.) Single carrier 100 Hz ac coded system as used in the U.S. The fifth aspect could be accomplished via addition of alternating carrier phase reversal to the present NEC system/80 ppm code.

b.) Intermittent Cab Signal System with either active or passive wayside transponders. This system could be derived from the BR configuration described in Subsection 2.2 of this report, the DB configuration described in the Task 1 report or the FS system identified in Section 2.2 of this report.

c.) Continuous Inductive Loop System as described in the Task 1 report and Subsection 2.2 of this report.

d.) The dual carrier coded ac system used by the FS railroad and described in Subsection 2.2 of this report.

e.) Location-Indication-Control (LIC) system used by British Columbia Railway and described in the Task I report.

The system which satisfies Category B requirements can utilize any of the above ATP mechanizations, but must add a data link from the passenger trains or the wayside portion of the cab signal system to a central monitoring point. This data link could be the existing train-borne VHF radio, could be comprised of separate telephone links to the existing TCS centers or be telephone/microwave links to the overlaid cab signal systems.

The implementation of a Category C system requires that a data link be added between the central control point and the overlaid Category B system so that commands can be sent to the Amtrak trains (and stations if required) to control schedule performance.

The above considerations result in identification of the following potential interfaces:

a.) Individual signal blocks in existing ABS systems.

b.) TCS data centers.

c.) Train to wayside VHF radio links.

d.) Wayside to TCS control center telephone or microwave links.

These interfaces will be considered in more detail in the following section of this report.

It has been assumed that the potential system candidate will be overlaid on an existing ABS system. This assumption was made to simplify the design requirements for the overlay system and to avoid over-complicating the system. Where TT and TO is in effect (less than 6% of the total track miles over which Amtrak operates) any one of the existing signal types could be installed or, if broken rail detection is not required, an axle counter system with wayside signals could be implemented. Similarly, if the existing ABS system is presently incompatible with electrification, the overlay system is not required to correct that incompatibility.

4.2 Technical Interface Mechanization

As noted in Subsection 3.3 of this report, more than 90% of the road miles over which Amtrak operates have some form of ABS. Figure 4-1 summarizes the track circuits utilized and their compatibility with the six potential Category A overlay systems described in Section 4.1.

EXISTING SYSTEM/ OVERLAY SYSTEM	STEADY DC	CODED DC	STEADY AC	CODED AC	AUDIO	TT & TO
5 Aspect (100 Hz) NEC	Track Circuit	Track Circuit	Track Circuit	Add to Existing Logic	Track Circuit	Total System Install
Intermittent (BR)	None	None	None	None	None	Not Useable
Intermittent (DB)	Signal	Signal	Signal	Signal	Signal	Add Axle Counters
Intermittent (FS)	Signal	Signal	Signal	Signal	Signal	Add Axle Counters
Dual Carrier Continuous FS	Track Circuit	Track Circuit	Track Circuit	Add to Existing Logic	Track Circuit	Total System Install
Inductive Loop Continuous (DB)	Signal or Track Circuit	Signal or Track Circuit	Signal or Track Circuit	Signal or Track Circuit	Signal or Track Circuit	Add Axle Counters
Location-Indication-Control (BCR)	None	None	None	None	None	Total System Install

Figure 4-1 INTERFACE TYPES

One of the simplest mechanizations is the BR intermittent cab signal system because there is no interface with the existing system. This system allows the engineer to interpret the existing wayside signal aspects in terms of his train's braking performance, with the cab signal system imposing the geographic restrictions on those speed limits. If additional signal aspects are required, they must be added to the wayside signal system. The use of this system also requires modifications to the operations handbooks for the railroads involved.

Another simple mechanization is the British Columbia Railway System described in the Task 1 report -- for use in TT&TO territory.

The FS and DB intermittent cab signaling systems can be interfaced with any ABS system if no additional aspects are required. The wayside transponders are simply located prior to (ahead of) the wayside signal they are to repeat and interfaced with the signal control circuitry. The transponder units draw no power so all that is required is a contact closure for each aspect to be designated. Although the discussions in Task 1 and in this report have reflected a three aspect system, the transponders are available to reflect as many as eight aspects. If it is desired to provide additional aspects to those provided by the existing wayside signaling system, the interface becomes more complex. Basically, it is necessary to provide the same quantity of track repeater relays and wiring logic that would be necessary to add additional aspects to the existing system.

The implementation of either the NEC or FS continuous cab signaling system requires that the interface be at the track relays. Additionally, these systems require large quantities of equipment (relays, code generators, receivers, etc.) which makes the interface very complex. In most cases, these systems could better replace the existing train detection system rather than attempt to integrate the two and the interface would then be with the wayside signals. The only existing system types which are amenable to interfacing with the NEC or FS continuous cab signaling are ac coded systems. These coded systems already contain the majority of the logic required, and only the additional aspects (or the second carrier) need be added.

The Continuous Inductive Loop cab signaling system must also interface with the track circuit but only requires a contact closure for each circuit denoting occupancy status. All of the logic is contained within the loop controllers. Since the rails are not used as a communications element, the 12.5 Km transposed loop sections must be installed between the rails in a manner which avoids interference with the rail and roadbed maintenance machines. Alternatively, the transposed loop can be mounted outside the rails if desired, the constraint being that the train-borne transponder must pass within 15 cm of the loop. In the event that minimum headway operation is not necessary, the wiring interface to the existing system could be made at the wayside signals only, thus simplifying the interface. Vandalism would be a major problem with this system.

In those portions of the system which are currently operated by TT and TO, the interface tasks for the potential system becomes quite interesting. Transponders are used on the BCR. For the DB and FS intermittent systems, the installation of axle counters to define the blocks would allow the cab signal system to be installed and wayside signals could then be installed to interface the axle counters. This same technique is also valid for the installation of the inductive loop system. The use of the NEC or FS continuous systems, however, requires rework of the rail system to provide insulated joints and installation of track circuits. In either case, if mixed traffic is to be considered with only passenger trains being cab signal equipped, wayside signals are required to be added.

A similar situation is presented if it is required to electrify any of the railroads over which Amtrak now operates. The only significant electrified territory at present is the NEC which Amtrak already owns. The only existing domestic train detection circuits compatible with electrification at 60 Hz are ac track circuits using phase selective relays. The overlay system can be used to replace existing incompatible systems in the same manner as described in the preceding paragraph.

In the event that it is desired to implement a system utilizing jointless CWR, the choice of systems becomes much more limited. The only available train detection systems are either audio frequency circuits or axle counter systems. The latter have the disadvantage of not providing broken rail protection but are much simpler from both implementation and maintenance standpoints. The choice of overlay systems is limited to the FS and DB intermittent and the DB continuous signaling systems since neither the NEC or FS coded track circuits are compatible with jointless CWR.

The implementation of Category B and C systems presupposes that one of the Category A cab signaling systems has been chosen. Any of these six systems can be expanded to achieve Category B and C requirements. The intermittent systems, however, are limited in that the achievable minimum headway is greater than that of the continuous system. The available interface for the data transmission to the central monitor point varies between systems as well as the types of data which can be transmitted. The types of data desired at the control monitor points are:

a.) train position

b.) train speed

c.) train identity

d.) train status

With the BR intermittent system, the wayside transponders can be location coded so that position data is available to the train at every check point. The most desirable data interface then would be the existing train VHF or UHF radio. There are data packages available for interfacing these radios to allow "burst" data to be transmitted to the central receiving point. With large systems, several receiving points may be utilized and the data receivers interfaced with modems for transmission to the central monitor point via telephone or microwave links. The train-borne transponder can easily be expanded to add the logic and memory to store train identity, speed and status information for input to the VHF radio data module. The burst transmissions could be initiated automatically as the train passes over a transponder, by on board status change such as the BCR system, or by call-up from the central monitor point. The FS and DB intermittent systems are limited to about 8 bits of data in the wayside transponder's coding, so for very large systems it might be necessary to use a repetitive location code. Otherwise, the mechanization would be the same as the BR system.

