FINAL REPORT

A STUDY OF ENERGY MANAGEMENT ALTERNATIVES FOR THE STARTER LINE OF THE SCRTD METRO RAIL PROJECT

DECEMBER 1981

PREPARED FOR SCRTD BY
BOOZ•ALLEN & HAMILTON INC.
WITH ASSISTANCE FROM
SRI INTERNATIONAL

BOOZ · ALLEN & HAMILTON Inc.
Transportation Consulting Division

2 HOPKINS PLAZA
SUITE 1417
BALTIMORE, MARYLAND 21201
837-8160
AREA CODE 301

December 30, 1981

Mr. Russell K. McFarland
Manager System Engineering and Analysis
Metro Rail Project
Southern California Rapid Transit District
Los Angeles, California 90013

Subject: Final Report on the Study of Energy Management Alternatives, WBS 13DAC

Dear Mr. McFarland:

Enclosed is the final draft of the subject document. Revisions based on your comments and those of the Metro Rail managers at the interim and final presentations have been incorporated.

Our study of energy management alternatives was undertaken prior to any substantive analysis of the major alternatives during Preliminary Engineering. Therefore, it is important to ensure that our findings, conclusions and recommendations are re-evaluated as additional information becomes available during Preliminary Engineering.

Submittal of the report and the previous demonstration of the computer programs for profile geometry, train performance and energy requirements complete the first phase of our simulation model development. The remainder of our efforts for WBS 13DAC will be devoted to a simulation that assists in selecting the preferred locations for crossovers and pocket tracks.

Please contact me at your earliest convenience to discuss any portions of this document.

Very truly yours,

Michael P. McDonald

BOOZ·ALLEN & HAMILTON Inc.

Michael P. McDonald
Senior Associate

TABLE OF CONTENTS

I. INTRODUCTION

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1. STUDY OBJECTIVES AND SCOPE

- TO PROVIDE A PRELIMINARY ANALYSIS OF PRIMARY ENERGY MANAGEMENT ISSUES, IN ORDER TO ASSIST THE SCRTD STAFF IN THE DEVELOPMENT OF A RECOMMENDED POLICY STATEMENT ON VERTICAL PROFILING

- TO MAKE RECOMMENDATIONS FOR FURTHER STUDY DURING PRELIMINARY ENGINEERING, AND TO IDENTIFY THE REQUIREMENTS FOR FURTHER SIMULATION

- TO DOCUMENT THE BASIC ANALYTICAL FORMAT AND ASSUMPTIONS IN ORDER TO FACILITATE FUTURE UPDATE OF THE ANALYTICAL MODELS DEVELOPED FOR THIS ANALYSIS

- SPECIFICALLY, TO:
  - ESTABLISH A BASELINE EQUIPMENT CONFIGURATION FOR EVALUATION
  - DEVELOP A PRELIMINARY OPERATING PLAN
  - EVALUATE THE OPERATING PROBLEMS AS THEY RELATE TO EQUIPMENT FAILURE MANAGEMENT
  - ANALYZE THE COST SAVING FACTORS OF ENERGY MANAGEMENT
  - CONSIDER SAFETY IMPLICATIONS.

2. KEY ELEMENTS OF SUBTASKS

THE KEY ELEMENTS OF EACH OF THESE SUBTASKS ARE GIVEN BELOW:

BASELINE EQUIPMENT

- VEHICLE SUBSYSTEM
- PROPULSION SUBSYSTEM
- TRAIN CONTROL SUBSYSTEM

OPERATING PLAN

- PEAK HEADWAYS
- OFF-PEAK HEADWAYS
- TRIP TIMES
- FLEET SIZE AND TRAIN CONSISTS
- OPERATOR STAFFING

OPERATING PROBLEMS

- EQUIPMENT RELIABILITY
- DEGRADED OPERATIONS
- SYSTEM BLOCKAGES

COST ANALYSTS

- ENERGY REQUIREMENTS
- ENERGY LOSSES
- RECOVERABLE ENERGY
- POTENTIAL SAVINGS
- IMPACT ON FIXED FACILITY DESIGN

THREE MAJOR SAFETY IMPLICATIONS OF VERTICAL PROFILING ARE THE EFFECT ON EMERGENCY EVACUATION, THE EFFECT ON EMERGENCY VENTILATION, AND THE CHANGES IN SAFE BRAKING DISTANCE REQUIREMENTS. THESE ARE BEYOND THE SCOPE OF THIS REPORT.

THE BASELINE EQUIPMENT AND THE OPERATING PLAN ARE INTERDEPENDENT AND MUST BE DEVELOPED IN PARALLEL. ONCE THESE ARE ESTABLISHED, IT IS POSSIBLE TO EVALUATE OPERATING PROBLEMS AND COST SAVINGS. THE REMAINDER OF THIS REPORT DISCUSSES EACH OF THESE ITEMS.

II. DEFINITION OF BASELINE SYSTEM TO BE USED IN THIS ANALYSIS AND IDENTIFICATION OF KEY VARIATIONS

II. DEFINITION OF BASELINE SYSTEM TO BE USED IN THIS ANALYSIS AND IDENTIFICATION OF KEY VARIATIONS

1. A BASELINE SYSTEM MUST BE DEFINED BEFORE A PRELIMINARY OPERATING PLAN CAN BE ESTABLISHED AND BEFORE ENERGY CONSUMPTION SAVINGS CAN BE CALCULATED

- THE HORIZONTAL ALIGNMENT IS BASED ON THE PREFERRED ALTERNATIVE REPORT OF SEPTEMBER 1979, WITH A MODIFICATION TO REFLECT THE ELIMINATION OF THE WILSHIRE/CRENSHAW STATION.

  OTHER MODIFICATIONS MAY OCCUR BEFORE FINALIZATION OF THE STARTER LINE CONFIGURATION. HOWEVER, THE IMPACT OF SUCH MODIFICATIONS ON THE OUTCOME OF THIS REPORT IS EXPECTED TO BE MINOR.

- PERFORMANCE CHARACTERISTICS HAVE BEEN SELECTED THAT REFLECT THE APPLICATION OF READILY AVAILABLE TECHNOLOGY.

- THE PERFORMANCE CHARACTERISTICS CONSIDER THE HORIZONTAL ALIGNMENT, THE STATION LOCATIONS AND THE PASSENGER FLOW PREDICTIONS FOR THE PREFERRED STARTER LINE ALTERNATIVE.

- THE BASELINE CHARACTERISTICS OF SUBSYSTEM ELEMENTS HAVE BEEN SELECTED TO REFLECT THE SCRTD DESIGN CRITERIA DOCUMENTS AND THE TECHNOLOGY OF PROVEN SUBSYSTEMS. VARIATIONS TO THE BASELINE THAT INVOLVE PRODUCT DEVELOPMENT HAVE BEEN INCLUDED WHERE THE POTENTIAL IS HIGH FOR BENEFIT VERSUS RISK.

2. <u>THE PERFORMANCE REQUIREMENTS ARE CHARACTERIZED BY THE NEED TO ACHIEVE OPTIMAL SERVICE CONSISTENT WITH RAIL RAPID TRANSIT TECHNOLOGY</u>

- TRAIN CONSISTS OF ELECTRICAL MULTIPLE UNITS WITH ALL CARS HAVING IDENTICAL PROPULSION AND BRAKING CAPABILITY.

- MAXIMUM SPEEDS THAT GIVE EFFECTIVE AVERAGE SPEEDS CONSIDERING THE STATION-TO-STATION DISTANCES:*

  - A TOP SPEED OF 60 MPH IS ADEQUATE FOR STATION SPACINGS OF ONE MILE OR LESS.

  - A TOP SPEED OF 70 MPH IS OF BENEFIT FOR STATION SPACINGS ABOVE ONE MILE.

  - STATION SPACINGS EXCEEDING TWO MILES ARE REQUIRED TO JUSTIFY A TOP SPEED IN EXCESS OF 70 MPH.

