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TRACK MEASUREMENT VEHICLE TX PROJECT SUMMARY

JULY 1981

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16. Abstract

This report summarizes the Federal Railroad Administration (FRA) project to design and fabricate an advanced self-propelled track geometry inspection vehicle (TX). The TX effort involves FRA contracts DOT-FR-9088 with the Budd Company for a Budd SPV-2000 diesel railcar, and DOT-FR-9112 wich ENSCO, Incorporated for a computer-based track geometry instrumentation system. The MITRE Corporation under Contract DOT-FR-54090 has provided a wide range of technical support starting in 1976 with assistance in preparing the requirements analysis, the statement of work and the specification through technical monitoring of the final systems tests and review of deliverables. Major features of the TX include a totally self-contained system, substantially improved reliability, improved measurement accuracy, expanded utilization of digital processing and increased system productivity. The first of the TX series of vehicles, the T-10, is capable of measuring track gage, curvature, cross-level, warp, profile, and alignment at one-foot intervals at speeds up to 80 miles per hour The project was completed on schedule and within three percent of the estimated budget.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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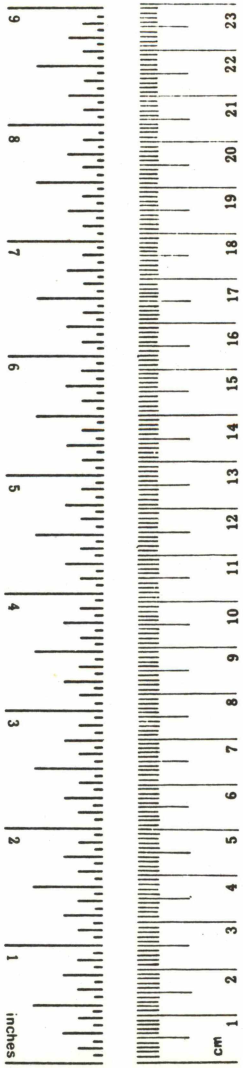
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	

MASS (weight)

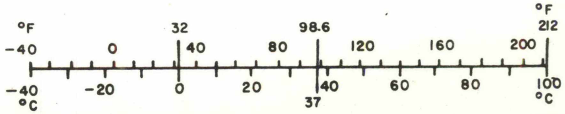
Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FOREWORD

This report describes the Track Measurement Vehicle - TX Program efforts performed over the period from July 1979 to April 1981 for the Office of Research and Development, Federal Railroad Administration (FRA.) This project consisted of the purchase and modification of a Budd SPV-2000 self-propelled diesel rail vehicle and the fabrication, installation and testing of track inspection instrumentation for that vehicle. (Contracts DOT-FR-9088 and DOT-FR-9112.)

The TX vehicle will be a significant addition to the Federal Railroad Administration's Track Safety Program because of the following technological advancements:

- Totally self-contained and self-propelled
- Improved track inspection vehicle reliability
- Improved instrumentation
- Increased utilization of digital processing
- Redundant computer capabilities
- The potential for reduced crew size and operating expense

These benefits could lead to a substantial increase in the number of miles of automated track safety inspection that can be performed at a fixed inspection budget level.

The TX effort was finished on schedule and at an unaudited cost of only three percent over budget. Precontract planning and contract management efforts played an important role in this accomplishment by the implementation of:

a. thorough pre-proposal investigation of track inspection vehicle requirements and specifications,

b. thorough statement of work and specification preparation and review,

c. preliminary and critical design reviews at the subsystem level,

d. structured programming software development procedures,

e. detailed quality control procedures and tests, and

f. milestone/cost-control monitoring procedures.

Because of the importance of increased operating efficiency projected for the (TX) vehicle, the report also includes an analysis of fuel savings that could be achieved over the existing track inspection vehicle fleet.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

Improved railroad safety standards enforcement, including the use of automated track inspection vehicles, was initiated by the FRA in an attempt to offset the increase in track related railroad accidents that occurred through the mid-1970's (Figure 1.1). Deferred track and roadbed maintenance during the 1950 to 1970 time period--when rail and tie replacement levels dropped to a point below that necessary to maintain a minimum replacement life cycle--appears to be one of the main reasons for the increase (Figure 1.2). Compounding the maintenance problem was the more than 30 percent increase in the average loaded axle weight of freight cars that were operated during the same time period, causing accelerated track and roadbed degradation.(1) This is further corroborated by comparisons between bankrupt versus non-bankrupt railroads which show a significant difference in track related accidents from 1966 to 1974, with bankrupt railroads experiencing twice as many accidents per million gross ton miles.(2)

Automated track geometry measurement/inspection vehicles have been developed both by the FRA and the railroad industry and are now an important part of the railroad safety/maintenance effort. The FRA inspects approximately 75,000 miles of railroad track annually with automated track geometry inspection vehicles.(3)

The first FRA track geometry measurement cars, the T1/T3 and T2/T4 were designed as research and development tools. (T3 and T2 are now the instrumented track geometry cars; T1 and T4 are support vehicles.) The cars originally used capacitive sensors for much track geometry measurement. These have since been replaced by displacement and inertial sensors for profile and alignment and magnetic for gage. In 1977, T6 was added to the fleet. Both instrumentation and support are included in the one vehicle. T6, in addition to having displacement, inertial and magnetic sensors had much improved signal processing. This digital processing effectively eliminated phase distortion inherent in previously used analog processing. All the vehicles mentioned are towed. Because it is operationally necessary, they operate as special trains usually pulled by a locomotive of the host railroad.

Field experience with these vehicles has provided the FRA with detailed information on the most desirable characteristics of high speed track geometry inspection railcars. This information formed the basis of the specification for a highly-reliable, accurate and cost-effective track inspection railcar with the following features:

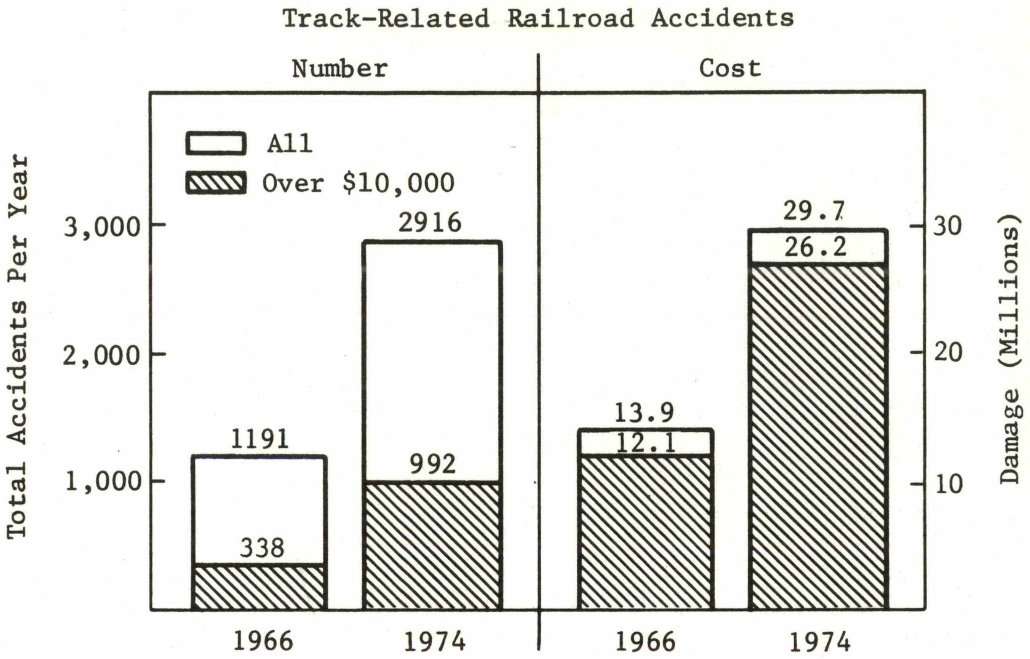


FIGURE 1.1. REPORTABLE RAILROAD ACCIDENTS (TRACK)(1)