With the NEC and FS coded AC systems, location data is not easily transmitted to the train, so the most logical data interface is at the wayside in the relay units (signal towers). These data interfaces are amenable to microprocessors and modem units to either telephone lines or microwave links to the central monitor point. This interface provides train position data, but train speed and identity must be indirectly obtained by a computer at the central monitor point. Train identity can be manually entered in the central computer as the train enters the system. The computer can then track the train through the system by the initial identity and can compute average speed from the time interval between checkpoints (blocks). Train status data is not directly available unless a VHF data link is installed on the train.

The inductive loop system provides the most options since two-way communication already exists between the train and the loop controllers. Also, train identity, location, speed, and status data are present at both locations so that the choice of interfaces is largely a matter of convenience and cost.

The implementation of a Category C system requires the addition of a data link from central control point to the train, which is merely making the data links described in Category B two-way links, <u>except</u> in the case of the NEC and FS coded AC systems. With these systems, a VHF data link from the central control point to the train-borne equipment must be implemented in addition to the wayside-to-central links installed to meet Category B requirements.

In all Category B and C implementations, the central monitor and control computers would interface color CRT's for display. For data entry, a standard teletype keyboard would be used and hard copy data provided via line printer.

An alternative interface for central monitoring and control data links is available in those portions of the network where TCS systems are in operation. The data concerning train movements could be obtained at the TCS computer interface. This interface might be attractive in some individual cases, but has several disadvantages which must be considered. The first consideration is that on the routes over which Amtrak runs, there is less than 50% coverage by TCS equipment which means that a data interface must be developed for the remaining 50% of the routes. Secondly, the types of computers and software implementations for TCS vary from one property to the next. This would require extensive software and memory in the central facility to adapt to these interfaces. Finally, since the TCS systems are railroad owned and operated, there would be a continuing need to update the interface programs as the individual railroads upgrade and expand their TCS equipment.

4.3 Interface Mechanization Costs

Figure 4-1 demonstrates the six most promising candidate overlay systems chosen for interfacing with the seven types of wayside signal systems over which Amtrak passenger trains operate. Each of these six candidate overlay systems represents a proven technology presently in successful operation.

Development of capital costs for any selected wayside overlay, or on-board signal/control system, involves a multitude of factors as to type and degree of sophistication of the existing signal system. Substantial cost variance is incurred by such factors as traffic density, speeds, headways, tonnages, number and size of interlockings, number of highway crossing protection devices, as well as the inherent problems involved in retrofitting a variety of different style locomotives with a selected train control equipment.

Therefore, the comparative cost projections identified herein for each candidate system are not designed to replace the detailed cost analysis required for application to any particular segment of U. S. railroad, but are meant to demonstrate only one of the comparative factors involved. The objective of Task 5 is to develop detail costs and cost benefit analyses for the selected systems.

Cost-Range estimating sheets were developed for Figure 4-1 and may be found in Appendix A of this report.

The following summarizes the assumptions made and the estimated cost-ranges developed for procurement and installation of each of the candidate overlay systems. All estimated costs were based upon 1978 prices for labor and material, with all installation and interfacing labor to be provided by railroad personnel. It is also assumed that each of the candidate overlay systems has been previously proven and accepted by a 10-mile conceptual test and evaluation followed by a 50-mile demonstration system interfaced to an existing U.S. railroad wayside signal system.

Category "A" - In order to establish a data base and relative means of measurement, the following criteria were developed upon which the cost-ranges for each candidate overlay system were based:

1. It is assumed that all timetable and train order (T.T.&T.O.) territory over which Amtrak operates (approximately 10% of the road mileage) is single track.

2. No costs are assumed to add bi-directional operation by signal indication where it does not now exist. The train control systems costed are for the normal direction of traffic only. The schedule time lost in slowing a 250 kmph (150 mph) train to medium speed to cross over or run around a freight train provides a poor operation in comparison to crossing over a freight train which has a much smaller differential between maximum and medium speed.

3. An average spacing of 4,500 to 7,500 feet for existing automatic block signals is used for cost estimating purposes.

4. Approximately 65% of the signaled road miles over which Amtrak operates is double track.

5. Based upon past studies of a similar nature, it is assumed that one highway grade crossing equipped with an automatic warning system exists at an average of every 10 miles. Of these automatically protected highway grade crossings, five percent are located on a track alignment that is capable of high speed operation. A cost range of $25,000 - $30,000 per double track crossing has been used to provide constant warning protection time at such existing highway grade crossings within high speed territory.

6. An equal number of cut sections as wayside block signals is assumed in calculation of track circuit costs.

7. An average spacing of 10 miles for existing locations of interlockings is used for cost estimating purposes.

8. In addition to wayside signal system interface, three civil speed restrictions per five-mile segment (for high speed operation) are assumed as a result of track curvature, city or town congestion, local ordinances, stations, etc.

9. The total Amtrak locomotive fleet to be equipped is estimated at 500 units of various types. This figure includes the necessary spare units required for locomotive availability at the optimum level of service estimated between 1980 and the turn of the century.

Category "B" - The assumptions made for the costing of the candidate overlay systems are:

1. The Category "B" costs are additional to those already derived from the Category "A" implementation.

2. It is assumed that the locomotives to be equipped already have a VHF radio as standard equipment and, therefore, only the cost of the data encoder is shown.

3. For the wayside central monitoring equipment, it is assumed that the central monitor facility is independent of the existing TCS centers. The interface points between the central monitor facility and the wayside track relays are assumed to be at the interlocking plants.

4. The data to be transmitted to central for the ac coded track circuit systems are assumed to be picked up at the track relays. The data encoder costs are for the equipment to store the block occupancy data and transmit the data in serial form via telephone lines.

5. The computer and peripheral equipment costs assume a Modcomp IV computer with 64K core storage, off line disc storage unit, card punch and reader, and line printer. The CRT cost includes a keyboard as an integral part of the unit.

6. The software costs include the train tracking and identification programs (manual entry of train ID), a program to provide line printer and CRT readout of train progress relative to realtime schedule and data reduction to provide daily train summaries.

Category "C" - The cost ranges presented for implementing a Category "C" system is additive to the Category "A" and "B" costs so that all three must be summed to obtain the total cost of each candidate system. Detail qualifying assumptions are:

1. The computer, memory and peripheral equipment costed in Category "B" are adequate to accomodate the additional software to implement the Category "C" system.

2. The Category "B" single color CRT and keyboard will be utilized for data entry and tabular data display.

3. The added color CRT will be utilized for train location and status display purposes.

4. The data link from central control to the locomotive will be via VHF radio in all cases. It is assumed (as in Category "B") that the VHF train radio already exists and only the on-board decoder must be added.

5. The additional software effort quoted is to provide the capability for transmitting schedule status data from central to each train. This will allow the engineer better control of train performance to schedule.

Cost Summary

Category "A" - Figure 4-2 summarizes the estimated cost ranges developed for procurement and installation of each of the six candidate overlay systems. These cost ranges include all required material, labor and testing to install the wayside equipment for each of the candidate systems. It should be noted that to determine the wayside cost for any particular segment of railroad, the right-of-way cost per mile must be added to the cost per track per mile for the total number of tracks signaled within the segment. Signal/control equipment for locomotives is shown on a per locomotive basis for each of the candidate wayside overlay systems.

Category "B" - Figure 4-3 summarizes the estimated additional costs for procurement and installation of train-to-central information systems. These additional costs (above base Category "A" costs) are based upon a road mile cost for additional wayside equipment, and a per unit basis for additional locomotive equipment for each of the candidate systems.

