MAINTENANCE PLANNING FOR THE SCRTD'S METRO RAIL

By

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1985 APTA Rapid Transit Conference
Atlanta, Georgia
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I. INTRODUCTION

Maintenance represents a large capital and operating cost for any rapid transit system. The Southern California Rapid Transit District (SCRTD) operates an extensive bus network and is acutely aware of the need for well designed maintenance facilities, good maintenance practices and effective management. This awareness has resulted in many maintenance innovations, the latest of which is the TRANSMIS management information system. The SCRTD is presently planning heavy rail and light rail service in the Los Angeles area. The heavy rail system is called Metro Rail and, early in its development, the SCRTD recognized the importance of a comprehensive maintenance plan to guide design activities and to supply a structure for the management of maintenance functions. The plan has three principal components:

- The maintenance programming which involves the organization of the preventive and corrective maintenance functions to achieve a satisfactory service dependability
- The manpower planning to ensure that personnel are available to perform the prescribed maintenance tasks
- The planning for the maintenance facilities which are used to store, service and repair the rolling stock; house the personnel and equipment necessary to maintain the track, stations, and electrification equipment; and service and repair the communications, automatic train control, and fare collection equipment.

These components are being used to provide information to the members of the design team and to help ensure successful integration with the bus and light rail maintenance activities. This paper briefly discusses each component. Detailed reports on the various aspects of Metro Rail maintenance planning have been written and are cited as references to the paper.

II. THE METRO RAIL SYSTEM

The SCRTD is in the final design stage for the 18-mile rapid transit line which will go from downtown Los Angeles via the Wilshire District, Fairfax, and Hollywood and to the San Fernando Valley. This line, Exhibit I-1, is planned to be the core element of a regional rail system and two future extensions of the Metro Rail System have been identified. While the entire mainline portion of the 18-mile line is planned as subway, the future extensions may involve surface or aerial segments as determined by design development.

The first four miles of the line have been identified as the initial operating segment because there are currently insufficient federal funds to construct either the 18-mile Metro Rail System or the 8.8-mile minimum operable segment identified in the Federal Environment Impact Statement. This initial segment, identified as MOS-1, consists of double-track mainline subway from Union Station to the Wilshire/Alvarado Station, with additional subway and surface track connecting to the yard southeast of Union Station. It includes all yard and shop facilities planned for the 18-mile system with the exception of part of the yard storage tracks, which will be installed as warranted by system extension and fleet expansion.

The MOS-1 line has five stations. The mainline route begins at Union Station, northeast of the Los Angeles Civic Center; and runs through the central business district, terminating on the west side at the Wilshire/Alvarado Station. The rail line is entirely in subway with line segments constructed by tunnel boring machines and stations and crossovers excavated by cut and cover construction techniques. Three double crossovers are included in the subway portion of MOS-1, one at each side of Union Station and one at the east end of the Wilshire/Alvarado Station.

The vehicles for the system will be stainless steel, standard gauge, 75 foot long rail cars, which will be configured in dependent pairs. They will be capable of operating at speeds up to 70 miles per hour and will operate on 750 VDC power supplied via third rail. The capacity of each single vehicle will be 59 seated passengers plus space for one wheelchair, up to 110 standing passengers at normal loads, and over 200 standing passengers at crush loads. The vehicle fleet for MOS-1 will consist of 30 vehicles, while 130 vehicles will be needed for the full 18-mile system.