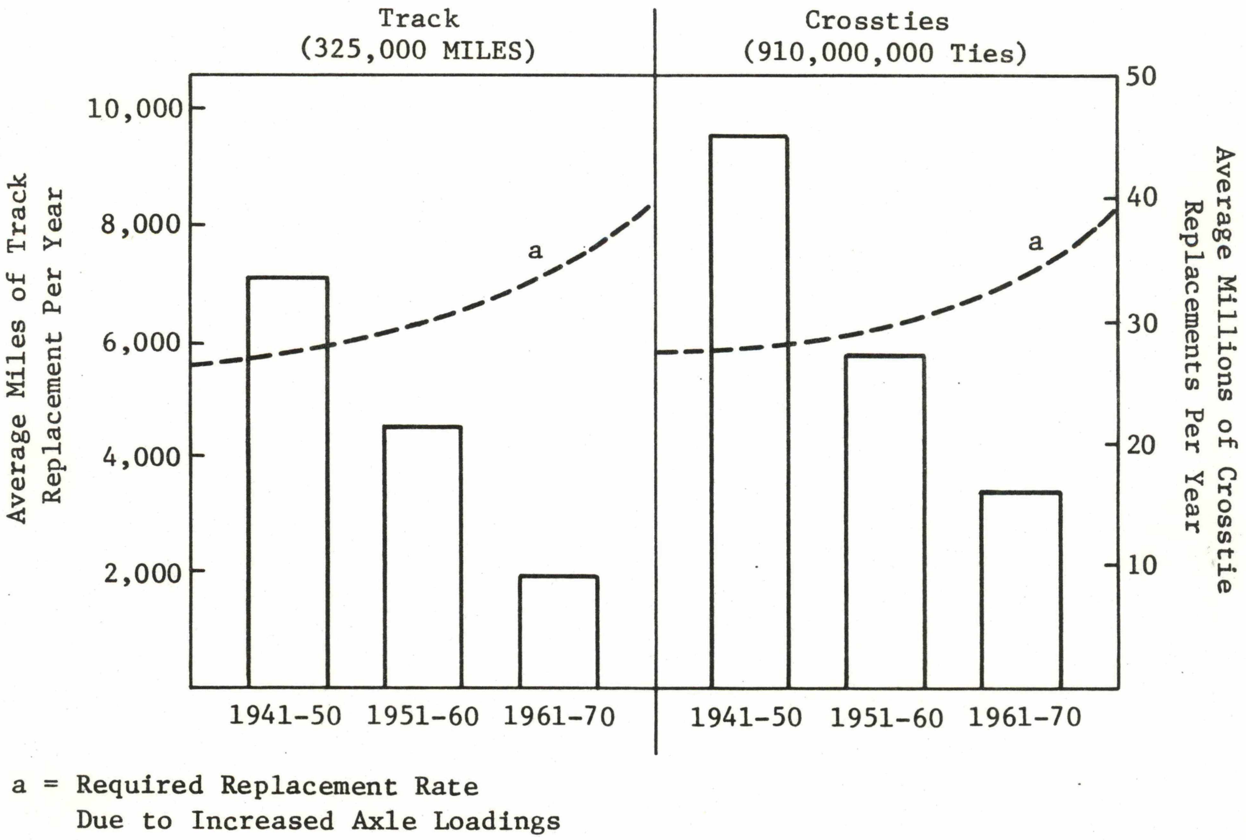


FIGURE 1.2. AVERAGE TRACK AND TIE REPLACEMENT AND REQUIRED REPLACEMENT RATE AS A FUNCTION OF TIME

- Self-propelled capability
- Improved instrumentation and processing
- Reduced crew size
- Modular electronics
- Redundant computer systems
- Reduced fuel requirements
- Improved productivity
- Reduced operating expenses

The first step of the pre-contract TX development effort was to perform a systems analysis study examining the most cost-effective mix of manual and automated track inspection.(4) The resulting recommendation suggested a moderate expansion of the manual track inspection force plus upgrading the existing track inspection fleet with up to three highly-reliable self-propelled heavy (railcars) and five light (hi-railer) track-geometry/rail flaw detection vehicles. This would permit the monitoring of railroad inspection efforts mandated under the Railroad Safety Act of 1970 at less cost than existing practices.

After completion of the systems analysis study, the next step of the TX development effort was to prepare a detailed statement of work and a system specification for competitive bid.(6) Two bids were received and evaluated. Both bidders proposed to use a Budd SPV-2000 self-propelled railcar for the TX vehicle. As the proposal evaluation effort approached completion, it became apparent that the initial production run of 20 SPV-2000 vehicles would be sold by the Budd Company prior to award of the TX contract. The FRA therefore purchased the last uncommitted SPV-2000 so it could be provided as government furnished equipment to the winning contractor. A fixed price contract for the SPV-2000 was awarded on 16 April 1979. The vehicle was accepted four weeks ahead of schedule by the FRA on 3 March 1980 (Figure 1.3.)

A cost plus incentive fee contract to build and install track geometry instrumentation on the SPV-2000 was awarded to ENSCO, Incorporated on 2 August 1979*, with an initial contract period of 18 months. During the period (1 July 1979 to 31 March 1981) fourteen formal engineering change proposals (ECPs) to provide for additional TX capabilities were approved by the FRA, resulting in a revised contract period of 20 months.

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*Preliminary contractual agreements were initiated in early July.

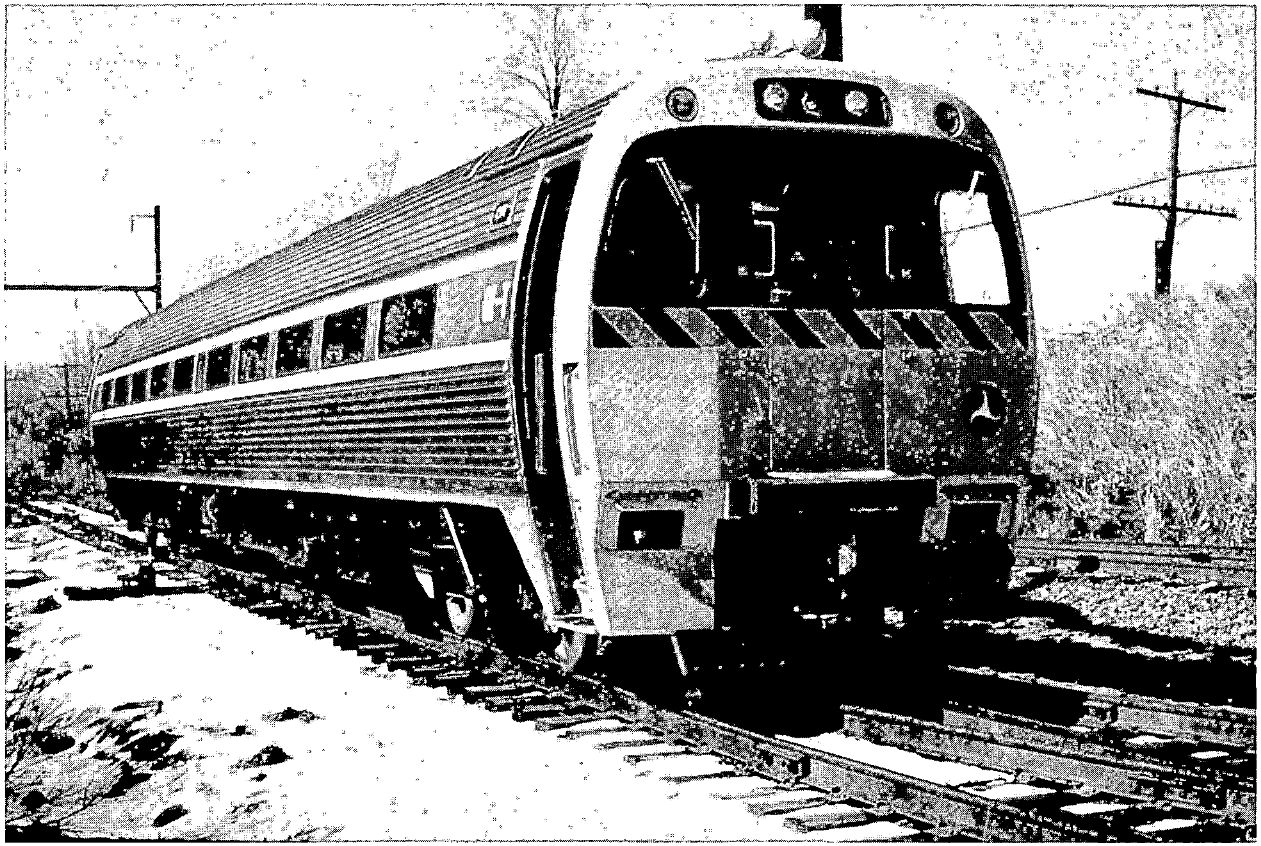


FIGURE 1.3. T-10 (TX) VEHICLE

Section 2 of this report describes accomplishments of the SPV-2000 TX effort. Section 3 highlights specific improvements expected to produce increased track inspection productivity/cost-effectiveness. A tabulation of major features of the TX track geometry inspection vehicle is contained in Appendix A. When the first TX vehicle goes into service as an inspection vehicle in the Spring of 1981, it will be designated T-10.

2. ACCOMPLISHMENTS

This section describes the technical and managerial accomplishments of the TX effort.

2.1 Technical

Although a substantial number of important track geometry measurement system advancements have been achieved by the FRA over the past decade, the TX effort presented the first opportunity to design and build a track inspection system to meet specific operational needs. The resulting technical accomplishments that occurred during the TX effort are described in the following order: vehicle subsystem; instrumentation subsystem; and data processing and display subsystem.

2.1.1 Vehicle Subsystem

Figure 2.1 shows the Vehicle Subsystem Milestone schedule. A production model SPV-2000 (serial #2007) was accepted from the Rail Products Division of the Budd Company by the FRA on 3 March 1980. The SPV-2000 was then turned over to ENSCO, Incorporated for structural modifications via subcontract with the Technical Center of the Budd Company. This subcontract was completed on schedule. The SPV-2000 was then moved to ENSCO, Incorporated for trim and equipment modifications, installation of the track geometry instrumentation and data processing subsystem, as well as other equipment required by the Statement of Work.

The SPV-2000 is a self-propelled (diesel/mechanical) passenger car. There have been 45 built to date. They are very efficient for their size and power and should average two to four miles per gallon of diesel fuel.(7) A tabulation of major dimensions and features of the SPV-2000 are contained in Appendix A.