Category "C" - Figure 4-4 summarizes the estimated additional costs for procurement and installation of central-to-train information systems. These additional costs (above the sum of Categories "A" and "B" costs) are based upon a road mile cost for additional wayside equipment, and a per unit basis for additional locomotive equipment for each of the candidate systems.

CATEGORY "A"

ESTIMATED COST RANGES - (PER MILE) - WAYSIDE SYSTEMS
(IN THOUSANDS)

EXISTING OVERLAY	STEADY DC	CODED DC	STEADY AC	CODED AC	AUDIO	TT&TO
5-Aspect (100 Hz) NEC:						
. ROW Cost/Mile	28/30	28/30	28/30	28/30	28/30	49/52
(+). Per Track Mile	11/12	7/9	11/12	4/7	11/14	NA
(+). Per Locomotive	45/58	45/58	45/58	45/58	45/58	45/58
Intermittent (BR):						
. ROW Cost/Mile	0	0	0	0	0	54/55
(+). Per Track Mile	8/9	8/9	8/9	8/9	8/9	NA
(+). Per Locomotive	27/30	27/30	27/30	27/30	27/30	27/30
Intermittent (DB):						
. ROW Cost/Mile	0	0	0	0	0	53/55
(+). Per Track Mile	6/7	6/7	6/7	6/7	6/7	NA
(+). Per Locomotive	22/23	22/23	22/23	22/23	22/23	22/23
Intermittent (FS):						
. ROW Cost/Mile	0	0	0	0	0	55/57
(+). Per Track Mile	8/9	8/9	8/9	8/9	8/9	NA
(+). Per Locomotive	30/31	30/31	30/31	30/31	30/31	30/31
Dual Carrier Continuous (FS):						
. ROW Cost/Mile	28/30	28/30	28/30	28/30	28/30	49/52
(+). Per Track Mile	15/20	11/14	15/20	7/13	19/22	NA
(+). Per Locomotive	67/72	67/72	67/72	67/72	67/72	67/72
Inductive Loop Continuous:						
. ROW Cost/Mile	28/30	28/30	28/30	28/30	28/30	50/55
(+). Per Track Mile	27/31	26/30	27/31	26/29	28/32	NA
(+). Per Locomotive	113/125	113/125	113/125	113/125	113/125	113/125

To find total cost per road mile, add right-of-way (ROW) cost and cost per track mile for total number of tracks signaled.

Figure 4-2

CATEGORY "B"

ESTIMATED CAPITAL COSTS - TRAIN TO CENTRAL INFORMATION SYSTEMS

(PER ROAD MILE)

CATEGORY "A" WAYSIDE SYSTEM	ADDITIONAL COSTS FOR TRAIN-TO-CENTRAL WAYSIDE/ROAD MILE	LOCOMOTIVE/EACH
5-Aspect (100 Hz) NEC Type	$17,000.00	$ NONE
Intermittent (BR)	9,500.00	3,000.00
Intermittent (DB)	9,500.00	3,000.00
Intermittent (FS)	9,500.00	3,000.00
Dual Carrier Continuous (FS)	17,000.00	NONE
Inductive Loop Continuous (DB)	9,500.00	3,000.00

Notes:

1. Above costs do not include any recurrent changes for leased commercial telephone or data circuits between railroad central offices and Amtrak national display center.

2. Above costs must be added to Category "A" base costs to obtain total including Category "B" for selected candidate wayside system and locomotive costs.

Figure 4-3

CATEGORY "C"

ESTIMATED CAPITAL COSTS - CENTRAL TO TRAIN INFORMATION SYSTEMS

(PER ROAD MILE)

	ADDITIONAL COSTS FOR CENTRAL-TO-TRAIN	
CATEGORY "A" WAYSIDE SYSTEM	WAYSIDE/ROAD MILE	LOCOMOTIVE/EACH
5-Aspect (100 Hz) NEC Type	$ 2,700.00	$13,000.00
Intermittent (BR)	2,600.00	NONE
Intermittent (DB)	2,600.00	NONE
Intermittent (FS)	2,600.00	NONE
Dual Carrier Continuous (FS)	2,700.00	13,000.00
Inductive Loop Continuous (DB)	2,600.00	NONE

Figure 4-4

Figure 4-5 summarizes the total costs for all three categories in a similar format as that shown for Figure 4-2 -- the base wayside candidate systems costs.

4.4 Candidate Systems and Costs

Since the performance attainable is quite different for Category A, B and C mechanizations, several candidate implementations will be examined. These systems could be implemented conceptually as Phase II of the SCC program and expanded to demonstration systems in Phase III and IV. Five implementation levels have been selected as shown in Figure 4-6.

Category A1 - The lowest level of performance acceptable is the provision of cab signaling which is mandatory for operation at speeds above 130 kmph (80 mph). The program requirements establish two constraints which must be imposed on any new signal and control system. The first (and most severe) is that the system must be capable of being overlaid on any railroad over which Amtrak operates. The second constraint is that the system to be implemented must be compatible with 25KV, 60 Hz electrification. The simplest cab signaling system which meets these constraints is an intermittent cab signaling system which merely repeats the existing wayside signals. One implementation which has been identified is the German "Indusi" system. This system provides three or more aspect indications in the cab. The hardware for this system is inexpensive and is comprised of passive wayside transponder units located near the wayside signals and adjacent to the track. These units

COMBINED CATEGORIES "A", "B" & "C"

ESTIMATED COST RANGES - (PER MILE) - WAYSIDE SYSTEMS
(IN THOUSANDS)

EXISTING OVERLAY	STEADY DC	CODED DC	STEADY AC	CODED AC	AUDIO	TT&TO
5-Aspect (100 Hz) NEC:						
. ROW Cost/Mile	48/50	48/50	48/50	48/50	48/50	69/72
(+). Per Track Mile	11/12	7/9	11/12	4/7	11/14	NA
(+). Per Locomotive	61/74	61/74	61/74	61/74	61/74	61/74
Intermittent (BR):						
. ROW Cost/Mile	12	12	12	12	12	66/67
(+). Per Track Mile	8/9	8/9	8/9	8/9	8/9	NA
(+). Per Locomotive	30/33	30/33	30/33	30/33	30/33	30/33
Intermittent (DB):						
. ROW Cost/Mile	12	12	12	12	12	65/67
(+). Per Track Mile	6/7	6/7	6/7	6/7	6/7	NA
(+). Per Locomotive	25/26	25/26	25/26	25/26	25/26	25/26
Intermittent (FS):						
. ROW Cost/Mile	40/42	40/42	40/42	40/42	40/42	61/64
(+). Per Track Mile	8/9	8/9	8/9	8/9	8/9	NA
(+). Per Locomotive	33/34	33/34	33/34	33/34	33/34	33/34
Dual Carrier Continuous (FS):						
. ROW Cost/Mile	48/50	48/50	48/50	48/50	48/50	69/72
(+). Per Track Mile	15/20	11/14	15/20	7/13	19/22	NA
(+). Per Locomotive	80/85	80/85	80/85	80/85	80/85	80/85
Inductive Loop Continuous						
. ROW Cost/Mile	40/42	40/42	40/42	40/42	40/42	62/66
(+). Per Track Mile	27/31	26/30	27/31	26/29	28/32	NA
(+). Per Locomotive	116/128	116/128	116/128	116/128	116/128	116/128
Location Identification Control(BCR)						
. Row Cost/Mile	NA	NA	NA	NA	NA	19/25
(+). Per Locomotive	NA	NA	NA	NA	NA	15/20

To find total cost per road mile, add right-of-way (ROW) cost and cost per track mile for total number of tracks signaled.