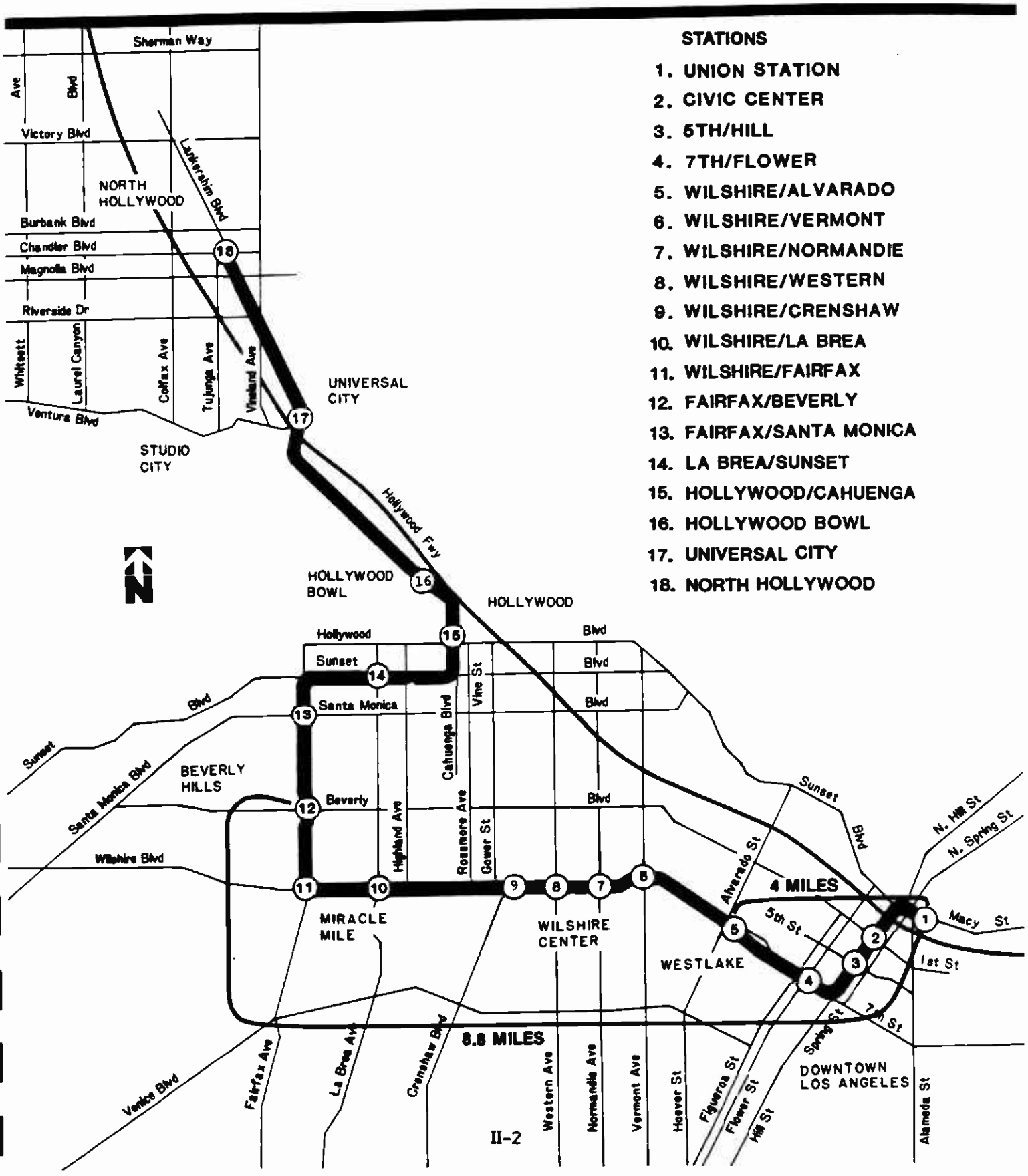
Ridership on MOS-1 is projected to be approximately 54,000 per day. Service for MOS-1 is planned to consist of 4-car trains operating at headways of 5 minutes during peak hours, increasing to 20 minutes during evenings and weekends. However, 6-car trains operating at 2 1/2 minute headways will be required to serve projected demand for the 18-mile line.

EXHIBIT I-1
System Map

Southern California Rapid Transit District

Metro Rail Project

TOTAL 18.6 MILES



MOS-1 trains will have Automatic Train Protection equipment to ensure safe speed and separation of trains. Automatic Train Operation (ATO) also will be included to regulate train speed and provide precision station stopping and train berthing verification for trains operating on the mainline in the ATO mode. System operation will be centrally controlled from the Rail Control Center, located in the Yard, using communication links with facilities and trains involving telephones, radios, CCTV and data transmission.

The five initial stations will be primarily of a double-ended design with two mezzanines, but one station, Wilshire/Alvarado, will be of the single-mezzanine design characteristic of the majority of the stations on the 18-mile line. Each mezzanine free area will have ticket vending machines and change machines and will be separated from the paid area by one or two arrays of entry/exit faregate barriers. The fare structure for MOS-1 will be based on a single zone, but fare collection equipment will have multi-zone capability to accommodate system extension. Escalators, stairs, and elevators will provide normal vertical circulation between surface, mezzanine, and platform levels. Stations will be equipped for both attended and unattended operation. Some stations will have adjacent parking facilities, pick-up/drop-off areas and/or bus pull-in areas to accommodate patrons arriving by automobile or by bus.

III. MAINTENANCE PROGRAM PLANNING

Maintenance program planning for the Metro Rail system involves both preventive and corrective maintenance activities. These activities are performed on all system components: ways and structures, passenger vehicles, power equipment, etc. They are required to achieve the four objectives which have been prescribed for the Metro Rail system:

- Provide the necessary maintenance to support a safe transit system
- Provide a high level of service dependability
- Provide clean vehicles and facilities
- Perform all maintenance activities in an efficient, cost effective manner.

In essence, the first three objectives mean "doing the right things" whereas the fourth objective means "doing things right." To conduct the right activities, a program of both preventive and corrective maintenance has been developed. To conduct those activities in the right manner, the necessary management controls will be integrated into the management information system which has been developed for the SCRTD's bus maintenance. Management reports delivering oversight at all levels of supervision will be an output of the information system.

PREVENTIVE MAINTENANCE PROGRAM

Preventive maintenance is a predetermined program where properly functioning equipment is either inspected and serviced while remaining in service or withdrawn from service to allow certain maintenance actions to be performed. These actions are performed at regular intervals (hours of operation, miles of operation, etc.) and normally consist of three generic activities:

- Inspection of the facilities and equipment to determine any conditions which require a maintenance action
- Servicing, consisting of such activities as lubrication, replacement of filters, etc.
- Cleaning of facilities or equipment.

The SCRTD's preventive maintenance program prescribes these activities for three major elements of the Metro Rail system:

- Ways and Structures

- o Systemwide elements
  - Train control
  - Communications
  - Fare collection
  - Electrification
- o Passenger Vehicles.

The program for ways and structures includes maintenance of running rails, tunnels, stations, yard and shops, and buildings and grounds. For each of these areas a set of tasks has been defined which must be conducted at specified intervals. Exhibit II-1 provides a sample of those tasks. In the sample, weekly inspections of the track and tunnel are performed and, each month, the tunnel equipment, the emergency systems and the station hardware are inspected, cleaned and tested. As the Exhibit shows, the total annual labor hours for each task have also been estimated. The time taken for each task was estimated by examining data from other properties, analyzing its applicability to the Metro Rail system and scaling the frequency and duration of the task.