The Budd Company Technical Center modified the vehicle as follows:

a. removed rear vestibule wall and exit steps to provide an open viewing area,

b. increased window space for better track inspector visibility,

c. provided interior electric power and cable conduits,

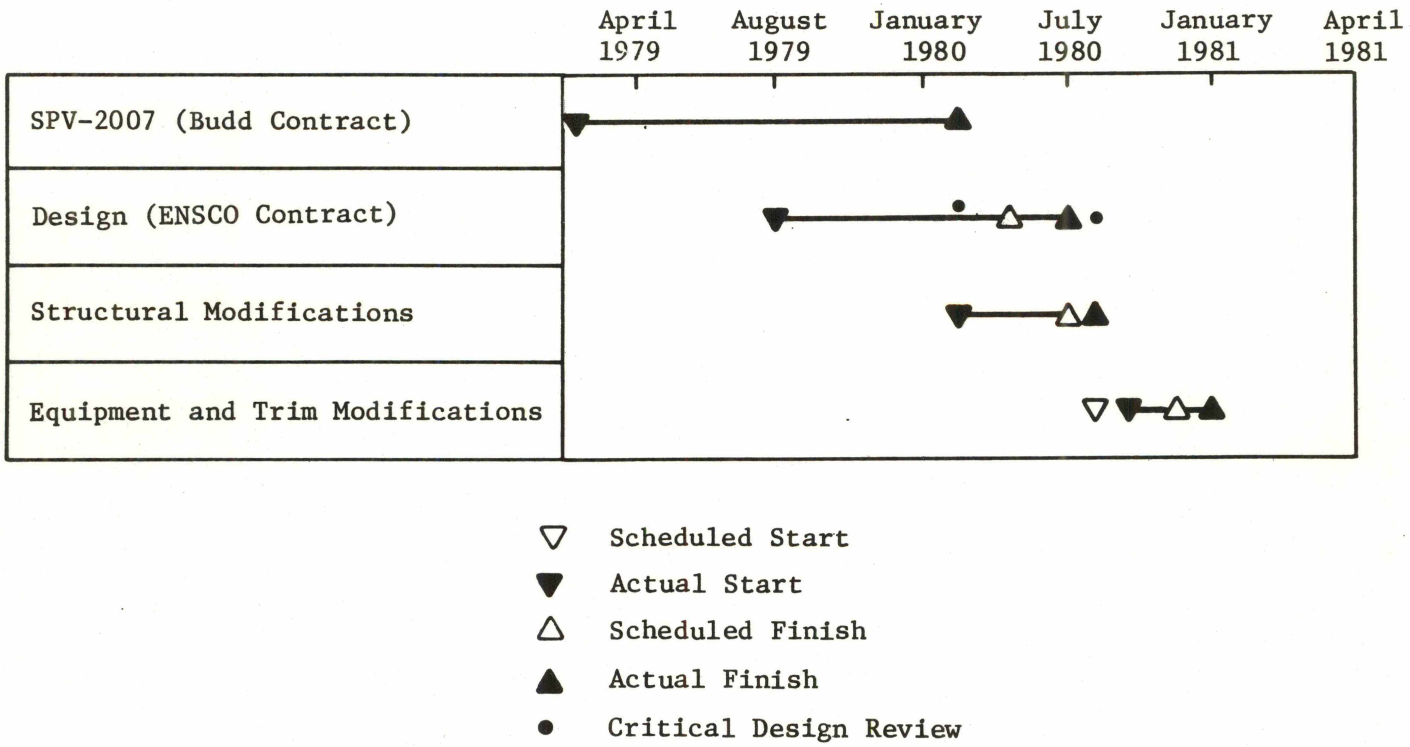


FIGURE 2.1. VEHICLE SUBSYSTEM MILESTONES

d. augmented exterior lighting, and

e. upgraded the capacity of the auxiliary power unit from 50 kW to 75 kW.

A finite element structural analysis was performed by the Budd Company prior to the modifications to assure that the structural integrity of the vehicle would not be impaired.

ENSCO, Incorporated performed the trim and equipment modifications. The SPV-2000 delivered by the Budd Company contained no interior panels, seats, restrooms or carpeting. When finished, the vehicle included a:

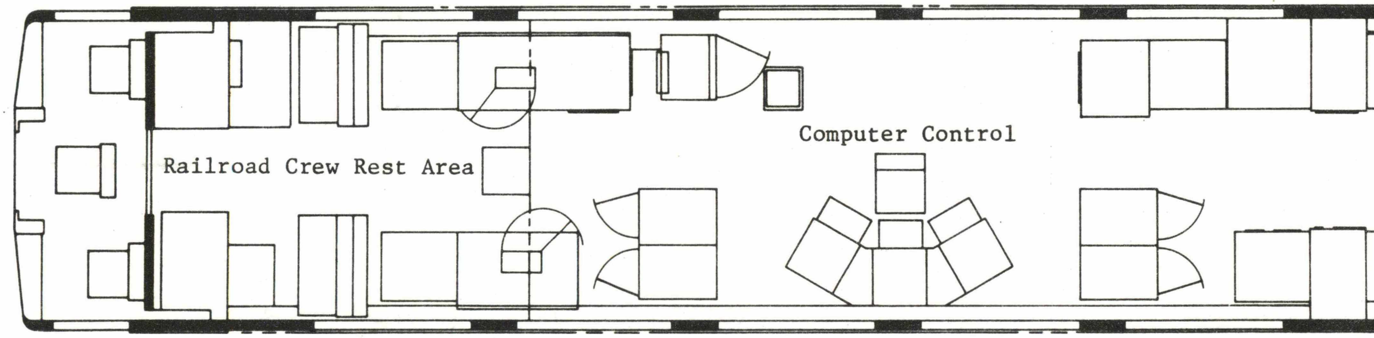
- Viewing area in the rear for observing the track,
- Kitchen with table,
- Office,
- Sleeping compartment/closet,
- Shop with tools,
- Control/computer center,
- Railroad crew rest area,
- Driving compartment,
- Storage throughout for at least 10 days of operations, and
- Lavatory with sink and biodegrading (Microphor) toilet.

A floor plan is shown in Figure 2.2 and a view of the rear vestibule observation area is shown in Figure 2.3.

2.1.2 Instrumentation Subsystem

The Instrumentation Subsystem Milestones are shown in Figure 2.4. The instrumentation subsystem final design was approved in May 1980. Design philosophy emphasized reliability and ease of operation and maintenance. The instrumentation subsystem block diagram is shown in Figure 2.5. Key instrumentation specifications are given in Appendix B. The purpose of the instrumentation subsystem is to gather and format the necessary input data to permit the generation of the following measurements by the data processing system:

- Gage
- Curvature
- Cross-level
- Profile (left and right rail)
- Alignment (left and right rail)