Figure 4-5

IMPLEMENTATION LEVEL	CONFIGURATION	CONCEPTUAL HARDWARE	DEMONSTRATION HARDWARE
A1 Intermittent Cab Signaling	Passive Wayside Inductors	10 Blocks, 2 trains Cab Signal monitor only	50 miles, several trains Cab signal enforces brakes
A2 Continuous Cab Signaling (CATC)	Continuous Inductive Loop	10 Blocks, 2 trains Cab signal and speed monitor only	50 miles, several trains CATC controls speed
B CATC + Central Traffic Monitor	Continuous Inductive Loop, VHF data link CRT display	CATC only as in level 2	CATC + data link and computer driven CRT
C-1 CATC + Central Traffic Control	Continuous Inductive Loop, Microwave Data Link, CRT Display	CATC plus dat link 10 Blocks, 2 trains	CATC + data link and software system for CTC control and monitor functions
C-2 CATC + Central Traffic Control	Same as Level 4	CATC plus data link control and monitor software and CRT display 10 Blocks, 2 trains	Expand conceptual system to 50 miles and several trains
C-3 Intermittent Cab Singalling + Central Traffic Control	Passive Wayside Transponders + VHF/ Microwave data link	10 Blocks, 2 trains, existing voice systems, Control and Monitor Computer and CRT	Expand Conceptual system to 50 miles and <u>all</u> trains.

Figure 4-6 - CANDIDATE SYSTEMS

typically cost $200 - $300 and are wired to repeat the wayside signal commands. The trainborne transponder is mounted so that its transmitting coil passes directly above the wayside units. The train-borne units, as manufactured, typically cost $8,000 - $12,000 including the cab indicator. For the concept evaluation (Phase II) a relatively small (5-10 blocks) portion of any railroad with ABS could be equipped with wayside units, and two train-borne units with performance recorders could be installed on any two locomotives or MU's operating regularly over the track on which the wayside units are installed. Since the only U.S. electrified territory is the Amtrak NEC, that probably would be the most appropriate test site. Since that area has continuous cab signaling, it would allow system compatibility to be evaluated in addition to system performance. Assuming these tests prove successful, a full demonstration (Phase III) system could be procured and demonstrated with the cab signaling system providing overspeed control for several (or all) trains running over a 50 mile route.

Category A2 - The next level of implementation to be considered for the evaluation program would be a continuous cab signaling system. The Category A1 system is limited in that it cannot achieve increased headways over those obtained with the existing wayside signals. A continuous system has the advantage that it can reflect a change in block occupancy status to the cab display in real time, whereas the intermittent system can only indicate changes when the cab transponder "reads" the wayside marker units. One such system identified in the technology assessment is the German CATC. It can be installed as an overlay and is compatible with electrification in the German CATC system. This system utilizes a continuous transposed loop in each block as the communications element. The loop is a cable laid midway between the running rails. This system provides the capability to transmit data between the train and the wayside so the system can be expanded to add TCS and ACI functions at a later date. The simplest implementation of this mechanization would be to use it to repeat the wayside signal aspect indication in the locomotive cab. Assuming successful operation of this equipment, the system would be expanded to a full demonstration system.

Category B - The next logical step to providing improved performance capability would be to transmit the location and movement data relative to each Amtrak train to a central control point. Category A2 system can easily be expanded to accomplish this. One possible way to demonstrate this capability is to add a data transponder to the existing train radio. The cab control unit can detect what block the train is in via the data word transmitted from wayside and the position within the block is determined by counting the number of loop transpositions from the start of the block. The train radio can then automatically transmit this data in short "bursts" to a central receiving point. The received data is input to a computer driven CRT display to show physical location of trains. The cab signaling and wayside transmitter costs will increase approximately 10% over the category A2 equipment; the trainborne data transponder is typically $1,500 and the central VHF receiver computer and CRT display is typically $150,000 exclusive of software. The successful testing of a 5-10 mile segment of the system, as in the previous cases, will provide the confidence required to deploy a full demonstration system.

Category C1 - The most sophisticated implementation to be considered is a system in which a full centralized control system is deployed. This system would, within the constraint of the cab signaling, allow the control computer to regulate train speed as required to maintain exact schedule. It would also allow the train to transmit identity, performance and malfunction data to the central monitoring point. This system differs from the Category B system in that more data is to be handled and the data communications would be between wayside transponders via a microwave system to the central control point. Data exchange between the train and wayside would be handled by the transposed loop. The wayside microwave transponders can easily handle 10 to 25 blocks, and the microwave system, at least for the demonstration programs, could be leased or might already exist depending on the test site chosen. In order to minimize development risks and required funding rates, it is suggested that the concept evaluation be limited to the train to wayside system only. This approach defers the installation of the microwave comunication system (which is not considered a development risk) until after the new elements of the system have been demonstrated. The 50 mile demonstration system would then add the full microwave communications link.

Category C2 - This implementation would be the same system as considered in the preceding paragraph but would allow a shorter time period and a lower overall funding level for the program. This approach would install the central microwave receiving station and one wayside transponder during the concept evaluation phase so that expansion to a full demonstration system could be accomplished more efficiently.

Category C3 - For a system in which short headways are not required, an interrmittent cab signaling system could be utilized with the data link between train and central control being superimposed on the existing voice radio link. Such a system is very cost effective but would require that all trains in the terrirory be equipped with cab signaling, or that unequipped trains run on Time Table and Train Order. A system of this type is described in paragraph 3.6 of the Task 1 report and is presently being installed on the British Columbia railway in Vancouver, Canada. The wayside units relay location data to the train, and it is continuously polled by central to determine location and speed. Based on this data, the central computer ascertains safe speeds and transmits speed limit data to the train. The system maintains a "buffer zone" behind each train, and any penetration of this zone by a following train, with its braking distance computed by Central Control results in an alarm and a reduced speed command to the following train.

SECTION 5.0

SUMMARY

Based on the results of the cost and performance analysis described in the preceding section, three implementation levels can be described for each of the candidate systems. The implementation levels are summarized according to performance as:

Category "A" - Cab Signaling Only

Category "B" - Cab Signaling with Central Monitoring

Category "C" - Cab Signaling with Central Monitoring and Control

The candidate systems can be grouped into three basic system types:

Intermittent Systems

Coded AC Systems

Continuous Automatic Train Control (CATC)

The intermittent systems are the simplest and most economical cab signal systems. The achievable headways, however, are limited to those obtainable with existing fixed wayside signals. Expansion to Category "B" or "C" implementation levels requires the addition of data collection, encoding and decoding equipment. The coded ac systems provide closer achievable headways by virtue of the ability to detect aspect changes at any point within a signal block. This increase in performance results in an intermediate cost level. Expansion to Category "B" or "C" implementation still requires the addition of data collection, encoding and decoding equipment. The CATC system, while the highest cost candidate, provides the most performance and growth flexibility. Since it already incorporates two-way data exchange between train and wayside, it can be expanded to Category "B" or "C" implementation levels without additional equipment.

The candidate systems, as defined and costed in Section 4.0, are configured to provide cab signaling for Amtrak trains only. The systems can be utilized for other traffic over the system by adding appropriate train-borne equipment to the additional locomotives.

In all of the candidate systems considered, compatibility with either 60 or 25 Hz electrification is achieved. The cost of impedance bonds for the ac coded systems is not included, since that would normally be included in electrification costs. Similarly, no costs are included to upgrade existing fixed wayside signal systems to achieve electrification compatibility.

The three candidate system types will be carried forward to the economics analyses (Task 5) with cost benefit analyses to be performed at each of the three implementation levels. On the basis of these analyses, the most promising system candidate and implementation level will be utilized as the basis of the specification to be developed in the Task 6 activity.