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* SOURCE: LANG AND SOBERMAN (1964).

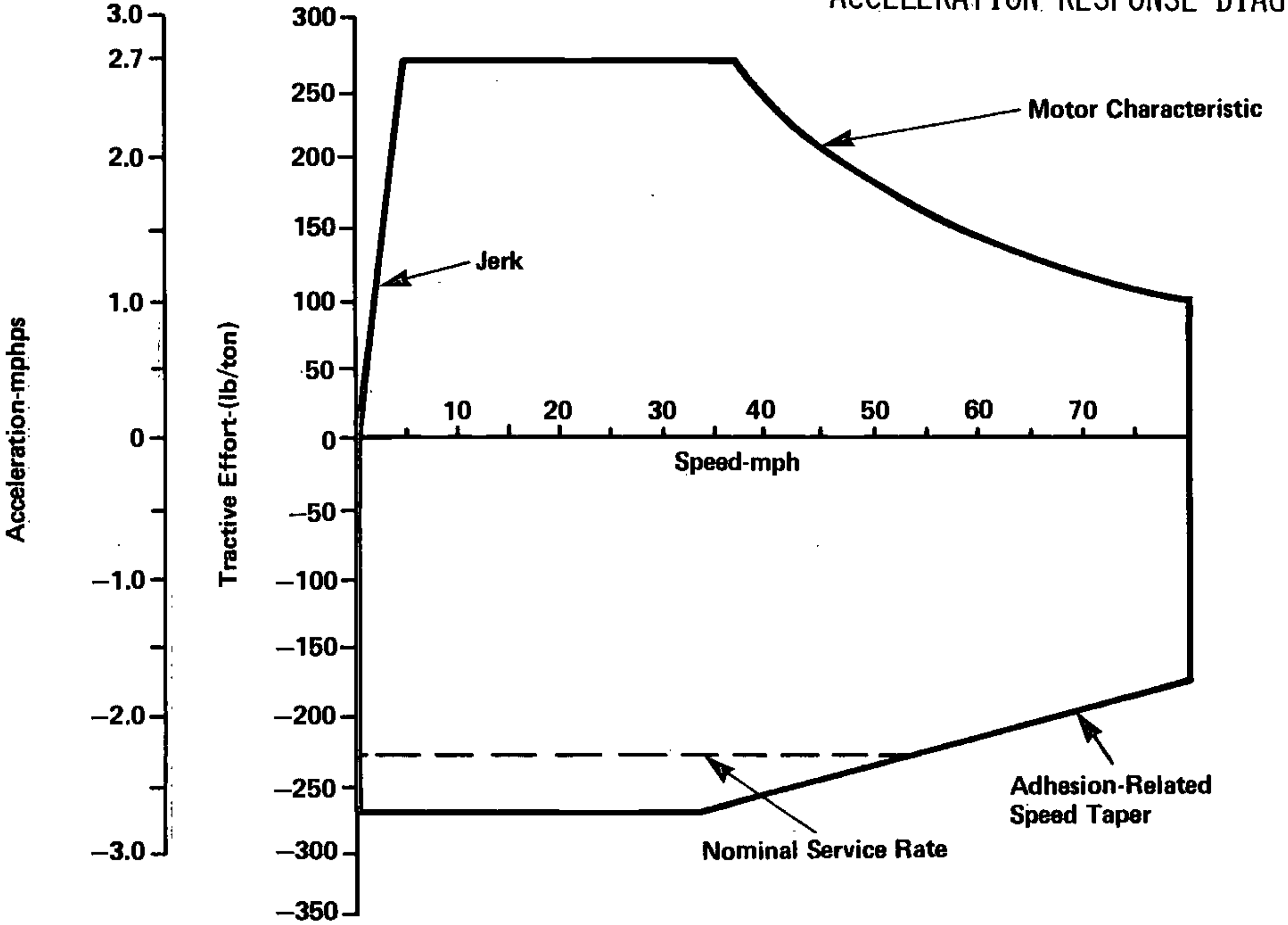
O THE ACCELERATION VERSUS SPEED CHARACTERISTIC OF A MODIFIED BART SPECIFICATION, SHOWN IN EXHIBIT II-1, REPRESENTS A HIGH PERFORMANCE SYSTEM:

- 1000 VOLTS DC TRACTION POWER SUPPLY
- TOP SPEED OF 80 MPH
- FULL ACCELERATION UP TO 37 MPH
- "SHALLOW" MOTOR CURVE GIVING SIGNIFICANT RESIDUAL ACCELERATION CAPABILITY AT 80 MPH.

O HOWEVER, THE HIGH PERFORMANCE CHARACTERISTIC MUST BE EVALUATED AGAINST SUBSYSTEM EQUIPMENT RESTRICTIONS AND REQUIREMENTS:

- 1000 VOLT SUPPLY MAY CONTRIBUTE TO RELIABILITY PROBLEMS.
- TOP SPEED OF 80 MPH IS NOT ACHIEVED ON MANY SECTIONS OF THE SYSTEM AND IS INTENDED FOR SCHEDULE MAKEUP.
- PERFORMANCE REFLECTS ALUMINUM CAR WHICH IS LIGHTER IN WEIGHT AND THUS GIVES HIGHER ACCELERATION FOR SAME MOTOR POWER OUTPUT.
- ACCELERATING UP TO 80 MPH INCURS SIGNIFICANT ENERGY PENALTIES DUE TO ENERGY LOSS TERMS THAT ARE A FUNCTION OF VELOCITY AND VELOCITY SQUARED.

EXHIBIT II-1
ACCELERATION RESPONSE DIAGRAM



Source: Booz·Allen Modification of BART Specification.

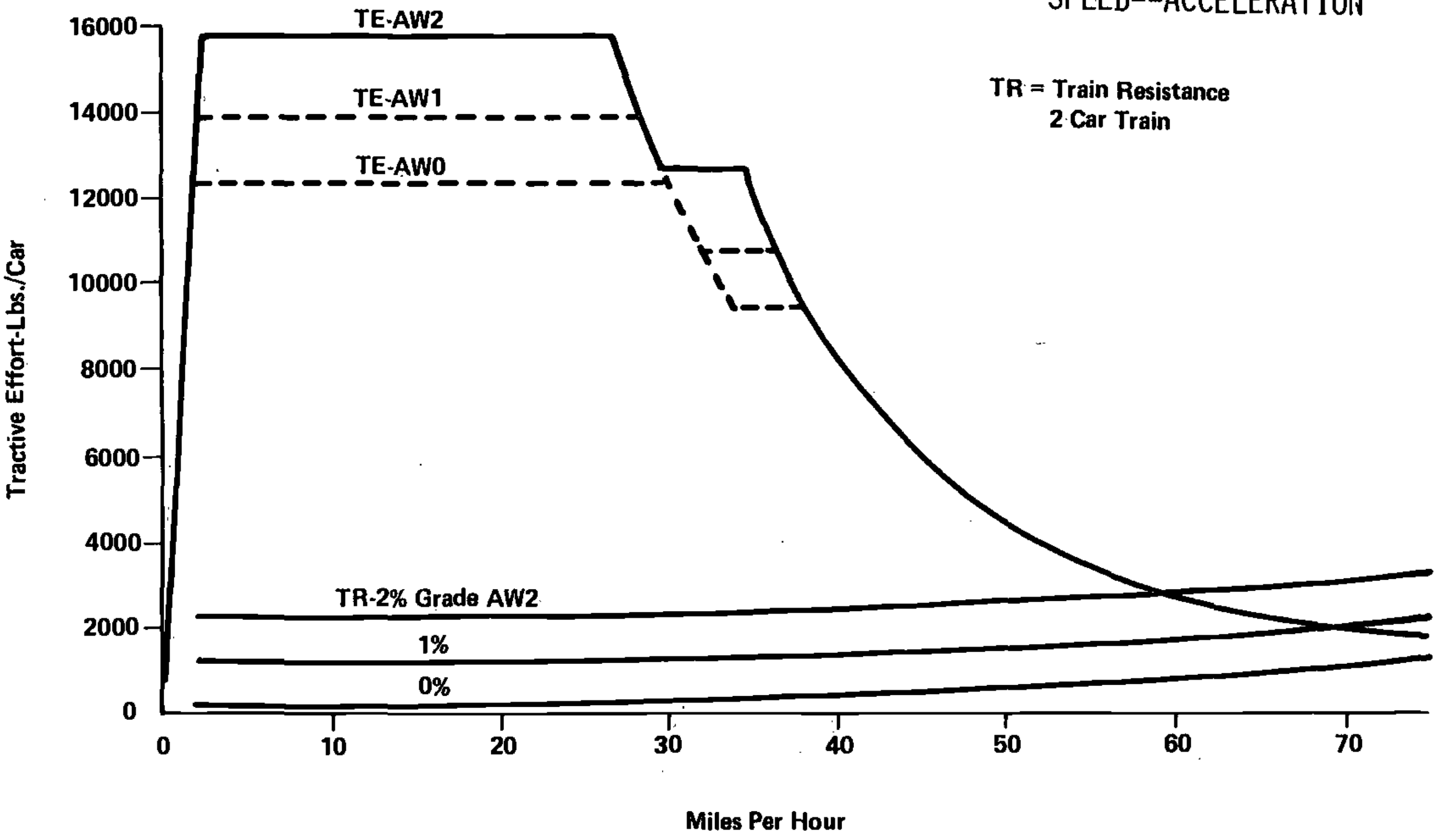
- THE ACCELERATION VERSUS SPEED CHARACTERISTIC OF THE BALTIMORE/MIAMI PROCUREMENT SPECIFICATION, SHOWN IN EXHIBIT II-2, REPRESENTS A MEDIUM PERFORMANCE SYSTEM:

  - 750 VOLTS DC TRACTION POWER SUPPLY
  - TOP SPEED OF 70 MPH
  - FULL ACCELERATION UP TO 27 MPH

  HOWEVER, THE LOW GEAR RATIO GIVES HIGH TORQUE CAPABILITY AT LOW SPEEDS (EQUIVALENT TO 3.3 MPHPS).

- SINCE GRAVITY-ASSIST PROFILES RESULT IN HIGHER NET PERFORMANCE DURING ACCELERATION, THE ACCELERATION CHARACTERISTIC WITH HIGHER PERFORMANCE ON LEVEL TRACK HAS BEEN SELECTED FOR THE SYSTEM BASELINE FOR COMPARISON PURPOSES. FOR A SIMILAR REASON A TOP SPEED OF 70 MPH IS SELECTED FOR THE SYSTEM BASELINE AS OPPOSED TO 60 MPH.

EXHIBIT II-2
SPEED--TRACTIVE EFFORT
SPEED--ACCELERATION



Source: Baltimore/Miami Vehicle Design Review

- A NOMINAL SERVICE BRAKE RATE MUST BE SELECTED THAT PROVIDES ADEQUATE MARGIN WHEN COMPARED WITH THE MINIMUM SERVICE RATE THAT THE EQUIPMENT IS EXPECTED TO DELIVER. THE MARGIN MUST BE ADEQUATE TO PREVENT OVERSHOOTS DURING STATION STOPS.

  - A MINIMUM SERVICE RATE OF 2.7 MPHPS HAS BEEN SELECTED AS THE BASELINE WHICH IS CONSISTENT WITH COMFORT LEVELS, BRAKE COMPONENTS AND ADHESION LEVELS.

  - A NOMINAL SERVICE RATE OF 2.2 MPHPS IS CONSIDERED TO PROVIDE ADEQUATE OPERATIONAL MARGIN FOR BRAKING PERTURBATIONS. HOWEVER, ADEQUATE MARGINS MAY NOT EXIST FOR CERTAIN BRAKE FAILURES.

- SELECTION OF THE EMERGENCY BRAKE RATE IS A CRITICAL PARAMETER FOR ESTABLISHING MINIMUM SAFE HEADWAYS.

  - A MINIMUM EMERGENCY (OR VITAL SERVICE) RATE OF 2.2 MPHPS HAS BEEN SELECTED. THIS IS CONSISTENT WITH SIMILAR SYSTEMS SUCH AS WMATA AND SAO PAULO. WMATA, HOWEVER, USES A WORST CASE OF 1.65 MPHPS TO ACCOMMODATE BRAKE FAILURES.

  - A MINIMUM EMERGENCY RATE OF 2.7 MPHPS HAS BEEN IDENTIFIED AS A VARIATION FOR GREATER OPERATIONAL THROUGHPUT. HOWEVER, THIS IS CONSIDERED APPLICABLE ONLY TO TUNNEL SECTIONS WHERE WATER AND POLLUTANT CONTAMINATION OF THE RAILS IS UNLIKELY.

- A SPEED TAPER REPRESENTING AVAILABLE ADHESION AS A FUNCTION OF SPEED IS SHOWN IN EXHIBIT II-1 AND IS INCLUDED AS A VARIATION TO THE BASELINE.

THE PREFERRED PERFORMANCE CHARACTERISTICS TO BE USED FOR THIS ANALYSIS ARE SUMMARIZED IN EXHIBIT II-3.

EXHIBIT II-3
PREFERRED PERFORMANCE CHARACTERTSTICS

ELEMENT	BASELINE	VARIATTONS
TOP SPEED	70 MPH	60 MPH
ACCLERATION, BELOW 27 MPH	2.7 MPH/SECOND (MINIMUM)	NONE
ACCELERATION, ABOVE 27 MPH	EXHIBIT II-1	EXHIBIT II-2
SERVICE BRAKE RATE	2.2 MPH/SECOND (NOMINAL)	NONE
	2.7 MPH/SECOND (MINIMUM SCALE)	NONE
EMERGENCY BRAKE RATE	2.2 MPH/SECOND (MINIMUM)	2.7 MPH/SECOND (TUNNEL ONLY)
BRAKE RATE TAPER	NO TAPER	EXHIBIT II-1

3. <u>SELECTION OF THE PASSENGER CARS AND THE MINIMUM TRAIN CONSIST SIGNIFICANTLY AFFECTS SYSTEM CAPACITY, CAPITAL COSTS AND OPERATING COSTS</u>

- PEER COMMITTEE REVIEW IS REFLECTED IN THE SCRTD CRITERION FOR A CAR LENGTH OF 75 FEET.
  - MAINTENANCE COSTS ARE MINIMIZED.
  - A HIGH RATIO OF PASSENGER CAPACITY PER UNIT LENGTH OF TRAIN (AND PLATFORM) IS ACHIEVED; I.E., PROPORTION OF SPACE FOR CONTROL CABS AND COUPLER CLEARANCES IS REDUCED WITH LONGER CARS.
  - HIGH PERFORMANCE PROPULSION AND BRAKING SUBSYSTEMS ARE READILY AVAILABLE.
  - CAPITAL COST PER UNIT CAPACITY IS MINIMIZED.
- THREE SETS OF DOUBLE-LEAF DOORS PER SIDE PROVIDE ADEQUATE PASSENGER INGRESS AND EGRESS TO MINIMIZE DWELL TIMES IN THE CRITICAL PEAK PERIODS.
- SINGLE-CAR TRAINS ARE EXCLUDED DUE TO HIGH PROBABILITY OF THEIR CAUSING SYSTEM BLOCKAGE UNLESS COSTLY REDUNDANT PROPULSION AND BRAKE SUBSYSTEMS ARE PROVIDED. ONLY MULTIPLES OF TWO-CAR COMBINATIONS ARE CONSIDERED IN THIS ANALYSIS. THIS ACCOMMODATES POSSIBLE SELECTION OF A MARRIED PAIR ALTERNATIVE.