The program for the systemwide elements involves train control, communications, fare collection and electrification equipment. For each of these areas a preventive maintenance program has been prepared. Exhibit II-2 shows a sample for the train control equipment maintenance tasks. In the sample, some of the automatic train protection and supervision equipment and the A.C. power system is inspected and tested at 90 day intervals. The corresponding labor hours to accomplish those tasks has been estimated to enable manpower planning to take place.

The preventive maintenance program for the fleet of passenger vehicles relies upon progressive maintenance inspections and servicing. The short interval (i.e., 5,000 and 10,000 mile) activities are intended to visually inspect components for excessive wear and damage, while also insuring that all fluid levels are maintained. The infrequent preventive maintenance activities (i.e., 30,000 and 60,000 mile) are more comprehensive and require maintenance actions, such as lubrication, adjustment and verification that components operate within design specifications. Preliminary preventive maintenance schedules have been prepared and will be refined to incorporate the vehicle manufacturer's recommendations and preventive maintenance specifications.

The initial preventive maintenance schedule for the passenger vehicles is shown in Exhibit II-3 and the associated labor requirements are shown below.

Inspection Interval	Labor Hours Per Inspection	Shop Hours Per Inspection	Estimated Labor Hours Per Year
5,000 mi.	10	4	10,400
10,000 mi.	10	4	6,500
30,000 mi.	30	8	3,900
60,000 mi.	40	10	5,200
Total			26,000

EXHIBIT III-1

Typical Preventive Maintenance Tasks for Ways and Structures

Inspection & Maintenance Item	Description of Activity	Interval (Days)	Estimated Annual Labor Hours
Track, Running Rails, and Roadbed	. Inspect rail, fasteners, clips, pads, joints, welds, etc., for indications of wear and damage. . Check track gauge.	7	6,240
3rd Rail and Cover	. Inspect power cable connects, rail, cover, and welds for signs of wear and damage.	7	520
Tunnel Equipment & Hardware	. Clean and inspect signs and handrails. . Inspect tunnel liner for cracks, leaks and other signs of damage. . Clean and inspect drains and cross passages. . Inspect electrical conduit.	30	1,040
Tunnel Emergency Systems	. Check and inspect wet stand pipe water pressure and valve operation. . Check condition and availability of emergency equipment. . Check fire extinguishers and replace those requiring a charge or other service.	30	50
Station Hardware and Equipment	. Inspect handrails and insure that they are tightly fastened. . Clean and inspect signing. . Check operation of climate control equipment.	30	860

EXHIBIT III-2

Typical Preventive Maintenance Tasks for the Train Control System

Inspection & Maintenance Item	Description of Activity	Interval (Days)	Estimated Annual Labor Hours
Automatic Train Protection	. Check track circuit adjustments. . Check Transmitter Power Level. . Check Track Receiver Level.	90	30
Automatic Train Supervision	. Check transformer output voltage of AC Track Circuit. . Measure Track Resistance and Relay end Voltage. . Test shunting and insulation. . Verify analog output and sensitivity of transmitter and receivers. . Verify carrier detection circuit.	90	40
AC Power System	. Inspection, clean and lubricate transfer panel switches. . Functional test of transfer pannel panel. . Measure power supply output and ripple voltage and amperage. . Check operation of power failure alarm.	90	220

EXHIBIT III-3

Preliminary Preventive Maintenance Schedule for Passenger Vehicles

MAJOR SYSTEM	SUBSYSTEM	PM INTERVAL (miles) 5,000	10,000	30,000	60,000
Interior					
Communications	Radio	x	x	x	x
	P.A. System	x	x	x	x
Seats	Passenger	x	x	x	x
Doors		x	x	x	x
Trucks and Truck Mounted Components					
Traction Motors	Brushes			x	x
	Armature			x	x
	Filters	x	x	x	x
	Wiring	x	x	x	x
Collector Assembly	Paddles		x	x	x
	Fuse	x	x	x	x
	Wiring	x	x	x	x
Gear Unit		x	x	x	x
Wheel and Axle	Inspect	x	x	x	x
	Bearings		x	x	x
Suspension	Shock Absorbers		x	x	x
	Air Bag			x	x
	Leveling valve			x	x
Brakes	Disc	x	x	x	x
	Pad	x	x	x	x
	Caliper	x	x	x	x
	Actuator	x	x	x	x
Automatic Train Control (ATC)					
Speed Sensors		x	x	x	x
Antennas		x	x	x	x
Exterior & Misc. Undercar Equipment					
Coupler & Draft Gear	Mechanical			x	x
	Draw Bar			x	x
Knife Switch Box				x	x
Emergency Systems	Batteries	x	x	x	x
	Charger	x	x	x	x
Reservoirs				x	x