APPENDIX A

CAPITOL COSTS

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: STEADY DC
OVERLAY SYSTEM: 5 ASPECT 100 HZ NEC
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Factory Wired Interface Cases	38	228,000.	247,000.
3.	Miscellaneous Equipment	1	39,000.	45,000.
4.	Stores Overhead		18,000.	21,000.
5.	Engineering		8,000.	10,000.
6.	Supervision/Testing		12,000.	14,000.
7.	Labor Installing		116,000.	135,000.
8.	Labor Overhead		74,000.	86,000.
		Total II	$525,000.	$611,000.
		Per Track Mile	$ 11,000.	$ 12,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$ 22,000.	$ 28,000.
2.	Miscellaneous Equipment	1	3,000.	4,000.
3.	Stores Overhead		2,000.	3,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,000.	1,000.
6.	Labor Installing		10,000.	13,000.
7.	Labor Overhead		6,000.	8,000.
		Total III	$ 45,000.	$ 58,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: CODED DC
OVERLAY SYSTEM: 5 ASPECT 100 HZ NEC
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Factory Wired Interface Cases	38	152,000.	171,000.
3.	Miscellaneous Equipment	1	27,000.	34,000.
4.	Stores Overhead		13,000.	15,000.
5.	Engineering		6,000.	7,000.
6.	Supervision/Testing		9,000.	11,000.
7.	Labor Installing		81,000.	101,000.
8.	Labor Overhead		52,000.	64,000.
		Total II	$370,000.	$456,000.
		Per Track Mile	$ 7,000.	$ 9,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$22,000.	$28,000.
2.	Miscellaneous Equipment	1	3,000.	4,000.
3.	Stores Overhead		2,000.	3,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,000.	1,000.
6.	Labor Installing		10,000.	13,000.
7.	Labor Overhead		6,000.	8,000.
		Total III	$45,000.	$58,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: STEADY AC
OVERLAY SYSTEM: 5 ASPECT 100 HZ NEC
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Factory Wired Interface Cases	38	228,000.	247,000.
3.	Miscellaneous Equipment	1	39,000.	45,000.
4.	Stores Overhead		18,000.	21,000.
5.	Engineering		8,000.	10,000.
6.	Supervision/Testing		12,000.	14,000.
7.	Labor Installing		116,000.	135,000.
8.	Labor Overhead		74,000.	86,000.
		Total II	$525,000.	$611,000.
		Per Track Mile	$ 11,000.	$ 12,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$22,000.	$28,000.
2.	Miscellaneous Equipment	1	3,000.	4,000.
3.	Stores Overhead		2,000.	3,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,000.	1,000.
6.	Labor Installing		10,000.	13,000.
7.	Labor Overhead		6,000.	8,000.
		Total III	$45,000.	$58,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: CODED AC
OVERLAY SYSTEM: 5 ASPECT 100 HZ NEC
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Factory Wired Interface Cases	38	72,000.	114,000.
3.	Miscellaneous Equipment	1	15,000.	25,000.
4.	Stores Overhead		7,000.	12,000.
5.	Engineering		3,000.	5,000.
6.	Supervision/Testing		5,000.	8,000.
7.	Labor Installing		46,000.	75,000.
8.	Labor Overhead		29,000.	48,000.
		Total II	$207,000.	$340,000.
		Per Track Mile	$ 4,000.	$ 7,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$22,000.	$28,000.
2.	Miscellaneous Equipment	1	3,000.	4,000.
3.	Stores Overhead		2,000.	3,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,000.	1,000.
6.	Labor Installing		10,000.	13,000.
7.	Labor Overhead		6,000.	8,000.
		Total III	$45,000.	$58,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: AUDIO
OVERLAY SYSTEM: 5 ASPECT 100 HZ NEC
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Factory Wired Interface Cases	38	247,000.	285,000.
3.	Miscellaneous Equipment	1	42,000.	51,000.
4.	Stores Overhead		19,000.	23,000.
5.	Engineering		9,000.	11,000.
6.	Supervision/Testing		13,000.	16,000.
7.	Labor Installing		124,000.	152,000.
8.	Labor Overhead		79,000.	96,000.
		Total II	$563,000.	$687,000.
		Per Track Mile	$ 11,000.	$ 14,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$22,000.	$28,000.
2.	Miscellaneous Equipment	1	3,000.	4,000.
3.	Stores Overhead		2,000.	3,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,000.	1,000.
6.	Labor Installing		10,000.	13,000.
7.	Labor Overhead		6,000.	8,000.
		Total III	$45,000.	$58,000.

CATEGORY "A"
EXISTING SYSTEM: TT&TO
OVERLAY SYSTEM: 5-ASPECT 100 Hz CONTINUOUS (or) DUAL CHANNEL CARRIER (FS)
(BASED ON 50 MILE SEGMENT)

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Wired Instrument Case	38	$ 247,000.	$ 285,000.
2.	Line Poles	2,000	260,000.	260,000.
3.	Pole Line Hardware	1	12,000.	12,000.
4.	Messenger 336. MCM-Aluminum	227,200	83,000.	83,000.
5.	2 Cond. #6-3000V Cable	277,200	554,000.	554,000.
6.	Lashing Wire	227,200	11,000.	11,000.
7.	Insulated Joints	76	12,000.	12,000.
8.	Transformer Locations	38	30,000.	53,000.
9.	Miscellaneous Equipment		181,000.	191,000.
10.	Stores Overhead/Taxes		83,000.	88,000.
11.	Engineering		38,000.	40,000.
12.	Supervision/Testing		57,000.	60,000.
13.	Labor Installing		542,000.	570,000.
14.	Labor Overhead		344,000.	362,000.
		Total Cost	$2,454,000.	$2,581,000.
		Cost Per Mile	$ 49,000.	$ 52,000.

CATEGORY "A"
CAPITAL COSTS
INTERMITTENT WAYSIDE OVERLAY SYSTEMS
(BASED ON 50 MILE SEGMENTS)

II. (BR) TRACK MILE WAYSIDE COSTS — COST RANGE

	ITEM	QUANT.	LOW	HIGH
1.	Additional Signal Heads	38	$ 26,000.	$ 26,000.
2.	Additional Signal Control Equipment	38	152,000.	171,000.
3.	Transponders	80	28,000.	28,000.
4.	Miscellaneous Equipment		31,000.	34,000.
5.	Stores Overhead		14,000.	16,000.
6.	Engineering		7,000.	7,000.
7.	Supervision/Testing		10,000.	11,000.
8.	Labor Installing		93,000.	101,000.
9.	Labor Overhead		59,000.	64,000.
		Total II (BR)	$420,000.	$458,000.
		Per Track Mile	$ 8,000.	$ 9,000.

(DB) TRACK MILE WAYSIDE COSTS — COST RANGE

	ITEM	QUANT.	LOW	HIGH
1.	Underground Cable	36,000	$ 47,000.	$ 47,000.
2.	Transponders	120	24,000.	24,000.
3.	Wired Interface Cases	38	76,000.	95,000.
4.	Miscellaneous Equipment		22,000.	25,000.
5.	Stores Overhead		10,000.	11,000.
6.	Engineering		5,000.	5,000.
7.	Supervision/Testing		7,000.	8,000.
8.	Labor Installing		66,000.	75,000.
9.	Labor Overhead		42,000.	47,000.
		Total II (DB)	$299,000.	$337,000.
		Per Track Mile	$ 6,000.	$ 7,000.