4. MAXIMUM TRAIN CONSIST HAS CONSIDERABLE EFFECT ON STATION COST AND OPERATING COST

- TWO-CAR CONSISTS CANNOT MEET PEAK-CAPACITY REQUIREMENTS:
  - HEADWAYS SIGNIFICANTLY SHORTER THAN NINETY SECONDS ARE REQUIRED, OR
  - RESULTANT LOW AVERAGE SPEEDS WILL NOT PROVIDE REASONABLE SERVICE LEVELS.
- EIGHT-CAR CONSISTS INVOLVE INCREASED COSTS THAT MAY BE PROHIBITIVE.
  - HIGH STATION CAPITAL COST DUE TO PLATFORM LENGTHS
  - FREQUENT DIVISION OF LARGER CONSISTS REQUIRED TO EFFICIENTLY MEET OFF-PEAK DEMANDS, WHICH MAY INCREASE OPERATING COSTS AND REDUCE RELIABILITY
  - LONGER POCKET TRACKS REQUIRED TO STORE EIGHT-CAR CONSISTS
  - INCREASED SUBSTATION CAPACITY REQUIREMENTS.

- PRELIMINARY INDICATIONS ARE FOR MAXIMUM CONSIST LENGTHS OF FOUR OR SIX CARS. THIS IS VERIFIED BY THE OPERATING PLAN OF THE NEXT CHAPTER. HOWEVER, DISTINCT ADVANTAGES AND DISADVANTAGES STILL EXIST BETWEEN FOUR- AND SIX-CAR CONSISTS. (SEE EXHIBIT II-4.)

- A SIX-CAR CONSIST MAXIMUM WAS SELECTED FOR THE BASELINE WITH A FOUR-CAR CONSIST MAXIMUM INCLUDED IN THE VARIATIONS AS A KEY ALTERNATIVE.

EXHIBIT II-4
PRELIMINARY COMPARISON OF FOUR- AND SIX-CAR CONSISTS

FOUR-CAR CONSISTS

ADVANTAGES

0 LOWER STATION COSTS
  - SHORTER PLATFORMS
  - LOWER PEAK DEMAND ON STATION EQUIPMENT SUCH AS FARE COLLECTION AND ESCALATORS

0 HIGHER PROBABILITY OF REGENERATION

DISADVANTAGES

0 MORE PART-TIME AND FULL-TIME OPERATORS REQUIRED

0 SHORTER DESIGN AND OPERATING HEADWAYS REQUIRED

SIX-CAR CONSISTS

DISADVANTAGES

0 LONGER TIME REQUIRED TO TRANSVERSE VERTICAL CURVES OF A GRAVITY ASSIST PROFILE

0 LESS EFFICIENT PASSENGER DISTRIBUTION ON PLATFORM

0 LENGTH OF POCKET TRACK

ADVANTAGES

0 LOWER LABOR COSTS FOR OPERATIONS

0 REDUCED NET EFFECT OF PROPULSION AND BRAKE FAILURES

5. SELECTION OF THE PROPULSION SUBSYSTEM IS FUNDAMENTAL TO THE OPTIONS AVAILABLE FOR ENERGY MANAGEMENT

- CAM (OR CONTACTOR) CONTROLLERS INHERENTLY DISSIPATE CONSIDERABLE HEAT ENERGY IN THE CONTROL RESISTORS WHILE ACCELERATING.
- CAM CONTROLLERS ARE MORE EFFICIENT AT THE BALANCING SPEED OF THE PROPULSION SYSTEM. HOWEVER, THIS IS NOT ACHIEVED FOR SIGNIFICANT PERIODS FOR THE SHORT STATION SPACINGS OF RAIL RAPID TRANSIT SYSTEMS.
- THYRISTOR CHOPPERS OFFER GREATER ADVANTAGES IN CONTROL FLEXIBILITY, ARE ENERGY EFFICIENT DURING ACCELERATION AND ARE MORE ADAPTABLE TO REGENERATIVE BRAKING. HOWEVER, THEIR RELIABILITY RECORD HAS BEEN POOR IN THE UNITED STATES. THESE HEAVY RAIL APPLICATIONS ARE:

	1960 TO 1969	1970 TO 1979
BART	250 UNITS	200 UNITS
MARTA	---	70 UNITS

HOWEVER, EXPERIENCE IN EUROPE AND SAO PAULO, BRAZIL, INDICATES HIGH LEVELS OF RELIABILITY ARE ACHIEVABLE. INCREASED CONFIDENCE IN THE FUTURE OF THYRISTOR CHOPPERS IS EXPRESSED IN THE RECENT ORDERS BY DOMESTIC HEAVY RAIL PROPERTIES, SHOWN BELOW:

	1970 TO 1979	1980 TO 1981
BALTIMORE/MIAMI	208 UNITS	ADD-ON OPTIONS
WMATA	12 UNITS	200 UNITS

- ADDITIONAL ADVANTAGES AND DISADVANTAGES OF CAM CONTROL AND THYRISTOR CHOPPERS ARE SUMMARIZED IN EXHIBIT II-5.

EXHIBIT II-5

COMPARISON OF CAM AND CHOPPER PROPULSION EQUIPMENT

CAM ADVANTAGES	CHOPPER DISADVANTAGES
LOWEST INITIAL COST	ADDITIONAL COST OF APPROX. $17,000/CAR
LONGER SERVICE PROVEN RECORD	INITIAL LOW RELIABILITY IN UNITED STATES
LOWEST WEIGHT CONTROL SYSTEM	UP TO 20% HEAVIER DUE TO CAPACITORS, LINE AND MOTOR REACTORS
SPECIAL COOLING NOT REQUIRED	SEPARATE AND FORCED AIR VENTILATION NOISE
FEWER MAINTENANCE SKILLS REQUIRED	POWER CONTROL ELECTRONICS SKILLS REQUIRED
PROVEN INTEGRATION WITH CODE RATE SIGNALING	HIGHER ELECTROMAGNETIC INTERFERENCE LEVELS

CAM DISADVANTAGES	CHOPPER ADVANTAGES
MORE MAINTENANCE FOR CONTACT TIPS	NO PREVENTATIVE MAINTENANCE REQUIRED FOR POWER ELECTRONICS
STEP CHANGES IN ACCELERATION/ DECELERATION	BETTER RIDE QUALITY
CONTROL INTEGRATION DIFFICULTY LEADS TO RELIABILITY PROBLEMS	BETTER ADAPTATION TO AUTOMATIC CONTROL
REQUIRES SEPARATE STATIC INVERTER TO REGENERATE	ABILITY TO REGENERATE
LIMITED REGENERATION EXPERIENCE	PROVEN REGENERATION RECORD
HIGHER CONTENT OF MACHINED PARTS	COST TRENDS IN SEMI-CONDUCTOR DEVICES
STEP CHANGES IN TORQUE CAUSE MORE SLIP-SPINS	CONTINUOUSLY VARIABLE CONTROL FOR SLIP-SPIN CORRECTION
SPEED REGULATION IS ENERGY INEFFICIENT	CONTINUOUSLY VARIABLE AND EFFICIENT SPEED REGULATION

O THYRISTOR CHOPPER CONTROL WAS SELECTED AS THE BASELINE PROPULSION/ELECTRIC BRAKE SUBSYSTEM BECAUSE OF ITS HIGHER POTENTIAL FOR ENERGY SAVINGS IN THE SCRTD STATES LINE APPLICATION.

O CAM CONTROL PROPULSION IS INCLUDED AS AN ALTERNATIVE TO THE BASELINE BECAUSE OF ITS LOWER INITIAL COST, LIGHTER WEIGHT AND EXTENSIVE DEPLOYMENT IN THE UNITED STATES, PRIMARILY AT NEW YORK AND CHICAGO.

O AC DRIVE SYSTEMS OFFER INHERENT ADVANTAGES IN SLIP-SLIDE CONTROL UNDER ADVERSE ADHESION CONDITIONS. THESE SYSTEMS ARE EXPERIMENTAL AND ARE NOT CONSIDERED AS A VIABLE VARIATION TO THE BASELINE PROPULSION SUBSYSTEM.