EXHIBIT III-3

Preliminary Preventive Maintenance Schedule for Passenger Vehicles

MAJOR SYSTEM	SUBSYSTEM	PM INTERVAL (miles) 5,000	10,000	30,000	60,000
HVAC					
Air Compressor	Filters	x	x	x	x
	Fluids	x	x	x	x
A/C Condensor		x	x	x	x
Blowers	Filters	x	x	x	x
	Motor		x	x	x
A/C Compressor			x	x	x
Fluids	Refrigerant	x	x	x	x
	Oil	x	x	x	x
Propulsion Motor Control					
Motor Control Box				x	x
Controllers	Loop		x	x	x
	Field		x	x	x
	Power Brake		x	x	x
Inductors				x	x
Body and Shell					
Exterior Lighting	Headlights	x	x	x	x
	Door	x	x	x	x
	Tail & Brake	x	x	x	x
Windows & Glazing	Windshield	x	x	x	x
	End Doors	x	x	x	x
	Windows	x	x	x	x
Doors	Edges		x	x	x
	Operation	x	x	x	x

In addition to the schedule shown in Exhibit II-3, the following maintenance actions will be performed:

- Each night, the passenger vehicles will be manually cleaned and inspected for graffiti, broken or damaged windows, lights, seats, interior liners, etc. Corrective action will be taken when the component can be easily cleaned, repaired, or replaced, or the vehicle will be scheduled for corrective maintenance.

- Twice weekly, all passenger vehicles will receive an exterior washing.

- Each month, all passenger vehicles will receive a heavy interior and exterior cleaning. The interior cleaning will consist of an interior washing of the floor, walls, and seats. The exterior washing will include the front and rear ends of the vehicle and the coupling area.

The preventive maintenance program which has been developed represents a compilation and refinement of programs being used by comparable rail systems. It represents a starting point for Metro Rail maintenance activities and the program will be refined and enhanced as actual experience and data is obtained from system operations.

CORRECTIVE MAINTENANCE PROGRAM

The objective of corrective maintenance is to restore inoperative equipment to a safe, fully functional state as quickly as possible with minimum cost. The method to be used to achieve that objective involves the replacement of a failed component or module with a serviceable spare unit. By using this module replacement technique, the system downtime is minimized and the actual repair time for the faulty module does not reduce system availability. However, the technique does require that sufficient spare units are available to be exchanged for faulty ones so that a significant inventory investment is required. The module replacement technique also allows some of the Metro Rail maintenance functions to be specialized and combined with similar SCRTD bus maintenance activities, e.g., communciations repair equipment, air conditioning equipment, and upholstery repair. These combined maintenance activities will be performed in a Central Maintenance Facility.

Since the conditions which require corrective maintenance are unpredictable events, the management process to achieve the objective is complex and dynamic. To effectively manage the corrective maintenance function, certain insights are necessary:

- The level of spares inventory and reorder points
- The staffing levels and skills of the labor force
- The type of facilities and tools which are required.

Key to effectively managing the corrective maintenance process is information on failure rates, the time required to repair components, lead time on purchased parts, etc. There is a paucity of such information in the rapid transit industry. Some transit properties, such as the Bay Area Rapid Transit District (BARTD), State of Maryland Mass Transit Administration (MTA), the Toronto Transit Commission (TTC) and the Port Authority Transit Corporation (PATCO), have collected reliability and maintenance data. However, there is considerable variance in that data because of differences in system components, system sophistication, the degree of vandalism experienced, etc.

To assess the corrective maintenance workload, data from the MTA system was analyzed. The MTA system is similar in design and complexity to the Metro Rail system and has been in operation for a short time. Booz, Allen had developed a Maintenance Reporting System for the MTA and we were able to extract failure rates and repair times for each element of the transit system. Not surprisingly, the analysis of the data showed that not all maintenance categories will require a full complement of staff for corrective maintenance tasks. Specifically, the labor requirements for corrective maintenance on ways and structures, train control, and traction power appear to be lower than those estimated to be required at steady state. For those maintenance categories, the personnel levels may be built up gradually to suit the workload. Therefore, the plan for corrective maintenance on the Metro Rail system includes an appropriate personnel build up and maintenance data will be periodically evaluated to provide an assessment of the rate of this build up.

Failure and repair data were analyzed for all elements of the system ways and structures, train control, passenger vehicles, traction power, fare collection, and communications. The same procedure was followed to produce a maintenance labor estimate for each element of the transit system. As an example, Exhibit II-4 shows the fare collection data including ticket vendors, fare gates, bill changers, etc. The number of failures and the associated repair times were collected for each fare collection component over a three-month period. From that data, the mean time to repair each component and the number of failures per passenger were calculated. That data was then used to estimate the Metro Rail corrective maintenance labor required for the MOS-1 fare collection system. The process was repeated for each element of the Metro Rail system to arrive at the total amount of corrective maintenance labor hours.

EXHIBIT III-4
Fare Collection Corrective Maintenance Estimate
For MOS-1

Component	Number of Failures	Total Maintenance Labor Hours	Failures/ Passenger	Mean Time to Repair (Hours)	Estimated SCRTD Labor Hours Per Year
Ticket Vendor	515	807.5	.000453	1.57	5,689
Fare Gates	301	598.7	.00026	1.99	4,139
Handicapped Gate	1	3.5	0	3.5	0
Bill Changer	818	839.4	.00072	1.026	5,909
Ticket Encoder	18	39.0	.0000158	2.166	274
				Total	16,011

NOTES:

1. Data obtained from the State of Maryland Mass Transit Administration for the reporting period 5/1/84 to 7/31/84.

2. Number of failures is the number of corrective maintenance actions in the reporting period.

3. The SCRTD labor estimate is based upon a scaling of those passengers, who do not have monthly passes, using the Metro Rail system. In the reporting period, 1,136,685 such passengers used the MTA system and approximately 8,000,000 such passengers are expected to use the MOS-1 system each year.