Railroad Crew Rest Area
Computer Control

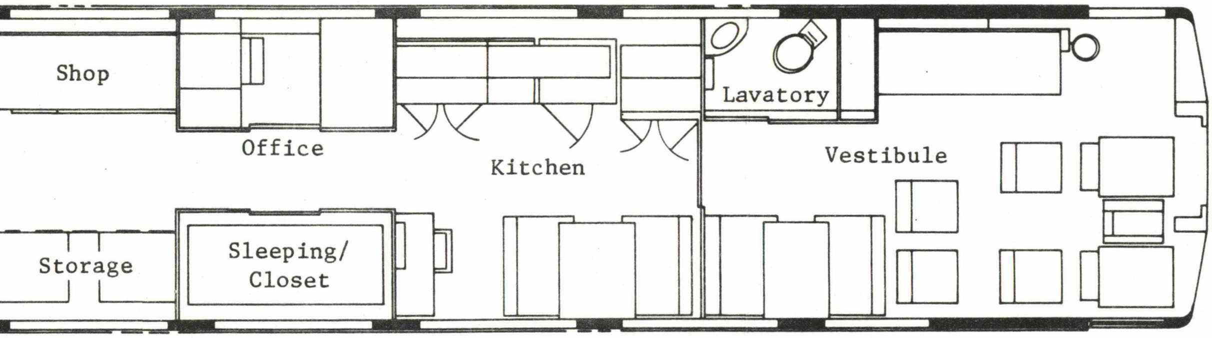


FIGURE 2.2. FLOOR PLAN

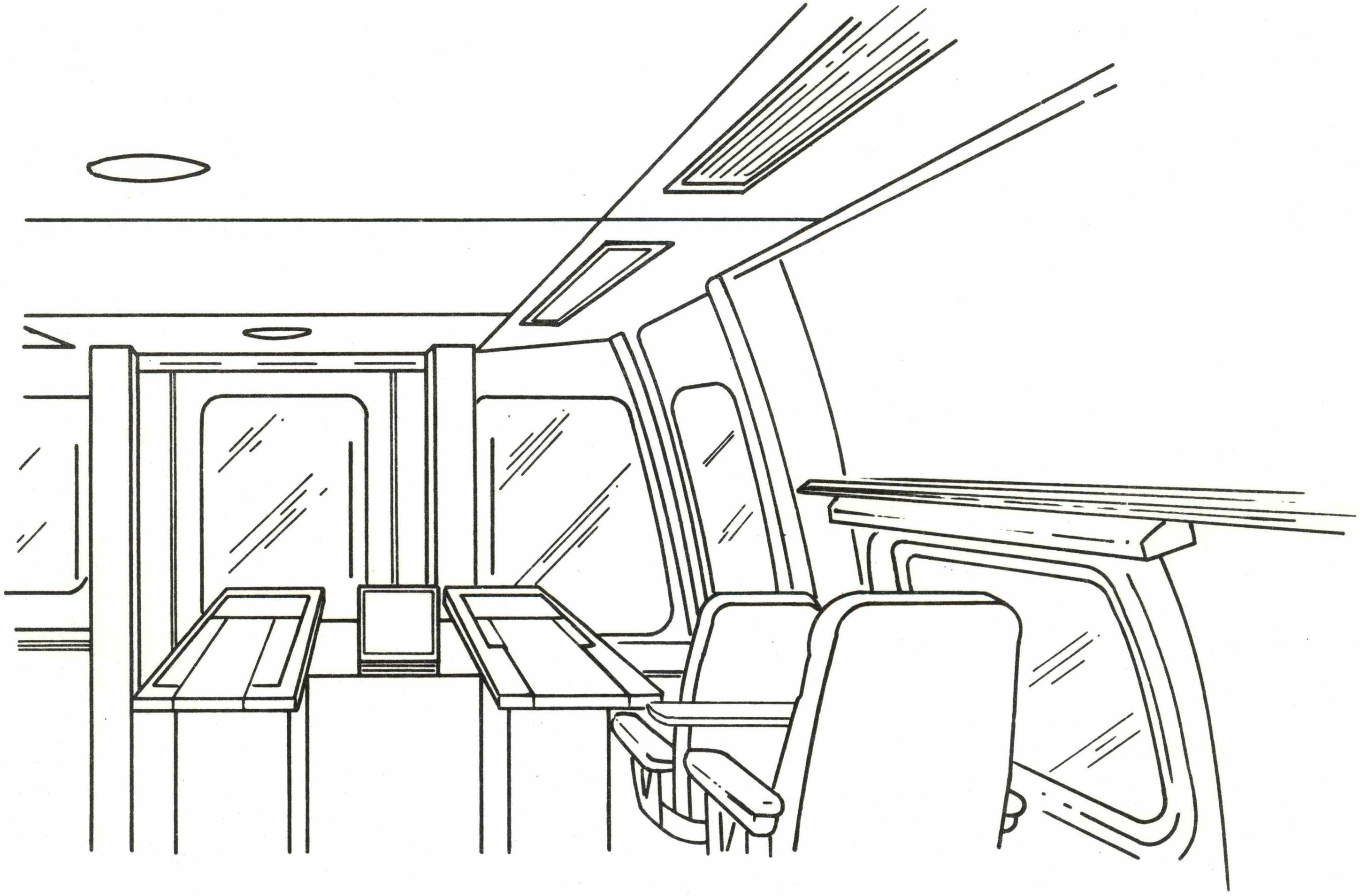


FIGURE 2.3. REAR OBSERVATION AREA

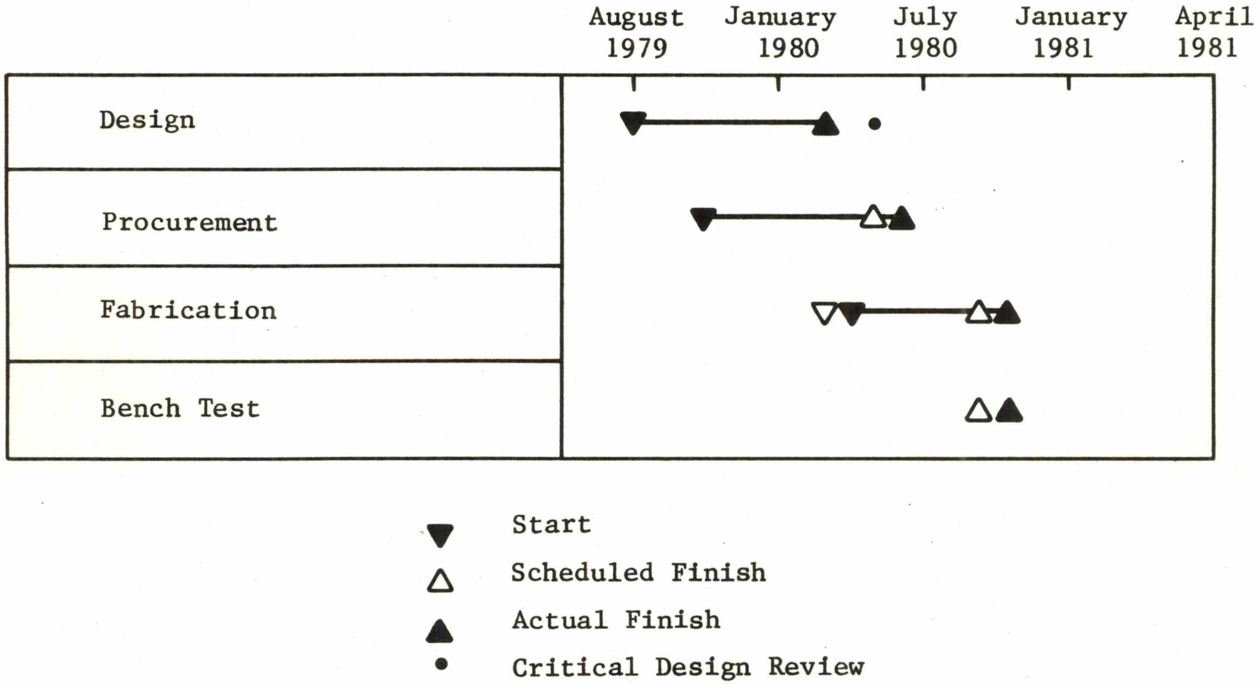


FIGURE 2.4. INSTRUMENTATION MILESTONES

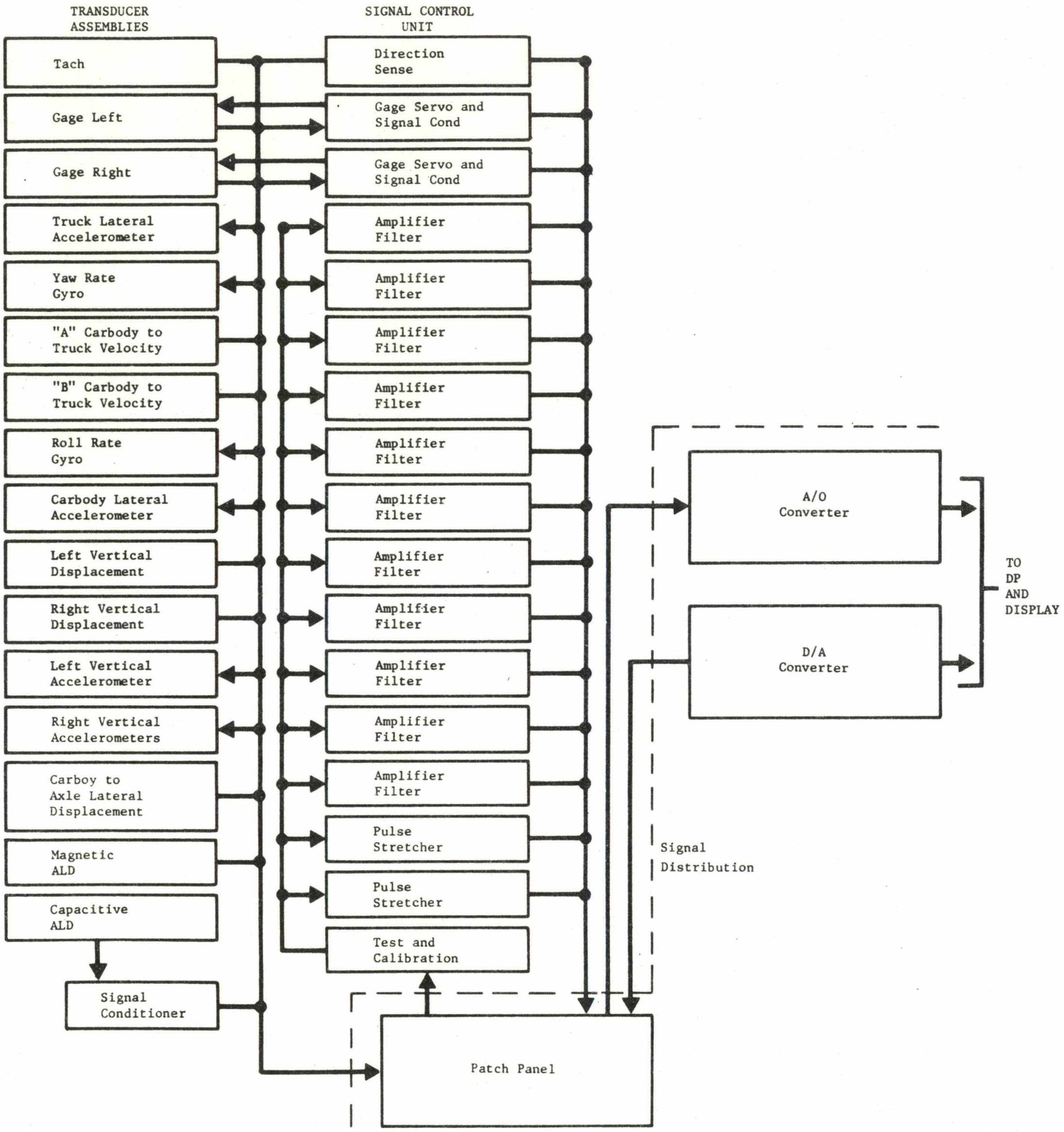


FIGURE 2.5. INSTRUMENTATION SUBSYSTEM BLOCK DIAGRAM

- Automatic location detection
- Speed and distance

Three separate types of assemblies were provided under the instrumentation subsystem effort. They included transducer assemblies, a signal conditioning unit and a signal distribution assembly. The transducer assemblies consist of acceleration, velocity and displacement sensors mounted to the carbody and the lead truck of the vehicle (Figure 2.6.) Truck mounted sensors include two servomagnetic* gage sensors, a lateral accelerometer, magnetic and capacitive proximity sensors, truck/carbody displacement transducers and a speed and distance tachometer. Carbody mounted profilometer accelerometers are being utilized for the first time on the TX vehicle as a means of achieving substantially improved sensor reliability. The signal conditioning unit consists of an array of filters/amplifiers that are used to filter and amplify displacement, velocity and acceleration data to a degree necessary for proper processing by the computer. Filter interchangeability is accomplished through a multi-port filter/amplifier design. TX data processing utilizes complementary analog and digital filtering to produce low phase distortion signals essential for forward/reverse track geometry measurement repeatability.

The signal distribution assembly consists of a patch panel, an analog to digital (A/D) converter for input signals and a digital to analog (D/A) converter for output signals. Although time-based digitization was initially proposed for the TX, distance-based digitization (one sample per foot) was selected to minimize data throughput requirements.

A hybrid track geometry data processing concept (previously used in less complex railroad inspection car applications) was agreed upon for the TX vehicle. It consists of a mix of distance-based and time-based data processing features. This hybrid approach provides many of the desirable data processing capabilities of a time-based system while still taking advantage of the relatively low throughput data rates common to distance-based systems. The impact of such an approach was to minimize the need for custom made analog devices, maximize commonality among the remaining analog devices and permit digital computer processing of all track geometry parameters.