(FS) TRACK MILE WAYSIDE COSTS — COST RANGE

	ITEM	QUANT.	LOW	HIGH
1.	Underground Cable	36,000	$ 47,000.	$ 47,000.
2.	Transponders	120	66,000.	66,000.
3.	Wired Interface Cases	38	76,000.	95,000.
4.	Miscellaneous Equipment		28,000.	31,000.
5.	Stores Overhead		13,000.	14,000.
6.	Engineering		6,000.	7,000.
7.	Supervision/Testing		9,000.	10,000.
8.	Labor Installing		85,000.	93,000.
9.	Labor Overhead		54,000.	59,000.
		Total II (FS)	$384,000.	$422,000.
		Per Track Mile	$ 8,000.	$ 9,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: TT&TO
OVERLAY SYSTEM: INTERMITTENT (BR)
(BASED ON 50 MILE SEGMENT)

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Wired Wayside Cases	38	$ 38,000.	$ 57,000.
2.	Line Poles	2,000	260,000.	260,000.
3.	Pole Line Hardware	1	12,000.	12,000.
4.	Messenger 336 MCM-Alum.	554,400 LF	166,000.	166,000.
5.	2 Cond.-#6, 3000V Cable	277,200 LF	554,000.	554,000.
6.	Communication Cable	277,200 LF	180,000.	180,000.
7.	Lashing Wire	600,000 LF	30,000.	30,000.
8.	Transformer Locations	38	30,000.	53,000.
9.	Mini Computer	2	8,000.	8,000.
10.	Axle Counters (Incl. Wayside Logic)	76	13,000.	13,000.
11.	Transponders	80	28,000.	28,000.
12.	Miscellaneous Equipment		198,000.	204,000.
13.	Stores Overhead/Taxes		91,000.	94,000.
14.	Engineering		42,000.	43,000.
15.	Supervision/Testing		63,000.	65,000.
16.	Labor Installing		592,000.	610,000.
17.	Labor Overhead		376,000.	388,000.
		Total	$2,681,000.	$2,765,000.
		Cost Per Mile	$ 54,000.	$ 55,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: TT&TO
OVERLAY SYSTEM: INTERMITTENT (DB)
(BASED ON 50 MILE SEGMENT)

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Wired Wayside Cases	38	$ 38,000.	$ 57,000.
2.	Line Poles	2,000	260,000.	260,000.
3.	Pole Line Hardware	1	12,000.	12,000.
4.	Messenger 336 MCM-Alum.	554,400 LF	166,000.	166,000.
5.	2 Cond.-#6, 3000V Cable	277,200 LF	554,000.	554,000.
6.	Communication Cable	277,200 LF	180,000.	180,000.
7.	Lashing Wire	600,000 LF	30,000.	30,000.
8.	Transformer Locations	38	30,000.	53,000.
9.	Mini Computer	2	8,000.	8,000.
10.	Axle Counters (Incl. Wayside Logic)	76	13,000.	13,000.
11.	Transponders	120	24,000.	24,000.
12.	Miscellaneous Equipment		197,000.	204,000.
13.	Stores Overhead/Taxes		91,000.	94,000.
14.	Engineering		42,000.	43,000.
15.	Supervision/Testing		62,000.	64,000.
16.	Labor Installing		586,000.	609,000.
17.	Labor Overhead		372,000.	387,000.
		Total	$2,665,000.	$2,758,000.
		Cost Per Mile	$ 53,000.	$ 55,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: TT&TO
OVERLAY SYSTEM: INTERMITTENT (FS)
(BASED ON 50 MILE SEGMENT)

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Wired Wayside Cases	38	$ 38,000.	$ 57,000.
2.	Line Poles	2,000	260,000.	260,000.
3.	Pole Line Hardware	1	12,000.	12,000.
4.	Messenger 336 MCM-Alum.	554,400 LF	166,000.	166,000.
5.	2 Cond.-#6, 3000V Cable	277,200 LF	554,000.	554,000.
6.	Communication Cable	277,200 LF	180,000.	180,000.
7.	Lashing Wire	600,000 LF	30,000.	30,000.
8.	Transformer Locations	38	30,000.	53,000.
9.	Mini Computer	2	8,000.	8,000.
10.	Axle Counters (Incl. Wayside Logic)	76	13,000.	13,000.
11.	Transponders	120	66,000.	66,000.
12.	Miscellaneous Equipment		204,000.	210,000.
13.	Stores Overhead/Taxes		94,000.	97,000.
14.	Engineering		43,000.	44,000.
15.	Supervision/Testing		64,000.	67,000.
16.	Labor Installing		609,000.	628,000.
17.	Labor Overhead		387,000.	399,000.
		Total	$2,758,000.	$2,844,000.
		Cost Per Mile	$ 55,000.	$ 57,000.

CATEGORY "A"
CAPITAL COSTS
TRAIN-BORNE EQUIPMENT
INTERMITTENT TC SYSTEMS

- PER LOCOMOTIVE -

III. TRAIN-BORNE EQUIPMENT (BR)

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Package	1	$12,000.	$12,000.
2.	Miscellaneous Equipment		3,000.	5,000.
3.	Stores Overhead		900.	1,000.
4.	Engineering		400.	500.
5.	Supervision/Testing		600.	700.
6.	Labor Installing		6,000.	7,000.
7.	Labor Overhead		4,000.	4,000.
	Total II (BR)		$27,000.	$30,000.

TRAIN-BORNE EQUIPMENT (DB)

	ITEM	QUANT.	COST RANGE LOW	COST RANGE high
1.	Train-Borne Package	1	$10,000.	$10,000.
2.	Miscellaneous Equipment		2,000.	3,000.
3.	Stores Overhead		1,000.	1,000.
4.	Engineering		300.	400.
5.	Supervision/Testing		500.	600.
6.	Labor Installing		5,000.	5,000.
7.	Labor Overhead		3,000.	3,000.
	Total II (DB)		$22,000.	$23,000.

TRAIN-BORNE EQUIPMENT (FS)

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Package	1	$14,000.	$14,000.
2.	Miscellaneous Equipment		3,000.	4,000.
3.	Stores Overhead		1,000.	1,000.
4.	Engineering		500.	500.
5.	Supervision/Testing		700.	700.
6.	Labor Installing		7,000.	7,000.
7.	Labor Overhead		4,000.	4,000.
	Total II (FS)		$30,000.	$31,000.

* ALL ABOVE COSTS TO NEAREST THOUSAND

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: STEADY DC
OVERLAY SYSTEM: DUAL CXR CONT. (FS)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Wired Interface Cases	38	342,000.	432,000.
3.	Miscellaneous Equipment		56,000.	73,000.
4.	Stores Overhead		26,000.	34,000.
5.	Engineering		12,000.	15,000.
6.	Supervision/Testing		18,000.	23,000.
7.	Labor Installing		167,000.	218,000.
8.	Labor Overhead		106,000.	138,000.
		Total II	$757,000.	$986,000.
		Per Road Mile	$ 15,000.	$ 20,000.

III. TRAIN-BORNE EQUIPMENT

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Package	1	$32,000.	$32,000.
2.	Miscellaneous Equipment	1	6,000.	9,000.
3.	Stores Overhead		2,000.	2,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,600.	1,700.
6.	Labor Installing		15,000.	16,000.
7.	Labor Overhead		9,000.	10,000.
		Total III (Per Loco.)	$66,600.	$71,700.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: CODED DC
OVERLAY SYSTEM: DUAL CXR CONT. (FS)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Wired Instrument Cases	38	228,000.	299,000.
3.	Miscellaneous Equipment	1	39,000.	53,000.
4.	Stores Overhead		18,000.	24,000.
5.	Engineering		8,000.	11,000.
6.	Supervision/Testing		12,000.	17,000.
7.	Labor Installing		116,000.	158,000.
8.	Labor Overhead		74,000.	100,000.
		Total II	$525,000.	$715,000.
		Per Track Mile	$ 11,000.	$ 14,000.