IV. MANPOWER PLANNING

Preliminary maintenance labor requirements have been estimated for the MOS-1 system based on the operating plan, the vehicle fleet size, and the preventive and corrective maintenance requirements to support Metro Rail operations in the year 2000. This longer view was taken to estimate the operating and maintenance costs for the system and to provide a framework for the evolution of the maintenance organization. A summary of the maintenance labor requirements for MOS-1 is shown below.

Summary of Maintenance Labor Requirements for MOS-1

	Personnel
Administration	11
Vehicles	50
Facilities	49
Central Maintenance	30
Electronics and Communications	39
TOTAL	179

Eleven people are required to direct maintenance activities and for clerical support; fifty people are required to inspect, service, and repair the passenger vehicles; the maintenance of the yard, shops, building, stations, power, and other facilities is estimated to require forty-nine people; the staff of the Central Maintenance Facility, who will repair and overhaul rotable components and electronic modules, is planned to be thirty people; and thirty-nine people are required to service and repair the fare collection, train control, and other electronics and communications equipment. For each major maintenance category, a detailed list of staffing requirements including labor grades has been prepared. This list will be used to prepare a recruitment plan and the job descriptions for each labor category.

No attempt has yet been made to rigidly prescribe an organizational structure. The SCRTD already has a large maintenance organization to support bus operations and a new light rail network is being designed. It is expected that the maintenance organization supporting the new heavy rail and light rail modes will be integrated into the existing management structure. This integration will draw upon the SCRTD's present technical and managerial strengths and add experienced rail maintenance personnel as necessary.

V. MAINTENANCE FACILITIES

Metro Rail maintenance will be conducted in two new facilities:

- o Main Yard and Shops
- o Central Maintenance Facility.

The design of these facilities is now well advanced and an evaluation of the layout and capacity of the main shop has verified that it can satisfy the maintenance demand.

MAIN YARD AND SHOPS

The main yard and shops are those facilities which are required to store, clean, and maintain the Metro Rail system's passenger vehicles, auxiliary vehicles, track, traction power system, and tunnels. The facilities will be located on a 40 acre site to the east of the Los Angeles Central Business District. The site extends from the Santa Ana Freeway in the north to approximately 1,100 feet south of the 6th Street Bridge; and from the Los Angeles River in the east to Santa Fe Avenue in the west. Exhibit V-1 provides a general plan of the main yard and shop facilities. The storage tracks in the yard will accommodate an ultimate fleet of 170 vehicles.

Transit vehicles will enter the main yard from Metro Rail's Union Station. The main body of the yard will consist of the storage yard for Metro Rail transit vehicles. Other facilities at the yard will include a main shop building for vehicle maintenance, vehicle cleaning facilities, and a maintenance-of-way shop. Each of these facilities is described below.

The main shop building provides the maintenance support for the passenger vehicles and houses the Central Control Facility for the Metro Rail system. The shop contains six maintenance areas:

- o Blow-down facility
- o Service and inspection area
- o Heavy repair area
- o Truck shop
- o Wheel shop
- o Equipment maintenance shops.

These areas are shown in Exhibit V-2. Supporting these maintenance areas are several specialized shops including welding, airbrake, electrical equipment, stores, etc., as well as employee facilities such as locker, lunch, and training rooms.

The blow-down facility is used to remove dirt from the under-carriage of passenger vehicles during scheduled maintenance inspections. The blow-down facility is long enough to accommodate one married pair of vehicles. It will provide compressed air and vacuum equipment to collect the dust and debris which is produced during the cleaning operation.