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*Magnetic proximity sensor positioned via servomotor.

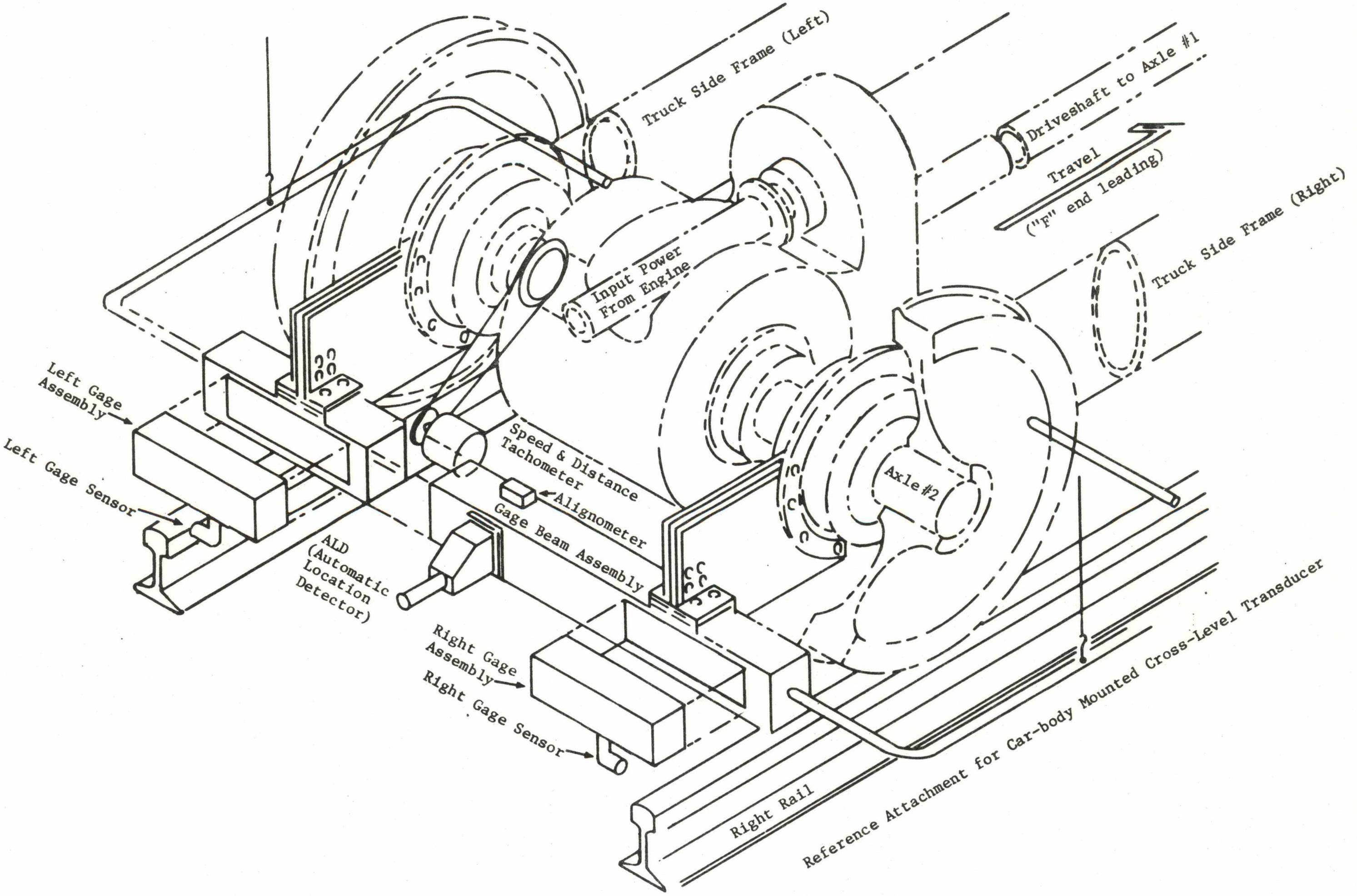

FIGURE 2.6. GAGE BEAM MOUNTING CONFIGURATION

2.1.3 Data Processing and Display Subsystem

Figure 2.7 shows the Data Processing and Display Subsystem milestones. The purpose of the Data Processing and Display (DP&D) Subsystem is to provide track inspectors with a strip-chart record of track geometry conditions and a line printer output summary of all potential exceptions to the Federal Track Safety Standards.(3) The DP&D subsystem accepts digitized analog data from the instrumentation subsystem signal distribution assembly as well as control/information inputs from the system operator and/or forward observer. The design philosophy of the DP&D subsystem was identical to that of the instrumentation system, i.e., high reliability, ease of operation and ease of maintenance. The DP&D equipment block diagram is shown in Figure 2.8. The primary feature of this design is the operational availability of a redundant computer.

The DP&D subsystem consists of two Hewlett-Packard (HP)-1000F series mini-computers each with its own floating point processor disk drive and terminal plus peripherals which can be made available to either computer including A/D, D/A, instrumentation control, timing control, forward observer control console (FOCC) line printer, three strip chart recorders, and two magnetic tape drives. A tabulation of key computer specifications is given in Appendix B.

To operate the track geometry software, one or the other computer must be linked to the peripherals via the I/O Extender. The computer that is not linked can operate independently on other software provided it does not require more than a disk and a terminal.

The HP-1000F mini-computer system is designed for highly reliable* real-time applications that require fast processing speed and extended arithmetic precision. An operator's control panel is standard with each HP-1000F (front panel of HP-2117F CPU.) The control panel allows operators or maintenance personnel to load the system; start and stop execution; execute CPU self-diagnostics; display and modify all registers and memory; and single-step program executions.

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*HP claims a MTBF for the 2117F CPU of 2,896 hours.

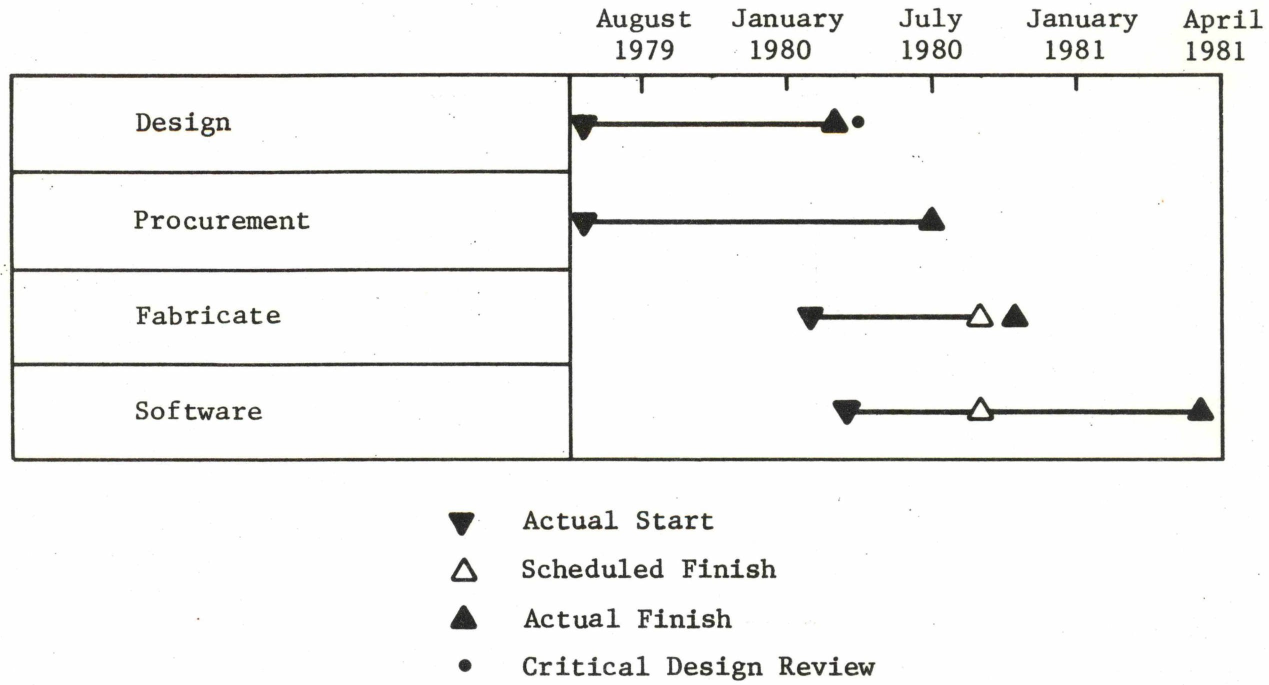
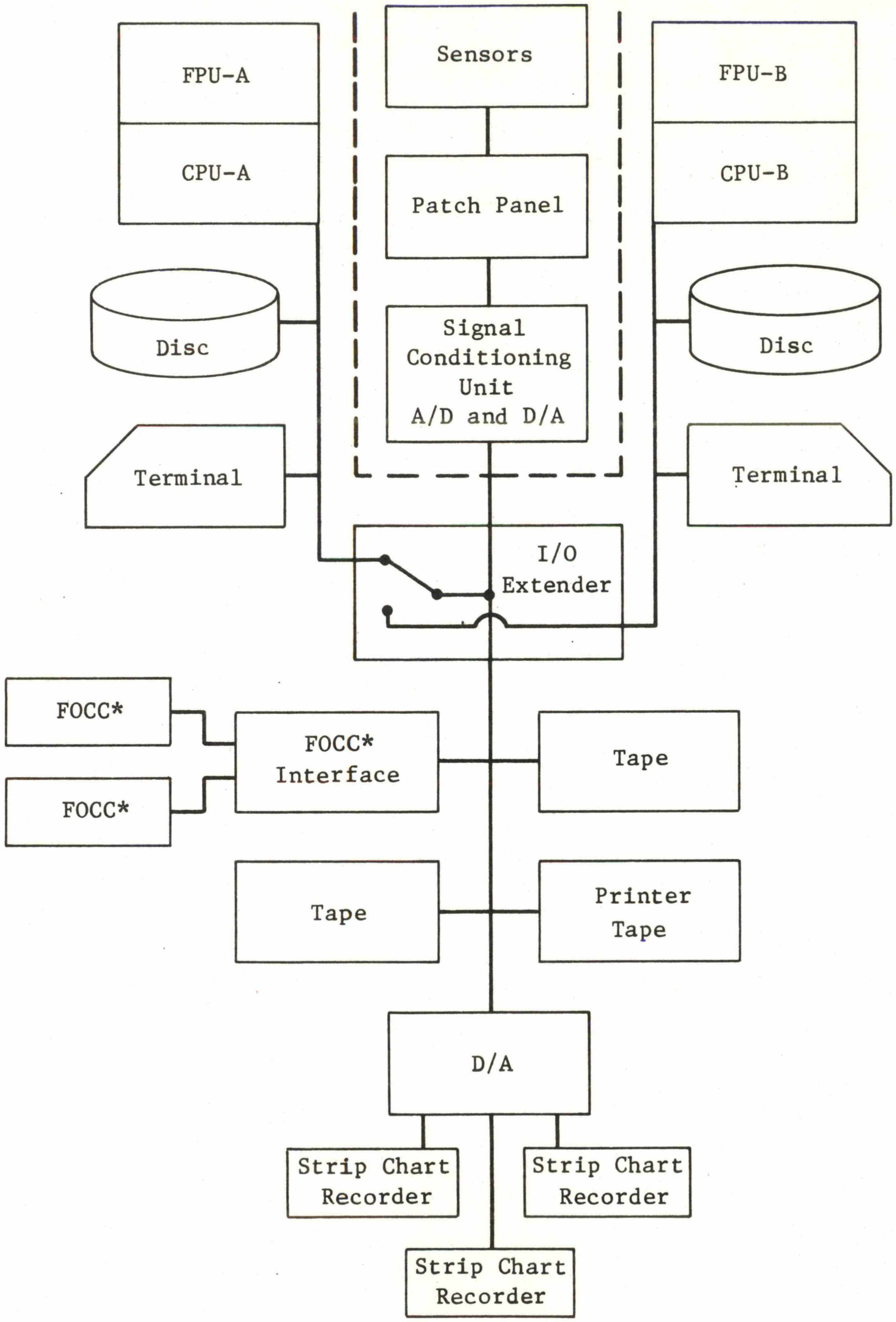