6. SELECTION OF THE AUTOMATIC TRAIN PROTECTION CHARACTERISTICS DETERMINES THE MINIMUM SAFE HEADWAYS THAT CAN BE ACHIEVED. CRITICAL POINTS ARE FOLLOWING MOVES AT THE STATION ZONES AND REVERSE TURNBACKS AT TERMINAL ZONES

- FIXED-BLOCK SIGNALING IS ABLE TO ACHIEVE 90-SECOND DESIGN HEADWAYS WITH 20-SECOND DWELL TIMES WHERE NOT CONSTRAINED BY GRADE, HORIZONTAL CURVES AND CROSSOVER LAYOUTS. HOWEVER, 120-SECOND DESIGN HEADWAY IS MORE PRACTICAL IF INTERFERENCE-FREE MOVEMENT AND HIGHER AVERAGE SPEED ARE CRITICAL OBJECTIVES.

- ADEQUATE MARGIN SHOULD BE ALLOWED BETWEEN DESIGN HEADWAYS AND AVERAGE OPERATING HEADWAYS TO ALLOW FOR OPERATIONAL DISTURBANCES. FOR EXAMPLE, A 90-SECOND DESIGN HEADWAY MAY REQUIRE A 30-SECOND MARGIN RESULTING IN A 120-SECOND OPERATIONAL HEADWAY.

- FIXED BLOCK HAS BEEN SELECTED AS THE BASELINE SINCE IT CAN BE IMPLEMENTED WITH PROVEN SIGNALING EQUIPMENT AND CAN ACHIEVE HEADWAYS CONSISTENT WITH THE SCRTD REQUIREMENTS.

- EXHIBIT II-6 SUMMARIZES THE KEY TECHNICAL FEATURES OF VARIOUS TRAIN CONTROL SYSTEMS.

EXHIBIT II-6
AUTOMATIC TRAIN CONTROL SYSTEMS: TECHNICAL PHILOSOPHY, KEY ELEMENTS, MANUFACTURERS AND PROPERTIES

*SEL–ITT
SIEMENS TRANSCONTROL
AEG–TELEFUNKEN

**JEUMONT SCHNEIDER
ALSTHOM
INTER–ELEC

	MANUFACTURER				
	UNION SWITCH & SIGNAL	GENERAL RAILWAY SIGNAL	WESTINGHOUSE ELECTRIC CORP.	GERMAN *	FRENCH **
1. AUTOMATIC TRAIN PROTECTION APPROACH: WAYSIDE AND STATION	FIXED BLOCK VITAL RELAY BASED	FIXED BLOCK VITAL RELAY BASED	FIXED BLOCK VITAL RELAY BASED	MOVING BLOCK MINI-COMPUTER BASED	FIXED BLOCK VITAL RELAY BASED (WELDABLE CONTACTS)
2. AUTOMATIC TRAIN PROTECTION APPROACH: CAR CARRIED	VITAL CIRCUITS AND RELAY LOGIC	VITAL CIRCUITS AND RELAY LOGIC	REDUNDANT MICRO–PROCESSORS WITH VITAL COMPARISON	REDUNDANT MICRO–PROCESSORS	DIVERSE LOGIC WITH VITAL COMPARISON
3. RECENT APPLICATIONS-PROPERTIES	BALTIMORE/MIAMI–ATP, ATS MBTA–ATO	WMATA–ATP, ATO, ATS MARTA–ATP, ATS MBTA–ATO	BART SAO PAULO	BERLIN SUBWAY	PARIS MEXICO CITY RIO DE JANEIRO
4. TRAIN DETECTION	AUDIO AND POWER FREQUENCY TRACK CIRCUITS	AUDIO AND POWER FREQUENCY TRACK CIRCUITS	AUDIO AND POWER FREQUENCY TRACK CIRCUITS	ACTIVE VEHICLE TRANSMISSION	IMPULSE TRACK CIRCUITS (J–S)
5. INTERLOCKING PROTECTION	RELAY LOGIC	RELAY LOGIC	RELAY LOGIC	RELAY AND SOLID STATE LOGIC	RELAY AND SOLID STATE LOGIC
6. TRAIN SEPARATION	FIXED BLOCK	FIXED BLOCK	FIXED BLOCK	MOVING BLOCK	FIXED BLOCK
7. CAB SIGNALLING	CODE RATE	CODE RATE	DIGITAL (FSK) COMMA–FREE CODE	HIGH SPEED FSK CODE	IMPULSE A. F.
8. SPEED/OVERSPEED CONTROL	SINGLE VITAL SENSOR FREQUENCY DETECTION	SINGLE OR REDUNDANT SENSORS LEVEL DETECTION	MULTIPLE SENSORS LEVEL DETECTION AND COMPARISON	REDUNDANT SENSORS AND CROSSOVER DETECTION	TRANSPOSED CABLE TIMING
9. BRAKE ASSURANCE	MERCURY U–TUBE	NONE RECENTLY B.O.S. (US&S)	PROTOTYPE ELECTRONICS	EMERGENCY BRAKE FOR PROFILE VIOLATION	EMERGENCY BRAKE FOR PROFILE VIOLATION
10. INTERFACE EQUIPMENT	RELAYS	RELAYS	RELAYS AND SOLID STATE DRIVERS	RELAYS AND SOLID STATE DRIVERS	RELAYS AND SOLID STATE DRIVERS
11. TRAIN OR TRACK SURVEILLANCE	BROKEN RAIL DETECTION	BROKEN RAIL DETECTION	BROKEN RAIL DETECTION	VISUAL	BROKEN RAIL DETECTION
12. AUTOMATIC DOOR PROTECTION: AND OPERATION	VITAL CIRCUITS (ATP)	VITAL CIRCUITS (ATP)	VITAL CIRCUIT PRINCIPLES SEPARATE DATA LINK	CHECKED LOGIC	CHECKED LOGIC
13. SPEED REGULATION	DISCRETE LOGIC	DISCRETE LOGIC	MICROPROCESSOR	MICROPROCESSOR	MICROPROCESSOR AND ANALOG CIRCUITS
14. STATION STOPPING	MARKERS	MARKERS	SEPARATE TRANSPOSED CABLE	VIA COMMON DATA LINK	SEPARATE TRANSPOSED CABLE
15. ACCELERATION CONTROL OR PERFORMANCE CONTROL	OPTIONAL	OPTIONAL	MULTIPLE OPTIONS	OPTIONAL	LIMITED OPTIONS
16. AUTOMATIC TRAIN SUPERVISION: ROUTE ASSIGNMENT, CONTROL AND TRAIN DISPATCHING	CENTRAL COMPUTER AND LOCAL LOGIC	CENTRAL COMPUTER AND LOCAL LOGIC	CENTRAL COMPUTER AND LOCAL LOGIC	CENTRAL COMPUTER AND LOCAL LOGIC	CENTRAL COMPUTER AND LOCAL LOGIC
17. AUTOMATIC TRAIN SUPERVISION: PERFORMANCE MONITORING, ALARMS AND MALFUNCTION RECORDING AND RECORD KEEPING SYSTEM	CENTRAL PROCESSING	CENTRAL PROCESSING	CENTRAL PROCESSING LOCAL MICROPROCESSOR	CENTRAL PROCESSING LOCAL PROCESSING POTENTIAL	CENTRAL PROCESSING

7. ENERGY SAVINGS MAY BE REALIZED FROM COAST STRATEGIES AND ACCELERATION CONTROL WHICH REQUIRE A MODERATELY SOPHISTICATED TRAIN CONTROL SYSTEM

- HOWEVER, THE DEVELOPMENT RISKS ARE CONSIDERED LOW SINCE THE FUNCTIONS CAN BE MADE EFFECTIVE UNDER THE SAFE RESTRICTIONS IMPOSED BY THE AUTOMATIC TRAIN PROTECTION.

- STATE-OF-THE-ART TECHNOLOGY IS AVAILABLE AND SIMILAR HARDWARE IS BEING DEPLOYED IN OTHER RAIL RAPID SYSTEMS.