EXHIBIT V-1
General Plan of Metro Rail Yard and Shop Facilities

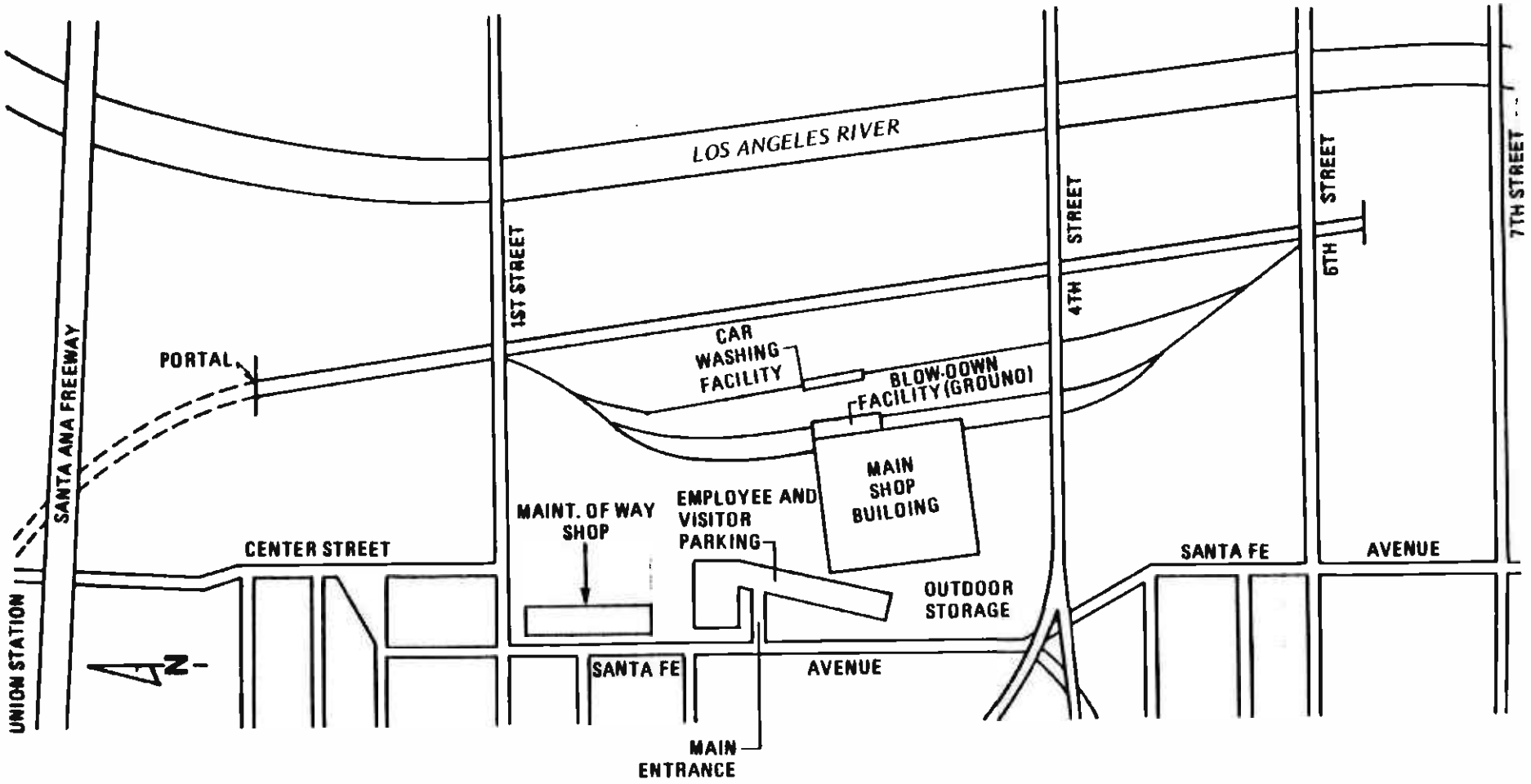
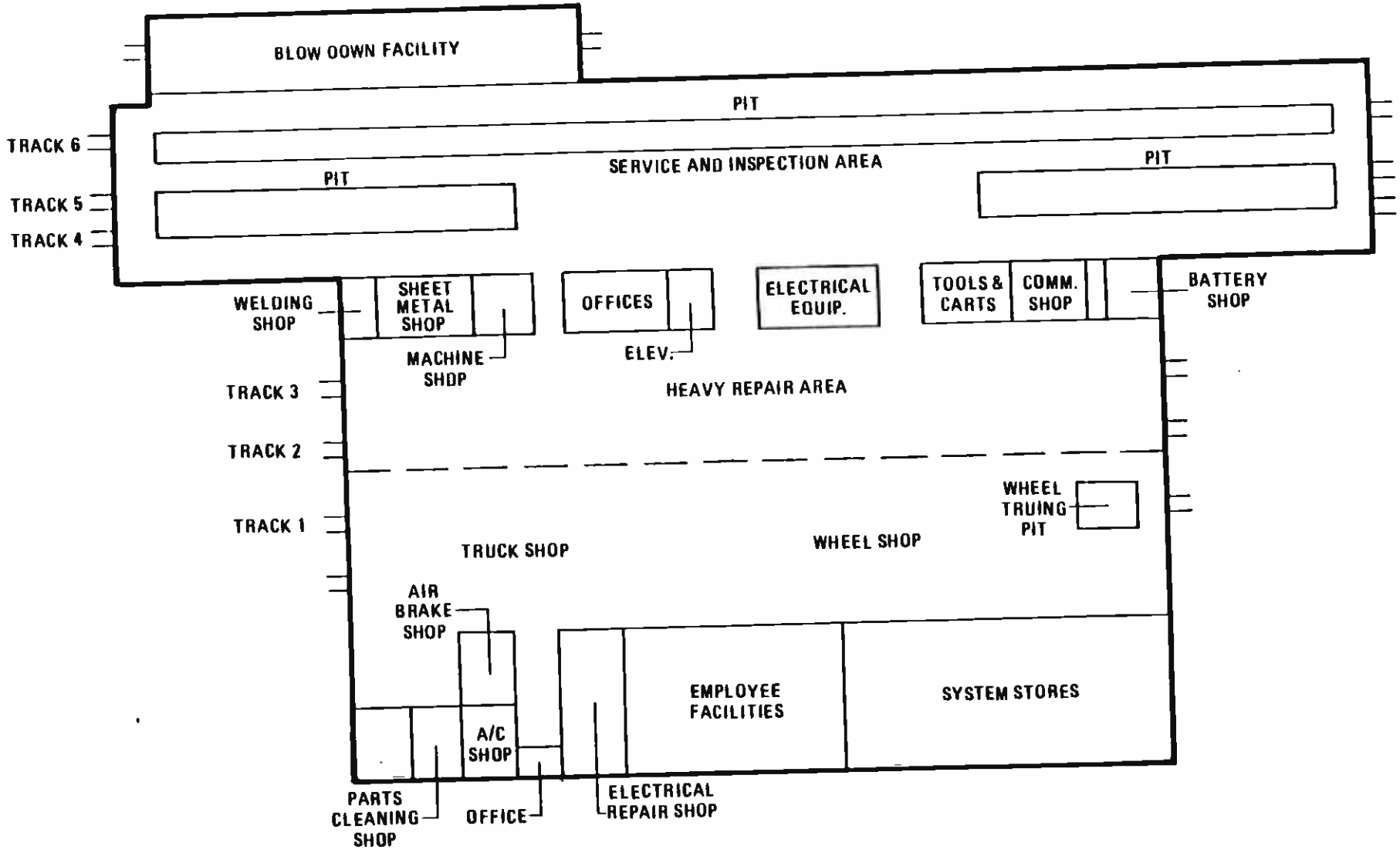