FIGURE 2.7. DATA PROCESSING AND DISPLAY SUBSYSTEM MILESTONES



*Forward Observer's Control Console

FIGURE 2.8. DATA PROCESSING AND DISPLAY BLOCK DESIGN

The line printer prints out exceptions to the FRA track safety standards and other operational messages (e.g. locations, sensor status.) The printer was designed for reliable operation and is controlled by a micro-processor with internal diagnostics for self-test. Two tape units are used for magnetic recording of track survey data. The tape drives are IBM/ANSI compatible. Tape consumption will be a function of many factors; however, normal operation should require no more than one magnetic tape per 185 miles of survey.

Analog traces of the track geometry are produced on three stripchart recorders. Movement of the paper is controlled by a distance driven stepper motor. Although operation of the DP&D subsystem will be performed asynchronously (to permit a block of one-foot track geometry measurements to be processed together,) output of the stripchart recorders will be presented in a smooth and continuous manner.

System control is provided for at redundant send/receive terminals. Certain limited control (i.e. raising or lowering sensors manually entering milepost and other location information and enabling the automatic location detectors) is provided for by remote forward observer control consoles (FOCC.) The terminals have a standard alphanumeric keyboard, eight additional special function keys, and a video display. Operator messages and entries are displayed on the left half of the screen while system status and numerical displays are displayed on the right half of the screen. The FOCC are small hand-held devices with a numeric keyboard, special function keys and a LED display.

Data processing is performed using Hewlett Packard's RTE-IV operating system and a set of ENSCO-developed track geometry processing software modules. Considerable effort was spent in the development of standardized procedures for the generation of these modules as a means of reducing risk, cost, rework and future software maintenance problems. Key steps in this "structured programming" development process were:

- Functional Descriptions
    - Inputs
    - Outputs
    - Processing Flow

- Functional Specifications
    - Algorithms
    - Data Structures
    - Control Blocks
    - Data Transfers

- Module Sizing
    - Memory Requirements
    - Operating Timing

The TX software consists of 34,000 lines of code with 12,000 lines written in assembly language and 22,000 lines in Fortran IV. A data flow map for the TX track geometry processing is shown in Figure 2.9.

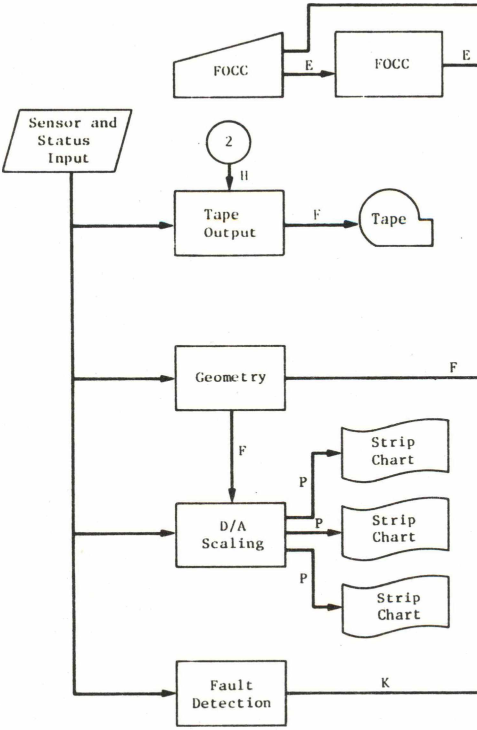
2.2 Management

In accordance with the statement of work, ENSCO, Incorporated was required to provide a number of project management deliverables in addition to building and installing the TX track geometry measurement equipment. It is appropriate therefore that a discussion of TX accomplishments also include a summary of the following deliverables:

- Project Management Plan
- Configuration Management Plan
- Software Description Plan
- Quality Assurance Plan

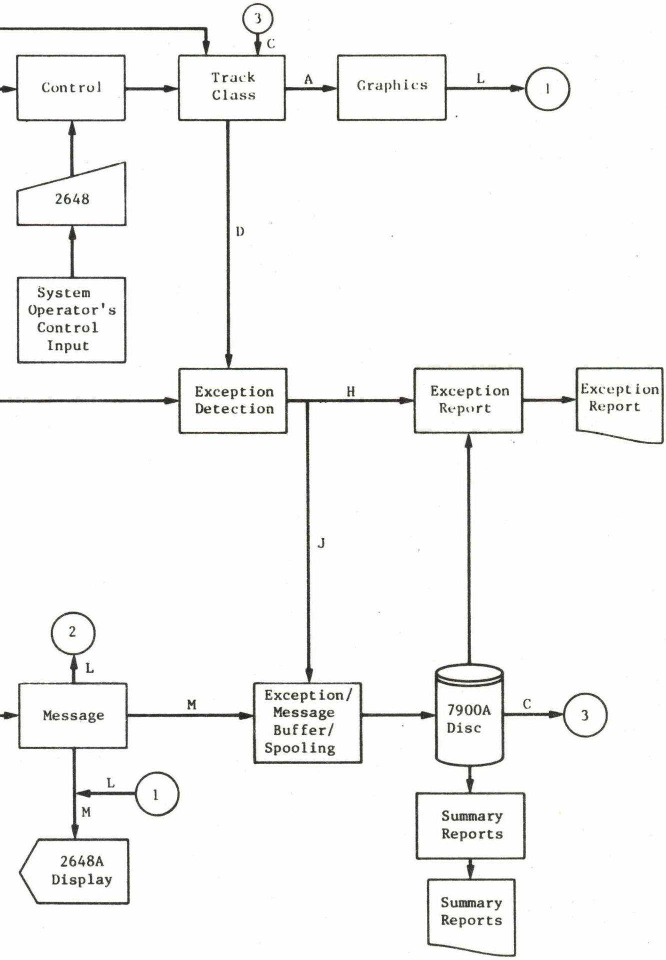
The Project Management Plan consisted primarily of a project schedule that identified the timing for major milestones, design reviews, target dates and the interrelationship of subsystem development phases. An important feature of the Project Management Plan was the use of preliminary and critical design reviews. The preliminary review consisted of a presentation of design plans and concepts in sufficient detail to permit government review and approval prior to contractor initiation of final designs and drawings.

Such an approach provided an organized structure for early government/contractor communications on individual work elements thereby minimizing the time and cost associated with potential misinterpretations of the statement of work; providing a mechanism for early resolution of alternative approaches; and providing well documented guidelines for those persons responsible for the development of the final plans and working drawings.



A - Speed, Milepost, Odometer, Etc.
B - Track Class
C - Milepost Table
D - Raw Input
E - Forward Observer Commands
F - Computed Geometry Parameters
H - Exception Blocks
J - Buffering
K - Fault Messages
L - Graphic Output
M - Status Messages
N - All CRT Output
P - Display Parameters

FIGURE 2.9.



DATA FLOW MAP

Following the critical design review and government approval of the final design package--including functional descriptions and illustrations that could be used later to meet TX documentation requirements--no further changes could be made to the design without contractor submission and FRA approval of an Engineering Change Proposal (ECP.)