- BECAUSE ENERGY MINIMIZATION REQUIRES OPTIMAL SCHEDULING AND OPERATIONAL CONTROL, DISTRIBUTED OR CENTRAL COMPUTER PROCESSING IS MANDATORY FOR SUPERVISORY CONTROL OF THE SYSTEM. IN ADDITION, CORRECT MOVEMENT OF TRAINS BECOMES MORE CRITICAL FOR DIPPED PROFILES IF THE FULL SAVINGS ARE TO BE REALIZED.

8. THE COMBINATION OF TRUCKS, GEARS, MOTORS AND PROPULSION POWER CONTROL UNITS DETERMINES THE SENSITIVITY OF TRAIN CONSISTS TO PROPULSION FAILURES.

- LOCOMOTIVE TRUCKS HAVE BEEN DESIGNED THAT MINIMIZE AXLE LOAD TRANSFER ON A GRADE, THUS ENSURING MAXIMUM ADVANTAGE IS TAKEN OF AVAILABLE ADHESION. CORRESPONDING PERFORMANCE FOR A RAIL RAPID TRANSIT TRUCK MAY REQUIRE A SIGNIFICANT DEVELOPMENT RISK, AND THEREFORE STANDARD RAIL RAPID TRUCK TECHNOLOGY HAS BEEN SELECTED FOR THE BASELINE SYSTEM.

- IMPROVEMENTS IN PROPULSION AVAILABILITY CAN BE ACHIEVED BY SPECIFYING TWO CHOPPERS PER CAR. A RELATED ADVANTAGE IS THE ABILITY TO PROVIDE SEPARATE SLIP-SPIN CONTROL FOR EACH TRUCK. IN ORDER TO MINIMIZE COSTS, ONE CHOPPER PER CAR HAS BEEN SELECTED AS THE BASELINE WITH SEPARATE CHOPPER CONTROL PER TRUCK AS AN ALTERNATIVE.

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EXHIBIT II-7 SUMMARIZES THE VEHICLE, PROPULSION AND TRAIN CONTROL SUBSYSTEM BASELINE AND VARIATIONS TO THE BASELINE. THE EXHIBIT REFLECTS PROVEN TECHNOLOGY AND SOME DEVELOPMENT REQUIREMENTS, AND CONSIDERATIONS ARE:

- LOWEST RISKS ARE ASSOCIATED WITH SPECIFICATION OF PROVEN TECHNOLOGY.
- SUBSTANTIAL BENEFITS MAY BE REALIZED IF STATE-OF-THE-ART TECHNOLOGY IS ADVANCED WHILE ENSURING THAT RISKS ARE MANAGED.

EXHIBIT II-7
SUMMARY OF SUBSYSTEM CHARACTERISTICS

ELEMENT	PARAMETER	BASELINE	VARIATIONS
VEHICLE BODY	LENGTH	75 FEET	NONE
	WEIGHT (EMPTY)	75,000 LB	72,000 LB (ALUMINUM)
	WEIGHT (MAXIMUM COMFORTABLE LOAD)	101,400 LB	98,400
	SEATING CAPACITY	75	NONE
VEHICLE DOORS	NUMBER PER SIDE	3 DOUBLE	NONE
	WIDTH	4 FT 2 IN	NONE
	OPEN & CLOSE TIME	TOTAL =< 10 SECONDS	NONE
	END DOORS	BOTH ENDS, ALL CARS	NONE
TRAIN CONSIST	BASIC UNIT	TWO-CAR UNITS	NONE
	MAXIMUM CONSIST	6 CARS (3 MARRIED PAIRS)	4 CARS
VEHICLE PROPULSION	MOTOR CONTROL	REGENERATIVE CHOPPER	CAM CONTROL WITHOUT REGENERATION
	TRACTION MOTORS	4 PER CAR	NONE
	CHOPPER CONFIGURATION	ONE CHOPPER PER CAR	ONE CHOPPER PER TRUCK**
	SLIP-SPIN CONTROL	PER CAR	PER TRUCK
	CUT-OUT MODE	PER CHOPPER	NONE
	THIRD RAIL VOLTAGE	750 VOLTS DC	NONE
	TORQUE LIMIT CONTROL	FIXED (STANDARD)	HIGHER TORQUE OPTION FOR RECOVERY OPERATIONS**

---

* RELATIVE TO CIVIL SPEED LIMIT.

** SOME DEVELOPMENT REQUIREMENTS.

EXHIBIT II-7
(CONTINUED)

ELEMENT	PARAMETER	BASELINE	VARIATIONS
VEHICLE TRUCKS		STANDARD HEAVY RAIL RAPID TECHNOLOGY	NONE
AUTOMATIC TRAIN PROTECTION	BLOCK DESIGN	FIXED BLOCK	NONE
	NON-ZERO SPEED CODES	SIX MAXIMUM	SEVEN MAXIMUM
	MAXIMUM REACTION TIME	7.0 SECONDS	4.5 SECONDS **
	OVERSPEED TOLERANCE	-0, +1.5MPH*	NONE
	CUT-OUT-CAR SPEED REDUCTIONS	TWO-LEVEL**	SINGLE-LEVEL
AUTOMATIC TRAIN OPERATION	SPEED REGULATION BAND	-1 TO -5 MPH*	-1 TO -2.5 MPH*, **
	PROGRAM STOP ENTRY SPEED	70 MPH	NONE
	PROGRAM STOP ACCURACY	± 5 FEET (2Σ)	NONE
	STATION STOP POSITIONS	SINGLE POSITION	NONE
	COAST STRATEGY	AUTOMATIC**	MANUAL, OR NO STRATEGY
	ACCELERATION	CLOSED LOOP**	OPEN LOOP

---

* RELATIVE TO CIVIL SPEED LIMIT.

** SOME DEVELOPMENT REQUIREMENTS.

III. PRELIMINARY OPERATING PLAN

III. PRELIMINARY OPERATING PLAN

1. A PRELIMINARY OPERATING PLAN WAS PREPARED FOR THE VERTICAL PROFILE ANALYSIS TO EVALUATE THE FOLLOWING:

   - O TOTAL TRACTION ENERGY CONSUMPTION: AN ANALYSIS OF THE MAGNITUDE OF ENERGY CONSUMED BY TRACTION POWER REQUIRES A DETERMINATION OF THE LEVELS OF SERVICE TO BE PROVIDED. THE ACCELERATION, BRAKING AND COASTING REQUIREMENTS ENCOUNTERED BY EACH TRAIN OPERATING ALONG THE ROUTE CAN BE OBTAINED FROM THE OPERATING PLAN.

   - O RESTRICTED TRAIN OPERATION: NORMAL PERTURBATIONS IN SERVICE HEADWAY WILL SOMETIMES REQUIRE A TRAIN TO OPERATE AT A RESTRICTED SPEED, DUE TO THE TRAIN AHEAD. THE EFFECT ON ENERGY CONSUMPTION AND VEHICLE PERFORMANCE REQUIREMENTS OF OPERATING AT RESTRICTED SPEED ON A STEEP GRADE MUST BE EXAMINED. THE SERVICE HEADWAY DEVELOPED IN THE OPERATING PLAN, ALONG WITH DESIGN HEADWAY OF THE SIGNAL BLOCK LAYOUT, WILL INFLUENCE THE PROBABILITY OF A TRAIN ENCOUNTERING A RESTRICTED SIGNAL.

   - O FAILURE MANAGEMENT: EXPERIENCE HAS SHOWN THAT IN-SERVICE FAILURES WILL OCCUR AND MUST BE ANTICIPATED. A DIPPED PROFILE WILL AFFECT THE OPERATIONAL IMPACT OF A REDUCTION IN A TRAIN'S PROPULSION/BRAKING COMPONENTS (I.E., FIVE LIVE CARS CAN PUSH ONE DEAD CAR UP A GRADE MORE EASILY THAN CAN THREE LIVE CARS). THE OPERATING PLAN DEFINES TRAIN CONSIST REQUIREMENTS.