EXHIBIT V-2
Main Shop Building



The service and inspection area consists of three tracks, each of which can accommodate a six-vehicle train. The area will have three pits, one under the entire length of track 6 and the ends of tracks 4 and 5. The two pits under tracks 4 and 5 will each be able to accommodate a married pair of vehicles. Track 6 is capable of handling all service and inspection activities. Tracks 4 and 5 are more limited and the service and inspection activities on those tracks must account for the lack of pit space at some vehicle positions.

The heavy repair area contains two tracks each having the capacity to accommodate four vehicles. In-floor car hoists are located along the tracks to raise the vehicles for undercar repairs and/or truck removal. Turntables, located at the mid-point of each track, are used to move the trucks from the heavy repair area to the truck shop. Bridge cranes are installed to move components around the heavy repair area.

Track 1, which will accommodate two married pairs of vehicles, provides access to the truck shop and the wheel shop. Wheel truing is performed at the end of track 1. A storage track is located adjacent to track 1 to accommodate trucks and wheelsets which are either waiting for maintenance or have been repaired.

The maintenance-of-way shop will contain repair shops, equipment and component stores, employee facilities, and office and administrative areas. This facility will serve as a base for personnel responsible for maintaining the fixed facilities and the track work (the track structure and hardware) for the Metro Rail system. Such work will generally be performed along the line, requiring personnel to travel to the site to perform the maintenance activities. Most of the tools, equipment, and material needed for this work will be stored within the shop or in outside storage.

The shop facilities include:

- Rail-mounted equipment repair area with overhead crane and stub-end tracks
- General repair area with adequate floor space for maintenance of work equipment such as compressors, emergency generators, emergency sumps, etc., as well as track work components and traction power components
- Offices for personnel, men and women's wash and locker rooms, lunch room, and training room
- Stores area for secured materials area and supplies area
- Mobile equipment repair area for over the road vehicles.

An outdoor material storage area will also be provided and is protected by security fencing. Vehicle storage areas for the maintenance-of-way fleet will be provided north of the building.

The vehicle cleaning facilities will be used for exterior and interior cleaning of the passenger vehicles. Exterior vehicle washing will be conducted in an unenclosed area located so that a train leaving the washer can proceed directly to the storage yard. The car washing facility will include equipment for the control, treatment, and recirculation of waste water to preserve the environment.

Interior car cleaning is performed in the storage yard when consists are out-of-service for lay-up. Equipment required for interior cleaning include a transport vehicle with trash container to remove bagged debris. No other specialized equipment is required for routine light cleaning. Heavy cleaning will require a mechanical scrubber for the car floors and stain removing equipment. A two-car platform is provided to allow cleaning crews easy access to the vehicles. The main shop building contains facilities to store cleaning equipment.

CENTRAL MAINTENANCE FACILITY

The Central Maintenance Facility (CMF) will provide support functions to the main yard shop and maintenance-of-way shop. The CMF will handle most electronics component repairs and that equipment which is common to both rail and bus operations, including:

- Radio
- Telephone
- Fare collection
- Data transmission equipment
- Antenna
- Closed circuit television
- Air conditioning
- Upholstery
- Destination signs.

In addition, the CMF will provide fuel dispensing, materials and inventory for rotable components, and will contain the upholstery shop, component paint shop, automotive repair facilities, and electronic component repair facilities.

EVALUATION OF THE LAYOUT AND CAPACITY OF THE MAIN SHOP

Initially, the main shop design was based on the qualitative judgments of design engineers and their previous experience with shop layout, capacity, and support requirements. Prior to finalizing the design, a quantitative evaluation was conducted to verify the shop's capacity to handle the maintenance demand of the full system fleet of 130 cars.

The main shop, like other repair facilities, will be subject to fluctuating demand for service. The level of maintenance demand is influenced by the:

- Requirements for preventive maintenance
- Number and type of vehicle failures
- Time required to correct each failure.

The interaction between the preventive and corrective maintenance actions and the maintenance facilities were considered to be too complex to be analyzed in terms of averages. For this reason, a Booz, Allen Monte Carlo computer program was exercised which simulates the random nature of failures and repair times, and incorporates a preventive maintenance schedule.

A description of the simulation model is shown in Exhibit V-3. There are three main parts to the program: simulation of system operations, determination of maintenance actions and simulation of main shop activities. The whole program is a time based simulation. The simulation proceeds in six minute intervals and random numbers are used to generate failures and repair times from probability estimates of failure and repair times. System operations are simulated using the Metro Rail operating schedule. When a vehicle failure is generated, random numbers are used to determine the type of failure and the associated repair time. The type of failure is based upon the relative mean time between failures for the subsystems (propulsion, brakes, HVAC, etc.). The repair time is based upon an assumed probability distribution.