III. TRAIN-BORNE EQUIPMENT

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Package	1	$32,000.	$32,000.
2.	Miscellaneous Equipment	1	6,000.	9,000.
3.	Stores Overhead		2,000.	2,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,600.	1,700.
6.	Labor Installing		15,000.	16,000.
7.	Labor Overhead		9,000.	10,000.
		Total III (Per Loco.)	$66,600.	$71,700.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: STEADY AC
OVERLAY SYSTEM: DUAL CXR CONT. (FS)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Wired Interface Cases	38	342,000.	432,000.
3.	Miscellaneous Equipment		56,000.	73,000.
4.	Stores Overhead		26,000.	34,000.
5.	Engineering		12,000.	15,000.
6.	Supervision/Testing		18,000.	23,000.
7.	Labor Installing		167,000.	218,000.
8.	Labor Overhead		106,000.	138,000.
		Total II	$757,000.	$986,000.
		Per Track Mile	$ 15,000.	$ 20,000.

III. TRAIN-BORNE EQUIPMENT

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Package	1	$32,000.	$32,000.
2.	Miscellaneous Equipment	1	6,000.	9,000.
3.	Stores Overhead		2,000.	2,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,600.	1,700.
6.	Labor Installing		15,000.	16,000.
7.	Labor Overhead		9,000.	10,000.
		Total III (Per Loco.)	$66,600.	$71,700.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: CODED AC
OVERLAY SYSTEM: DUAL CXR CONT. (FS)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Wired Instrument Cases	38	152,000.	200,000.
3.	Miscellaneous Equipment	1	27,000.	38,000.
4.	Stores Overhead		13,000.	17,000.
5.	Engineering		6,000.	12,000.
6.	Supervision/Testing		9,000.	19,000.
7.	Labor Installing		82,000.	175,000.
8.	Labor Overhead		52,000.	111,000.
		Total II	$371,000.	$625,000.
		Per Track Mile	$ 7,000.	$ 13,000.

III. TRAIN-BORNE EQUIPMENT

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Package	1	$32,000.	$32,000.
2.	Miscellaneous Equipment	1	6,000.	9,000.
3.	Stores Overhead		2,000.	2,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,600.	1,700.
6.	Labor Installing		15,000.	16,000.
7.	Labor Overhead		9,000.	10,000.
		Total III (Per Loco.)	$66,600.	$71,700.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: AUDIO
OVERLAY SYSTEM: DUAL CXR CONT. (FS)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Transformer Locations	38	$ 30,000.	$ 53,000.
2.	Wired Instrument Cases	38	432,000.	499,000.
3.	Miscellaneous Equipment		69,000.	83,000.
4.	Stores Overhead		32,000.	38,000.
5.	Engineering		15,000.	18,000.
6.	Supervision/Testing		22,000.	26,000.
7.	Labor Installing		207,000.	248,000.
8.	Labor Overhead		132,000.	157,000.
		Total II	$939,000.	$1,122,000.
		Per Track Mile	$ 19,000.	$ 22,000.

III. TRAIN-BORNE EQUIPMENT

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Package	1	$32,000.	$32,000.
2.	Miscellaneous Equipment	1	6,000.	9,000.
3.	Stores Overhead		2,000.	2,000.
4.	Engineering		1,000.	1,000.
5.	Supervision/Testing		1,600.	1,700.
6.	Labor Installing		15,000.	16,000.
7.	Labor Overhead		9,000.	10,000.
		Total III (Per Loco.)	$66,600.	$71,700.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: STEADY DC
OVERLAY SYSTEM: INDUCTIVE LOOP CONTINUOUS (DB)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Loop Wire	580,800	$ 261,000.	$ 261,000.
2.	Hardware	1	13,000.	13,000.
3.	Factory Wired Interface Houses	5	400,000.	490,000.
4.	Miscellaneous Equipment	1	101,000.	115,000.
5.	Stores Overhead		47,000.	53,000.
6.	Engineering		21,000.	24,000.
7.	Supervision/Testing		32,000.	36,000.
8.	Labor Installing		302,000.	343,000.
9.	Labor Overhead		192,000.	218,000.
		Total II	$1,369,000.	$1,553,000.
		Per Track Mile	$ 27,000.	$ 31,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$ 55,000.	$ 55,000.
2.	Miscellaneous Equipment	1	5,000.	8,000.
3.	Stores Overhead		8,000.	20,000.
4.	Engineering		2,000.	2,000.
5.	Supervision/Testing		3,000.	3,000.
6.	Labor Installing		25,000.	25,000.
7.	Labor Overhead		16,000.	16,000.
		Total III (Per Loco.)	$114,000.	$129,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: CODED DC
OVERLAY SYSTEM: INDUCTIVE LOOP CONTINUOUS (DB)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Loop Wire	580,800	$ 261,000.	$ 261,000.
2.	Hardware	1	13,000.	13,000.
3.	Factory Wired Interface Houses	5	375,000.	465,000.
4.	Miscellaneous Equipment	1	97,000.	111,000.
5.	Stores Overhead		45,000.	51,000.
6.	Engineering		21,000.	23,000.
7.	Supervision/Testing		31,000.	35,000.
8.	Labor Installing		291,000.	332,000.
9.	Labor Overhead		185,000.	211,000.
		Total II	$1,319,000.	$1,502,000.
		Per Track Mile	$ 26,000.	$ 30,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$ 55,000.	$ 55,000.
2.	Miscellaneous Equipment	1	5,000.	8,000.
3.	Stores Overhead		8,000.	20,000.
4.	Engineering		2,000.	2,000.
5.	Supervision/Testing		3,000.	3,000.
6.	Labor Installing		25,000.	25,000.
7.	Labor Overhead		16,000.	16,000.
		Total III (Per Loco.)	$114,000.	$129.000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: STEADY AC
OVERLAY SYSTEM: INDUCTIVE LOOP CONTINUOUS (DB)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Loop Wire	580,800	$ 261,000.	$ 261,000.
2.	Hardware	1	13,000.	13,000.
3.	Factory Wired Interface Houses	5	390,000.	480,000.
4.	Miscellaneous Equipment	1	100,000.	113,000.
5.	Stores Overhead		46,000.	52,000.
6.	Engineering		21,000.	24,000.
7.	Supervision/Testing		32,000.	36,000.
8.	Labor Installing		299,000.	338,000.
9.	Labor Overhead		189,000.	215,000.
		Total II	$1,351,000.	$1,532,000.
		Per Track Mile	$ 27,000.	$ 31,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$ 55,000.	$ 55,000.
2.	Miscellaneous Equipment	1	5,000.	8,000.
3.	Stores Overhead		8,000.	20,000.
4.	Engineering		2,000.	2,000.
5.	Supervision/Testing		3,000.	3,000.
6.	Labor Installing		25,000.	25,000.
7.	Labor Overhead		16,000.	16,000.
		Total III (Per Loco.)	$114,000.	$128,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: CODED AC
OVERLAY SYSTEM: INDUCTIVE LOOP CONTINUOUS (DB)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Loop Wire	580,800	$ 261,000.	$ 261,000.
2.	Hardware	1	13,000.	13,000.
3.	Factory Wired Interface Houses	5	360,000.	440,000.
4.	Miscellaneous Equipment	1	95,000.	107,000.
5.	Stores Overhead		44,000.	49,000.
6.	Engineering		20,000.	23,000.
7.	Supervision/Testing		30,000.	34,000.
8.	Labor Installing		284,000.	320,000.
9.	Labor Overhead		181,000.	203,000.
		Total II	$1,288,000.	$1,450,000.
		Per Track Mile	$ 26,000.	$ 29,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$ 55,000.	$ 55,000.
2.	Miscellaneous Equipment	1	5,000.	8,000.
3.	Stores Overhead		8,000.	20,000.
4.	Engineering		2,000.	2,000.
5.	Supervision/Testing		3,000.	3,000.
6.	Labor Installing		25,000.	25,000.
7.	Labor Overhead		16,000.	16,000.
		Total III (Per Loco.)	$114,000.	$129,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: AUDIO
OVERLAY SYSTEM: INDUCTIVE LOOP CONTINUOUS (DB)
(BASED ON 50 MILE SEGMENT)

I. ROAD MILE SIGNAL COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Pole Line Hardware	1	$ 6,000.	$ 6,000.
2.	Messenger 336. MCM-AL	277,200 LF	83,000.	83,000.
3.	2C#6 - 3000V Cable	277,200 LF	554,000.	554,000.
4.	100 Hz Substation	2	50,000.	70,000.
5.	Miscellaneous Equipment	1	104,000.	107,000.
6.	Stores Overhead		48,000.	49,000.
7.	Engineering		22,000.	23,000.
8.	Supervision/Testing		33,000.	34,000.
9.	Labor Installing		311,000.	320,000.
10.	Labor Overhead		197,000.	203,000.
		Total I	$1,408,000.	$1,449,000.
		Per Road Mile	$ 28,000.	$ 30,000.