The Configuration Management Plan involved the use of a formal procedure to standardize subsystem development efforts and to assure total coordination of all contractor and/or government initiated ECPs. Such procedures helped all parties understand what was approved for development.

The Software Description Plan consisted of a comprehensive 350 page functional description that addressed both TX data processing hardware and software configurations.

The Quality Assurance Plan (QA) consisted of traditional controls for inventory and assembly plus the development of a QA Requirements Index where every requirement of the TX specification was made to correspond to a specific QA plan, procedure, activity and/or report. All QA plans and procedures generated by the contractor required government approval prior to implementation.

These management techniques significantly changed the way previous R&D and prototype FRA track geometry inspection vehicles were developed. The major advantage was earlier documentation and closer contractor/government communications. The payoff has been more credible cost projections and more dependable estimates of time to complete each major task of the program.

3. PRODUCTIVITY IMPROVEMENTS

Technical improvements in the Track Measurement Vehicle - TX project fall into four areas; instrumentation, computer, software and vehicle subsystems. Improvements in these areas provide the basis for increased productivity and reduced operating costs.

The basic philosophy of the TX project was to develop an operations-oriented track inspection vehicle capable of meeting the needs of the FRA Office of Safety during the next decade. Experience with existing FRA R&D-oriented track inspection vehicles provided an important input to the design of the TX track inspection vehicle. Improved measurement accuracy and repeatability, improved reliability, simplified operation, ease of maintenance, elimination of special purpose analog electronics and freedom from the restrictions of towed operation were all desired improvements based on operational experience.

3.1 Instrumentation

Instrumentation system improvements were primarily related to increased accuracy, repeatability, accessibility, maintainability and reliability. Highlights include:

a. redesign of the servo-magnetic gage measurement system for ease of maintenance (selected over an originally proposed optical gage system,)

b. elimination of velocity transducers,

c. improved profilometer reliability through carbody accelerometer mounting,

d. improved accuracy and repeatability through the use of low noise accelerometers both for the profilometer and alignometer sensors, and

e. utilization of interchangeable circuit board-mounted filters/amplifiers.

The net gain of these improvements is increased system accuracy and stability; improved protection for sensitive and expensive track geometry measurement sensor components (including the alignometer which will be protected with additional foam isolation material;) simplified operations and maintenace personnel training; lower spare part inventories; and improved hardware accessibility for calibration and maintenance.

3.2 Computer

Computer system improvements were made in such traditional areas as: increased memory speed, expanded processing capabilities, and the use of micro-processors; as well increased system reliability, and maintainability (e.g. most computer components are built by a single manufacturer.) Even though all of these improvements are important, the most significant advancement over existing track geometry measurement systems was improved operational capabilities though redundancy. On-line availability of a second computer system will substantially help to minimize operational uncertainties associated with single computer system operations.

Track inspection vehicle down-time costs of $500 to 600 per hour plus a strong desire by the FRA to meet pre-arranged inspection schedules provides the motivation for high levels of computer system availability. Additional improvements that are included as an integral part of the HP-1000F computer system are circuit board level maintenance; computer chassis mounting of all peripheral controllers and associated interface circuit boards; self-checking fault detection systems; and system-wide diagnostics.

3.3 Software

TX software improvements include the replacement of external instrumentation and signal conditioning functions allowing the elimination of hardware used for those functions in present FRA track inspection vehicles. Specifically, the compensated accelerometer subsystem and portions of the data input signal conditioning and filtering subsystem were eliminated through software techniques. Additional software improvements were made including:

- Structured programming type design,
- Standardized coding rules and formats,
- Modular design for ease of maintenance,
- Use of HPs standard operating system, and
- Improved system operator controls.

3.4 Measurement Accuracy and Repeatability

Although operational experience is necessary to prove the total value of the technical improvements, performance improvements in the crucial area of measurement accuracy and repeatability were documented during field tests.

Accuracy and repeatability specified for TX were derived using detection theory. The assumption was made that the number of false exceptions should be negligibly small in order to instill maximum confidence in the system. TX measurement accuracy and repeatability specifications were significantly more stringent than those required for existing FRA track inspection railcars (T2 and T6), which were based on what was achievable within the state of the art at the time they were built.

TX track geometry measurement accuracy cannot be measured absolutely in the field as there is no practical standard with which to compare its measurements. The TX system was, however, tested in the laboratory for absolute accuracy and met or exceeded all specification requirements.

The best test that can be made in the field to indicate relative measurement accuracy is to measure the same piece of track many times at different speeds in both directions. The differences between any two runs are then compared for repeatability by computing the mean (m) and standard deviation (σ) using each measurement of each run.

Table 3-1 compares the TX specification for repeatability versus results obtained on T2, T6 and TX. The numbers shown are average values for an entire test. The results show that the TX is better than T2* in all measurements and is as good or better than T6** in all measurements except gage. Of particular note is the dramatic improvement in profile measurement. This is attributable to the use of low hysterisis, low g accelerometers mounted on the carbody.

3.5 Vehicle

Vehicle improvements cover a broad area of subjects since the characteristics of the existing FRA track inspection vehicles are quite different from the SPV-2000. The most important difference is that the SPV-2000 will be self-propelled. An additional difference is that the entire track inspection system and the associated compliment of support equipment fit on one car.

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* T2 and T6 have been modified several times, thus the comparison is only valid for the state they were in on the day of test (i.e. 23 August 1976 and 4 April 1977 respectively.)

**However, it is two and a half times better than the specification.

TABLE 3-1 - REPEATABILITY TEST COMPARISONS - CLASS 4 TRACK

		T2 23 Aug 76	T6 4 Apr 77	T-10 24 Feb 81	TX SPECIFICATION
Gage	m	.00	.00	.00	.03
	σ	.07	.00	.02	.05
Profile	m	.00	.00	.00	.03
	σ	.14	.21	.03	.05
Alignment	m	(1)	.04	.00	.03
	σ		.1 (2)	.09 (3)	.1
Crosslevel	m	.03 (4)	.03	.01	.03 (5)
	σ	.05	.03	.03	.05
Curvature	m	.02	.03	.03	.15
	σ	.1	.07	.01	.25

Notes:

(1) T2 does not measure alignment.

(2) T6 alignment does not measure effectively below about 30 mph.

(3) Repeatability on an earlier test when track was frozen was twice as good, i.e. = .04., indicating that track motion may have affected results.

(4) T2 test results for crosslevel on class 4 track were an order of magnitude worse indicating there was probably a fault in this system.

(5) TX specification calls for m = .03 and = .05 for tangent track and m = .06 and = .1 for curved track.

A two-thirds consist weight reduction (from one locomotive and two railcars to one self-propelled railcar) and the use of higher efficiency diesel-mechanical propulsion will result in an inspection capability that will reduce per mile fuel requirement by 80 percent.(7) This is equivalent to a saving of approximately 100,000 gallons of diesel fuel per year for a three car SPV-2000 inspection fleet. Other features of the SPV-2000 vehicle include:

- All axles powered,
- Standard locomotive controls,
- Integrated throttle/air-brake controls,
- Ability to be towed in standard trains when required,
- Wheel slip control system, and
- 150 second acceleration time to 80 mph.

Some disadvantages of TX single car inspection vehicle have been noted since the preparation of the specification. These include the need for full railroad crews on certain railroads plus reduced operating speeds through certain types of signaled territories and road crossings. However, these problems have been examined in some detail and it is conservatively estimated that full crews and/or towed operation will be required no more than 25 percent of the time. As a result, the potential savings of reducing the normal 4 to 5 man railroad crew to 1 to 2 man crews will occur at least 75 percent of the time. Therefore, the average railroad crew size per consist would drop by:

$$\frac{(4.5 \times .25 + 1.5 \times .75)100\%}{4.5} = 50\%$$

It is further projected that any inspection delays due to signaling incompatibility or road-crossing slow orders (currently experienced on some railroads by existing FRA track inspection consists) would be offset by increased system availability resulting from improved reliability.

3.6 Increased Productivity and Reduced Operating Costs

The objective of the TX development effort was to fabricate an improved track inspection system that could be operated more efficiently, economically and with greater reliability. Although operational experience will be required to quantify the true success of this effort, it is possible to generate engineering estimates of the potential impact of these improvements on increased productivity and reduced operating costs.

The following manpower and operating cost estimates were made based on 75,000 miles of track inspection by a fleet of three SPV-2000 TX vehicles. Current contractor/railroad manpower utilization rates for the existing three-consist FRA track inspection fleet total 79 man years of effort per year (based on operational experience during the first six months of 1980.) Manpower requirements for a fleet of three SPV-2000 TX inspection vehicles are given in Table 3-2. This would result in a savings of approximately 16 man-years of effort per year. Individual productivity would increase twenty-five percent from 35 to 44 million track geometry measurements per man-year. (Seven track geometry measurements are made every foot of railcar travel.)

Cost reduction projections are as shown in Table 3-3, resulting in a savings of approximately $2,000 per survey day over the current costs of $9,200 per survey day for a potential fleet savings of approximately $900,000 per year.

TABLE 3-2 - MANPOWER REQUIREMENTS FOR TX FLEET

Labor Category	Current mm	TX/ Existing	Projected mm
Operations	370	5/6	308
Maintenance	219	7/8	192
Data Processing	63	6/7	54
Field Engineering	44	6/7	38
Management and Administration	99	6/7	85
Railroad Support	155	1/2	78
	950 mm 12 = 79 my/y		755 mm 12 = 79 my/y

TABLE 3-3 - COST PER SURVEY DAY (SD) FOR TX FLEET

Category	Labor* $	TX/ Existing	Other $	TX/ Existing	Projecte Cost/SD $
Operations	2,913	5/6	300	1**	2,728
Maintenance	1,592	7/8	1,115	3/4**	2,229
Data Processing	385	6/7	190	6/7	493
Field Engineering	429	6/7	42	6/7	404
Management and Administration	651	6/7	41	6/7	593
RR Support	900	1/2	600	1/2	750
		$9,158			$7,197

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* Plus labor related ODC.