   - O OPERATING COSTS: OPERATING ALTERNATIVES THAT SEEK TO TAKE MAXIMUM ADVANTAGE OF A DIPPED PROFILE MAY HAVE COSTS OTHER THAN THOSE ASSOCIATED WITH ENERGY CONSUMPTION. EXAMPLES OF THESE ARE CROSSOVER AND POCKET TRACK LOCATIONS.

2. AN OPERATING PLAN DESCRIBES THE TRAIN SERVICE OBJECTIVES:

- O PROVIDE ADEQUATE CAPACITY FOR THE MOVEMENT OF THE PROJECTED RIDERSHIP
- O SATISFY POLICIES DEFINING SERVICE STANDARDS, SUCH AS HOURS OF SERVICE, LOAD FACTORS AND MINIMUM FREQUENCIES OF SERVICE
- O ADHERE TO THE OPERATING CHARACTERISTICS OF BOTH ROUTE AND VEHICLE.

THE PRELIMINARY OPERATING PLAN DEVELOPED FOR THIS ANALYSIS ASSUMED THAT ALL TRAINS WOULD MAKE ALL STOPS, OPERATING BETWEEN THE TWO TERMINALS. THE FOLLOWING DATA WERE THEREFORE REQUIRED:

- O RIDERSHIP CHARACTERISTICS = PASSENGER FLOW BY TIME OF DAY THROUGH THE MAXIMUM LOAD POINT.
- O SERVICE STANDARDS = HOURS OF SERVICE, LEVELS OF SERVICE, VEHICLE LOAD FACTORS.
- O TRAIN CYCLE TIMES = STATION-TO-STATION RUN TIMES, STATION DWELL TIMES AND TERMINAL RECOVERY TIMES.

3. RIDERSHIP DATA FROM SEVERAL SOURCES WERE UTILIZED:

- O BARTON-ASCHMAN ASSOCIATES HAS PREPARED PRELIMINARY RIDERSHIP ESTIMATES FOR THE 24-HOUR, PEAK-HOUR AND PEAK 20-MINUTE PERIODS. THESE ESTIMATES ARE:

  - 24-HOUR (TWO-WAY): 164,348
  - PEAK HOUR (ONE-WAY): 14,791, (9 PERCENT OF TOTAL DAILY)
  - PEAK 20-MINUTE (ONE-WAY): 5,620, (38 PERCENT OF PEAK HOUR).

  THE PEAK PERIOD ESTIMATES WERE ASSUMED FOR OUR PURPOSES TO BE APPLICABLE TO BOTH MORNING AND EVENING PEAK HOURS.

- O SIXTEEN-HOUR (6 AM TO 11 PM) CORDON COUNTS* OF ALL BUS PASSENGERS ENTERING AND LEAVING DOWNTOWN LOS ANGELES PERMITTED AN EXTRAPOLATION OF THE BARTON-ASCHMAN ESTIMATES. ASSUMPTIONS WERE MADE TO EXPAND THESE DATA FURTHER TO ESTIMATE RIDERSHIP FOR A 20-HOUR PERIOD. THE RESULTING RIDERSHIP BY TIME OF DAY IS ILLUSTRATED IN EXHIBIT III-1. THE ASSUMPTIONS ARE:

  - MINIMAL RIDERSHIP FROM 11:00 PM TO 1:30 AM AND FROM 5:30 AM TO 6:00 AM (LESS THAN 1/2 PERCENT OF TOTAL RIDERSHIP PER HALF-HOUR).

  - NON-ROUTE-SPECIFIC CORDON COUNT DATA CAN BE APPLIED TO THE STARTER LINE.

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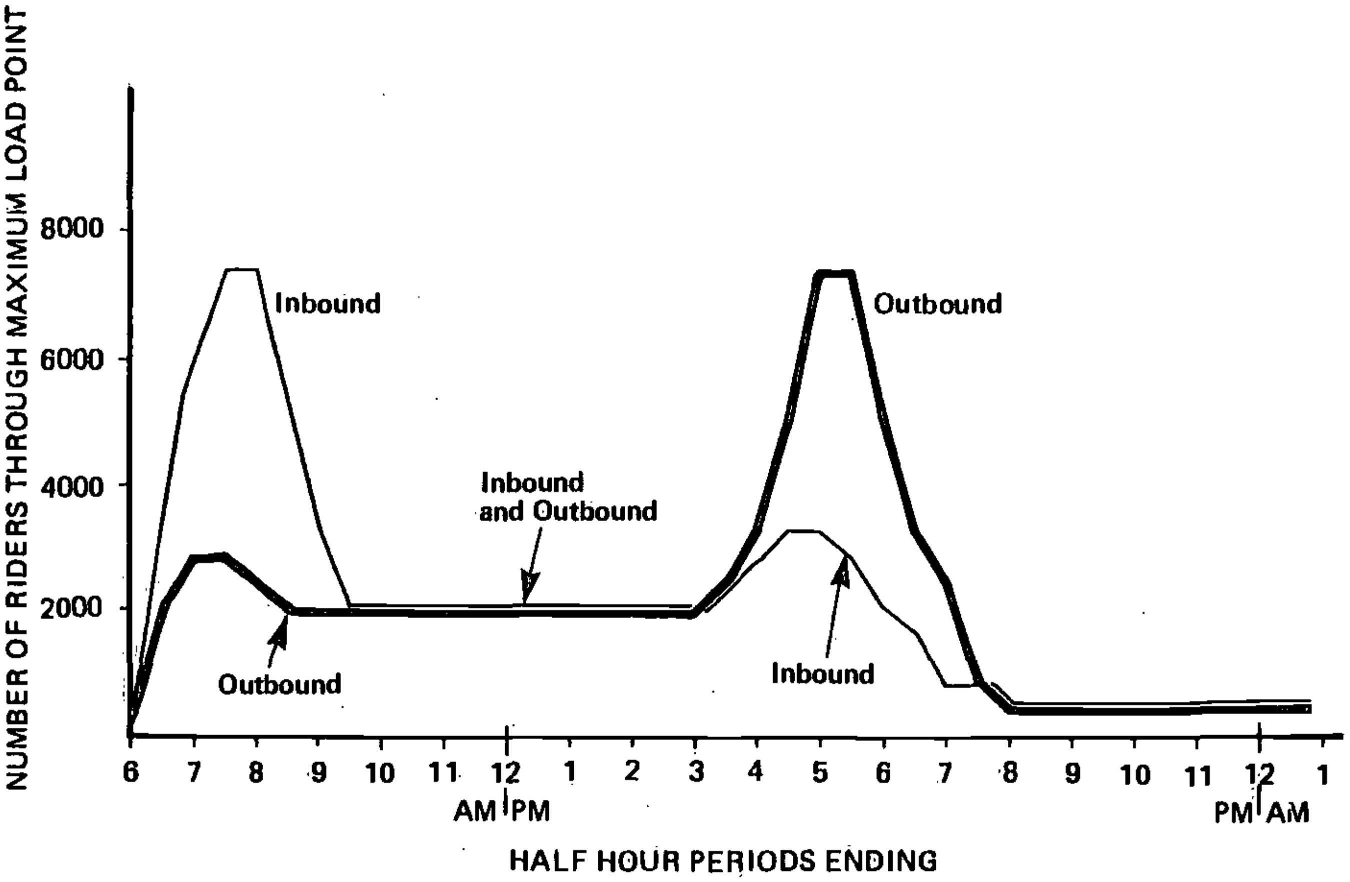
* SOURCE: SCRTD SCHEDULING DEPARTMENT.