II. TRACK MILE WAYSIDE SIGNAL EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Loop Wire	580,800	$ 261,000.	$ 261,000.
2.	Hardware	1	13,000.	13,000.
3.	Factory Wired Interface Houses	5	425,000.	525,000.
4.	Miscellaneous Equipment	1	105,000.	120,000.
5.	Stores Overhead		48,000.	55,000.
6.	Engineering		22,000.	25,000.
7.	Supervision/Testing		33,000.	38,000.
8.	Labor Installing		314,000.	358,000.
9.	Labor Overhead		199,000.	277,000.
		Total II	$1,420,000.	$1,622,000.
		Per Track Mile	$ 28,000.	$ 32,000.

III. TRAIN-BORNE EQUIPMENT COST

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Train-Borne Equipment	1	$ 55,000.	$ 55,000.
2.	Miscellaneous Equipment	1	5,000.	8,000.
3.	Stores Overhead		8,000.	20,000.
4.	Engineering		2,000.	2,000.
5.	Supervision/Testing		3,000.	3,000.
6.	Labor Installing		25,000.	25,000.
7.	Labor Overhead		16,000.	16,000.
		Total III (Per Loco.)	$114,000.	$129,000.

CATEGORY "A"
CAPITAL COSTS
EXISTING SYSTEM: TT&TO
OVERLAY SYSTEM: INDUCTIVE LOOP CONTINUOUS
(BASED ON 50 MILE SEGMENT)

	ITEM	QUANT.	COST RANGE LOW	COST RANGE HIGH
1.	Line Poles	2,000	$ 260,000.	$ 260,000.
2.	Pole Line Hardware	1	12,000.	12,000.
3.	Messenger 336 MCM, Alum.	277,200 LF	68,000.	68,000.
4.	Communication Cable	277,200 LF	180,000	180,000.
5.	Lashing Wire	600,000 LF	30,000.	30,000.
6.	Axle Counters (Incl. Wayside Logic)	76	13,000.	13,000.
7.	Loop Wire	580,000 LF	261,000.	261,000.
8.	Mtg. Hardware	1	13,000.	13,000.
9.	Factory Wired Logic Houses	5	490,000.	490,000.
10.	Miscellaneous Equipment		166,000.	332,000.
11.	Stores Overhead/Taxes		89,000.	100,000.
12.	Engineering		39,000.	43,000.
13.	Supervision/Testing		58,000.	65,000.
14.	Labor Installing		549,000.	610,000.
15.	Labor Overhead		349,000.	388,000.
		Total I	$2,577,000.	$2,865,000.
		Cost Per Mile	$ 51,000.	$ 57,000.

CATEGORY "B"
CAPITAL COSTS
TRAIN-TO-CENTRAL INFORMATION
for
5-ASPECT 100 Hz (NEC) or DUAL CHANNEL CARRIER (FS) SYSTEMS
(BASED ON 50 MILE SEGMENT)

	ITEM	QUANT.	UNIT COST	TOTAL
1.	2-Pair Tel. Cable	277,200 ft.	0.28 LF	$ 77,616
2.	Messenger 336.4 MCM	277,200 ft.	0.30 LF	68,160
3.	Lashing Wire	277,200 ft.	0.05 LF	11,360
4.	Pole Line Hardware		LS	6,000
5.	Data Encoder	1	45,000	45,000
6.	CRT (Single Color)	1	5,000	5,000
7.	Computer & Peripherals	1	140,000	140,000
8.	Miscellaneous Material			52,970
9.	Stores Overhead/Taxes			24,375
10.	Engineering			11,200
11.	Supervision/Testing			16,800
12.	Labor Installing (Incl. Software)			258,400
13.	Labor Overhead			154,600
			Total	$871,481

Total Per Road Mile/$17,500

Above costs do not include any recurrent charges for leased commercial telephone circuits between railroad central offices and Amtrak national display center.

CATEGORY "B"
CAPITAL COSTS
TRAIN-TO-CENTRAL INFORMATION
for
INTERMITTENT OR INDUCTIVE LOOP CONTINUOUS LOOP SYSTEMS
(BASED ON 50 MILE SEGMENT)

I. WAYSIDE COSTS

	ITEM	QUANT.	UNIT COST	TOTAL
1.	Base Station	1	12,000	$ 12,000
2.	Computer & Peripherals	1	140,000	140,000
3.	CRT (Single Color)	1	5,000	5,000
4.	Miscellaneous Material			23,500
5.	Stores Overhead/Taxes			10,800
6.	Engineering			4,900
7.	Supervision/Testing			7,500
8.	Labor Installing (Incl. Software)			170,400
9.	Labor Overhead			98,700
			Total	$478,800

Total Per Road Mile/$9,500

II. PER LOCOMOTIVE COSTS

	ITEM	QUANT.	UNIT COST	TOTAL
1.	Locomotive Radio Modules	1	1,500	$ 1,500
2.	Miscellaneous Material		LS	225
3.	Stores Overhead/Taxes			105
4.	Engineering			50
5.	Supervision/Testing			75
6.	Labor Installing			675
7.	Labor Overhead			430
		Total Per Locomotive		$ 3,000

CATEGORY "C"
CAPITAL COSTS
CENTRAL TO TRAIN INFORMATION
for
5-ASPECT 100 Hz (NEC) or DUAL CHANNEL CARRIER (FS) SYSTEMS
(BASED ON 50 MILE SEGMENT)

I. WAYSIDE COSTS

	ITEM	QUANT.	UNIT COST	TOTAL
1.	Base Station (Add'l)	1	3,000	$ 3,000
2.	CRT (Full Color)	1	25,000	25,000
3.	Miscellaneous Material			4,200
4.	Stores Overhead/Taxes			1,900
5.	Engineering			900
6.	Supervision/Testing			1,400
7.	Labor Installing			62,500
8.	Labor Overhead			34,900
			Total	$133,800

Total Per Road Mile/$2,700

II. PER LOCOMOTIVE COSTS

	ITEM	QUANT.	UNIT COST	TOTAL
1.	Train-Borne Radio	1	1,500	$ 1,500
2.	Decoder	1	5,000	5,000
3.	Miscellaneous Material		LS	975
4.	Stores Overhead/Taxes			450
5.	Engineering			200
6.	Supervision/Testing			310
7.	Labor Installing			2,925
8.	Labor Overhead			1,850
		Total Per Locomotive		$ 13,000

CATEGORY "C"
CAPITAL COSTS
CENTRAL-TO-TRAIN INFORMATION
for
INTERMITTENT OR INDUCTIVE CONTINUOUS LOOP SYSTEMS
(BASED ON 50 MILE SEGMENT)

	ITEM	QUANT.	UNIT COST	TOTAL
1.	CRT (Full Color)	1	25,000	$ 25,000
2.	Miscellaneous Material		LS	3,750
3.	Stores Overhead/Taxes			1,725
4.	Engineering			800
5.	Supervision/Testing			1,125
6.	Labor Installing (Incl. Software)			61,200
7.	Labor Overhead			34,100
			Total	$127,700
		Total Per Road Mile		$ 2,600