**Engineering estimate based on (1) reduced instrumentation system maintenance costs; (2) additional propulsion system costs.

APPENDIX A - REFERENCES

(1) Association of American Railroads, Yearbook of Railroad Facts, Washington, D.C., 1980 edition.

(2) Association of American Railroads, "Analysis of Nine Years of Railroad Accident Data," Report No. R-223, Washington, D.C., April 1976.

(3) Peterson, C., "Government Initatives for a National Track Inspection Program," Limited Distribution Report, ENSCO, Incorporated, December 1976.

(4) Nussbaum, E., "The Role of Automated Vehicles in the National Track Inspection Program," MTR-79W00423, The MITRE Corporation, McLean, Virginia, December 1979.

(5) Code of Federal Regulations, Volume 49, Parts 200-299.

(6) Nussbaum, E. Romanzi, R., Vogel, H., "Design, Performance and Quality Assurance Specifications for Track Measurement Vehicle - TX," MTR-7627, The MITRE Corporation, McLean, Virginia, September 1977.

(7) Dyer, J., SPV-2000 Survey Report, prepared for the Budd Company, 1 July 1977.

APPENDIX B - KEY TX VEHICLE SPECIFICATIONS

VEHICLE

Type: Model SPV-2000, Self-Propelled Railcar

Manufacturer: The Budd Company

Propulsion: Two 360-Hp Naturally-Aspirated Diesel Engines (Detroit Diesel 8V92)

Transmissions: Two-Speed (Forward and Reverse) Automatic with Torque Converter (Twin Disc TDC-22-1500)

Trucks: Budd Pioneer III Type; Safety Electric Gear Units; All Axles Driven; 80 mph Gearing; Air-Coil Spring Suspension; Timken Roller Journal Bearings

Dimensions and Weights

Weight, Ready-to-Run - 137,537 pounds (68.76 tons)
Length Over Pulling Force of Couplers (PFC) - 85'4"
Truck Center Distance - 59'6"
Truck Wheelbase - 8'6"
Maximum Width - Carbody - 10'6"
Maximum Height - Rail to Top Roof Corrugation - 12'10"
Maximum Height - Rail to Stack, New Wheels, Light Car - 14'5"
Height, Rail to Top of Finished Floor - 53-1/2"
Wheel Diameter (New) - 33"
Loading Each Axle - 17.19 tons

Fuel Capacity: 300 U.S. gallons

Auxiliary Power Unit (APU) (Empire Generator Corporation)

Engine: 122 Hp Naturally-Aspirated Diesel (Perkins V8.540)
Alternator: 75 kw, 480 VAC, 3 , 60 Hz (Lima Electric Type MAC-R)

Cooling System Capacities

Propulsion Engines (Each) - 50 gallons
APU Engine - 25 gallons

Brakes: No SPV26 Unit Tread Brakes; Spring-Activated Parking Brake with Manual Override

Sanders: Outer Axles

Environmental Control: Two 6-ton Air Conditioners; Engine Waste Heat Supplemented by Two-Stage Electric Floor Heat; Integrated Temperature Control System; 1,200 cfm Ventilation

ACCOMMODATIONS

Potable Water: 65-Gallon Overhead Tank (Gravity Fed); 30-Gallon Pressurized Tank; 6-Gallon Hot Water Heater; Water Chiller

Observation: Three Enlarged Windows on A-end.

Communications: Internal Public Address System with External Jacks; Forward Observer's Control Console

Safety Equipment: Stretcher; First Aid Kits; Escape Rope; Wrecking Tools; Fire Extinguishers; Derail; Wheel Chocks; Blue Flag, Blue Lights

Seating: Seating for 25 People (Including Engineer): Rear Vestibule (8); Kitchen (4); Office (3); Computer Room (7 With 2 Optional); Forward Vestibule (3 With 1 Optional)

Toilet Facilities: Self-Contained Microphor System (Serves 16 People); Lavatory

Crew Accomodations: Bunk Room; Emergency Cot; Office With File Cabinet

Work Area: 3 Work Benches; Drill Press; Grinder; Vise; Tool Storage Cabinets

MISCELLANEOUS

Flammable Stores Locker

Track Illumination Lights, A-End

Instrumentation Illumination Lights

APPENDIX C - KEY INSTRUMENTATION, DP AND DISPLAY SPECIFICATIONS

System Console

The System Control Console provides the operator the means to monitor the computer and instrumentation signals. The console consists of one MFE 1800 series eight-channel strip chart recorder, two HP 2648A data display graphic terminals, a display switch assembly and a public address system.

Signal Conditioning Unit

The Signal Conditioning Unit provides the central location for the circuits needed for sensor signal conditioning, computer digital control and magnetic gage servo control.

Servo Magnetic Gage

The Servo Magnetic Gage Sensor Units left and right, are mounted on the crossbeam assembly (Figure 2.5) that is mounted beneath the vehicle on the F-end truck. The two servo-positioned magnetic non-contact distance measuring sensors provide the voltages necessary for the computer to determine track gage.

Compensated Accelerometer Sensor

The Compensated Accelerometer Sensor System (CAS) consists of a Dual Axis Rate Gyro and a Servo Accelerometer (±0.5 g). An analog electronic buffering circuit is also contained within the package. This device provides the carbody roll angle and roll and yaw rate information required in evaluating many of the track geometry parameters.

Profile/Cross-level

The Left and Right Profile/Cross-level Units provide the measurement of vertical track deviations necessary to yield the carbody to track roll angle and individual rail profile measurements. Both units are mounted inside the vehicle and contained within each unit is a displacement transducer and a 0.5g servo accelerometer.

Displacement Transducers

The displacement transducers provide relative motion information between the truck and vehicle body. The transducers are spring loaded spiral potentiometers and are mounted in several locations outside and underneath the vehicle.

Magnetic ALD Sensor

The Automatic Location Detector Sensor (Magnetic ALD Sensor) detects the presence of materials that are sufficiently conductive to support eddy currents. The sensor is mounted on the crossbeam beneath the vehicle.

Capacitive ALD Sensor

The Capacitive ALD Sensor generates unique signal traces for each object located between the rails such as targets, turnout rails, road crossings, etc. Measurement of metal objects near the sensor and directly below it is also possible.

Alignometer

The Alignometer yields the data necessary to provide the inertial reference required to measure rail alignment. The package contains a 10 g servo accelerometer surrounded with foam and is mounted near the center of the crossbeam.

Tachometer Assembly

The tachometer assembly houses an incremental shaft encoder that is belt-driven from the axle. The pulsed signal generated corresponds to vehicle travel and thus provides necessary distance reference data for the Track Geometry Measurement System.

Graphics Terminal

The HP 2648A Terminal provides operator communications with the system, both character dialog and graphic status display. It has the following features: alphanumeric keyboard including control and editing keys, automatic plotting control and eight soft keys; composite video output; and twin 10 ips 800 bpi 110 kb capacity cartridge tape drives.

Patch Panel

The Patch Panel Unit provides a common distribution point for all signals within the Track Geometry Measurement System. Provisions are incorporated to monitor or interrupt certain signals for calibration and diagnostic reasons.

A/D and D/A

The Analogic AN5400 provides A/D and D/A interface to the computer. It has the following options and capabilities: 16-bit A/D converter; 32 single-ended channel input multiplexer (expandable to 384 channels); and three 4-channel 12-bit D/A converters for 12 output channels.

CPU

The Hewlett Packard (HP) 1000F CPU (Central Processing Unit) provides control and processing capabilities for the Track Geometry Measurement System. It has the following options and basic features: a basic instruction capability of approximately one million instructions per second; direct, indirect and indexed addressing; 16 and 32-bit integer arithmetic; interface to floating point unit for 32, 48 and 64-bit floating point arithmetic; 192 K words of 16-bit 350 ns parity memory; vectored priority interrupt structure; hardware bootstrap; memory expansion module (virtual memory control); memory protection; thermal protection; up to 2.28 Mb/sec I/O transfer rate; fast FORTRAN processor instruction sets; memory and processor self tests; power fail battery backup ROMs for cassette tape, disc and 9-track tape.

Magnetic Tape Unit

The HP 7970E Magnetic Tape Units are used to output raw transducer, control and message information. They have the following characteristics: 45 ips; 9-track; read after write; 1600 bpi (cpi) phase encoded; and mechanical tape buffers.

Disc

The HP 7900A Discs supply program and data direct access storage. They have the following characteristics: 2.5 Mbyte resident platter; 2.5 Mbytes mountable cartridge; 30 ms average head positioning; 12.5 ms average rotational latency; and 312 k bytes/sec pivot transfer rate.

Printer

The HP 2608A Line Printer is a medium speed hard-copy system list and plot device. It is microprocessor controlled and capable of alphanumeric output in both programmable selectable languages and print formats.

Rear Video Monitor

The Rear Video Monitor mounted between the recorder cabinets in the V-end of the vehicle, displays the same information displayed at the System Control Console Graphics Terminal. Observers in the vestibule end of the car are able to visually monitor the status of the system in regards to speed, milepost, distance, etc.

Strip Chart Recorders

There are three MFE 1800 series eight-channel strip recorders, one mounted in the System Control Console and two mounted in the vestibule for use by the inspectors. Writing on each of the eight channels is via a heated stylus on heat sensitive paper.

Track Measurement Vehicle TX Project Summary,
1981, C. Peterson, H. Vogel, US DOT, FRA, 01-
Track & Structures