The "failure" and its characteristics are then placed in a queue to wait for its maintenance action to begin. The corrective maintenance actions are integrated with the preventive maintenance schedule to determine the total workload in the main shop. The throughput of the shop is simulated from its layout and the capabilities of each location within it. Some locations are reserved for service and inspection activities while others are reserved for specific repair actions. In some instances, such as wheel truing, corrective maintenance actions can only occur at locations equipped with the necessary tools and equipment. In other instances the assignment of repairs to specific locations was arbitrary.

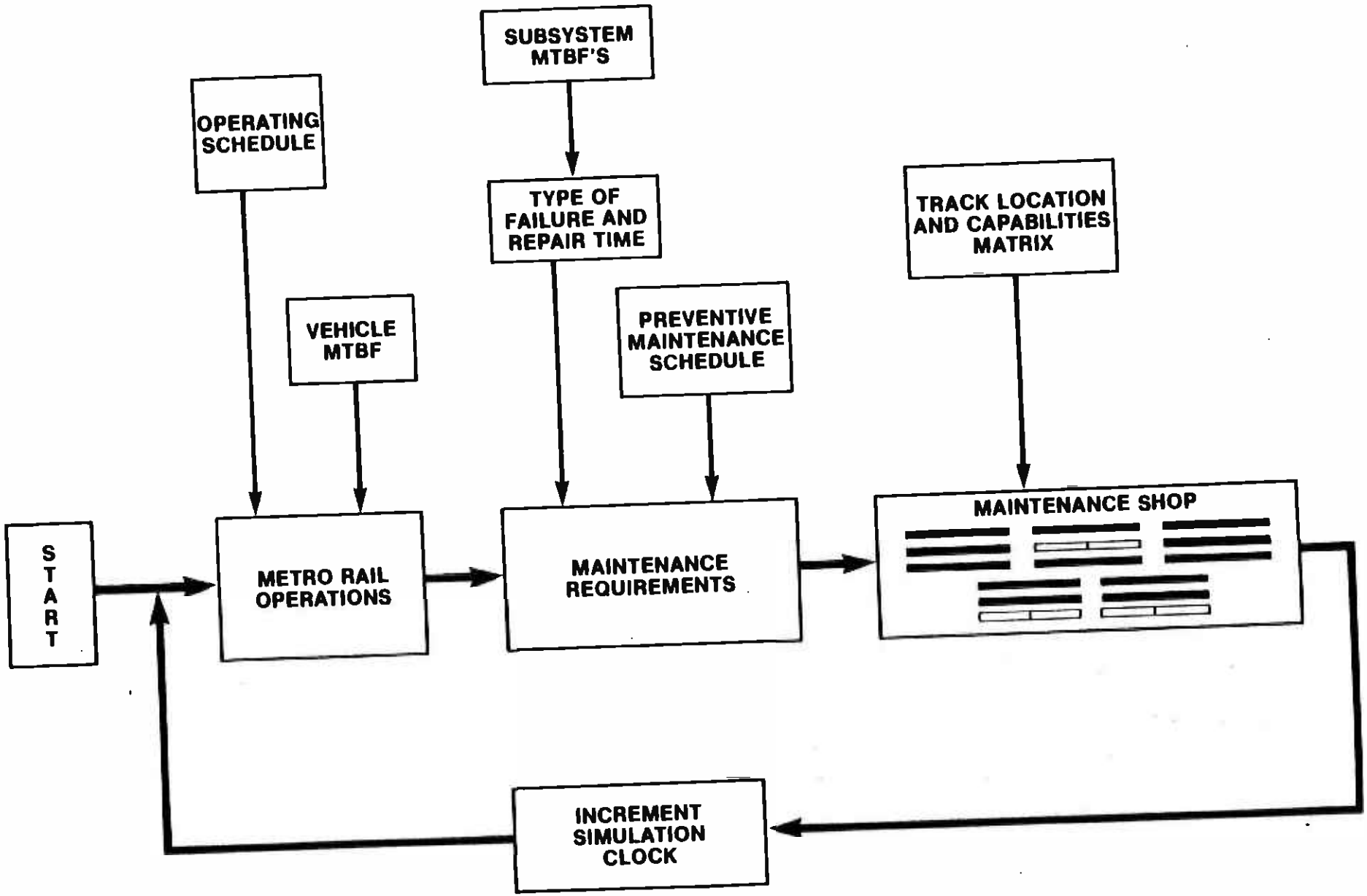
A six week operating period was simulated using two vehicle reliability cases:

- With a dependent pair mean time between failures of 150 hours, provided in the vehicle specification. For this case, the shop capacity was found to be adequate and the queuing times were quite short.

- With a dependent pair mean time between failures of 40 hours. A significantly different picture emerged in this case. For some failure types, significant queue times developed because some corrective maintenance actions were restricted at some shop locations. These restrictions were arbitrary and did not involve physical limitations or characteristics of the shop. Accordingly, these restrictions have been lifted and a more flexible approach will be used in practice.

Based on these simulations, the shop layout and capacity was found to be satisfactory. However, a more flexible assignment of corrective maintenance tasks to locations within the shop has been adopted and the shop design has been finalized.

EXHIBIT V-3
Booz, Allen Shop Simulation Model



VI. REFERENCES

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2. Operating and Maintenance Cost Estimate for MOS-1, Southern California Rapid Transit District, Metro Rail Project, March 1985, prepared by Booz, Allen & Hamilton.

3. Evaluation of Shop Layout and Capacity, Southern California Rapid Transit District, Metro Rail Project, October 1984, prepared by Booz, Allen & Hamilton.