EXHIBIT III-1
RIDERSHIP BY TIME OF DAY



4. PRELIMINARY SERVICE STANDARDS WERE ESTABLISHED FOR THE PURPOSES OF THIS ANALYSIS:

- LOAD FACTOR: 165 PASSENGERS PER CAR (COMFORTABLE LOAD PER DESIGN CRITERIA)
- CONSIST: TWO-CAR UNITS, WITH A MAXIMUM TRAIN OF SIX CARS*
- HOURS OF SERVICE*: 20 HOURS, 5:30 AM TO 1:30 AM, 7 DAYS PER WEEK (SUNDAYS FROM 7:30 AM)
- LEVELS OF SERVICE*:

WEEKDAYS:	EARLY MORNING AND NIGHT:	15-MINUTE HEADWAY
	PEAK PERIODS:	TO MEET DEMAND (3.5 TO 6.0 MINUTES)
	MIDDAY:	7-1/2-MINUTE HEADWAY
SATURDAYS:	EARLY MORNING AND NIGHT:	15-MINUTE HEADWAY
	MIDDAY:	10-MINUTE HEADWAY
SUNDAYS:	ALL DAY:	15-MINUTE HEADWAY.

---

* SOURCE: BOOZ, ALLEN ASSUMPTIONS.

5. CYCLE TIMES REQUIRE AN ESTIMATE OF RUN, DWELL AND TURNBACK TIMES

- USING AN AVERAGE DWELL TIME OF 30 SECONDS* PER STATION AND A TERMINAL TURNBACK TIME OF 5 MINUTES* (AT EACH TERMINAL), A MINIMUM CYCLE TIME OF 73 MINUTES WAS OBTAINED AS PRESENTED IN EXHIBIT III-2.

- RUN TIMES FROM TERMINAL TO TERMINAL WERE MANUALLY CALCULATED FROM AVAILABLE DATA ON ROUTE PROFILE AND VEHICLE PERFORMANCE CHARACTERISTICS.

  - THE ROUTE PROFILE IS ILLUSTRATED IN EXHIBIT III-3.

  - VEHICLE MOTOR CHARACTERISTICS WERE ASSUMED TO BE SIMILAR TO THOSE OF THE BART CARS. MAXIMUM ACCELERATION AND BRAKING RATES WERE ASSUMED TO BE 2.7 MPHPS AND 2.2 MPHPS, RESPECTIVELY. PERFORMANCE CHARACTERISTICS UTILIZED IN THIS ANALYSIS ARE PRESENTED IN EXHIBITS III-4, III-5 AND III-6.

- IT IS IMPORTANT TO NOTE THAT THE MINIMUM CYCLE TIME REPRESENTS A CONDITION APPROACHING BEST-CASE. THE MINIMUM CYCLE TIME ALSO CONSUMES THE MOST ENERGY. A TRADEOFF STUDY BETWEEN TRIP TIME AND ENERGY COSTS CAN BE CONDUCTED BY LIMITING THE MAXIMUM SPEED BETWEEN STATIONS TO VARIOUS VALUES BELOW 70 MPH.

---

* SOURCE: BOOZ, ALLEN FLEET SIZE STUDY FOR BALTIMORE METRO.

EXHIBIT III-2
MINIMUM CYCLE TIME

5 MIN

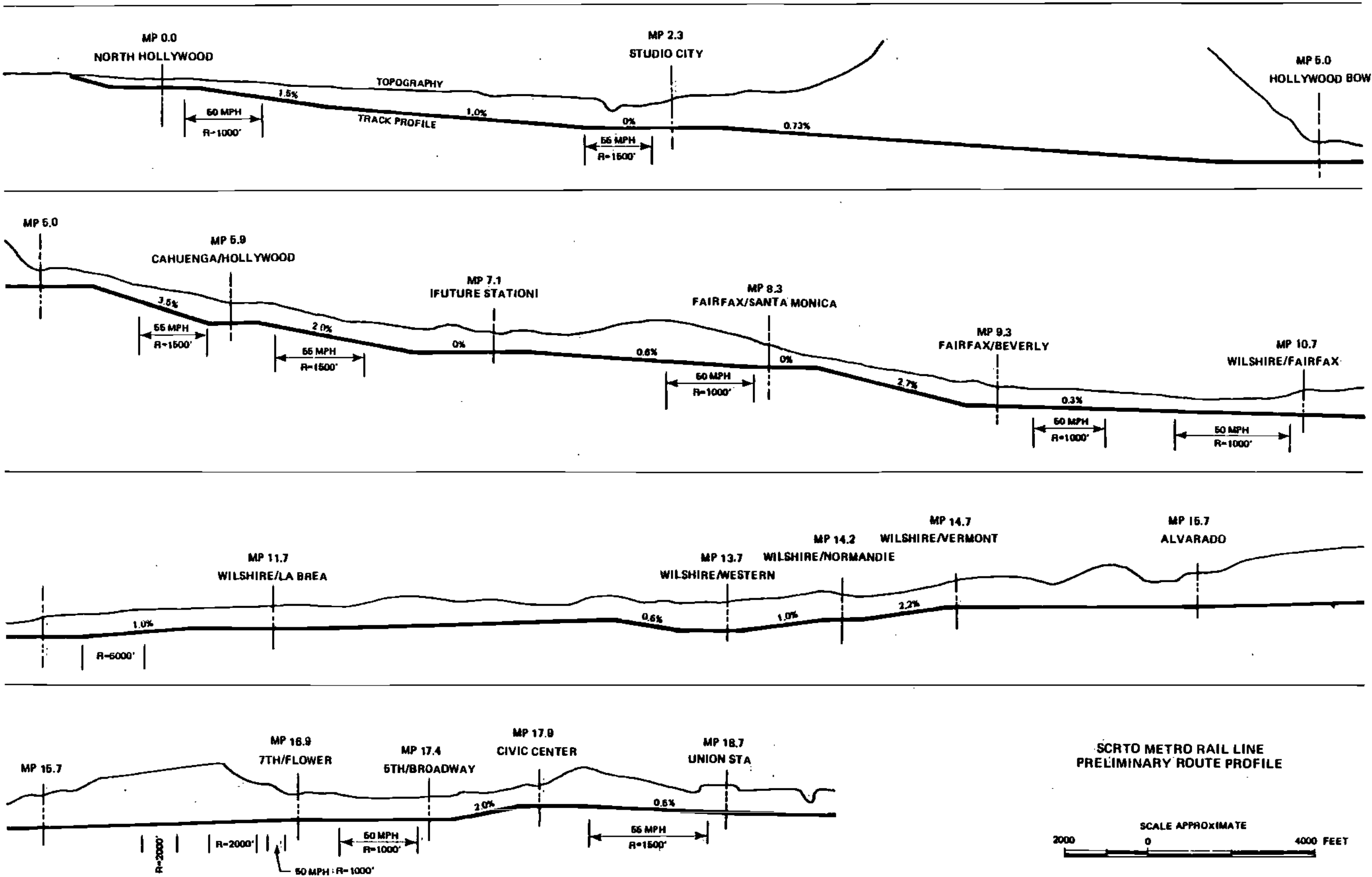
MILEPOST	STATION	INBOUND	OUTBOUND
0.0	NORTH HOLLYWOOD	DP 0:00	AR 1:08
2.3	UNIVERSAL CITY	0:03	1:05^2
5.0	HOLLYWOOD BOWL	0:06^2	1:02
5.9	CAHUENGA/HOLLYWOOD	0:08	1:00^2
8.3	FAIRFAX/SANTA MONICA	0:11^2	0:57
9.3	FAIRFAX/BEVERLY	0:13^2	0:55
10.7	WILSHIRE/FAIRFAX	0:16	0:52^2
11.7	WILSHIRE/LABREA	0:17^2	0:51
13.7	WILSHIRE/WESTERN	0:20^2	0:48
14.2	WILSHIRE/NORMANDIE	0:22	0:46^2
14.7	WILSHIRE/VERMONT	0:23	0:45^2
15.7	WILSHIRE/ALVARADO	0:25	0:43^2
16.9	7TH/FLOWER	0:27	0:41^2
17.4	5TH/BROADWAY	0:28^2	0:40
17.9	CIVIC CENTER	0:30	0:38^2
18.7	UNION STATION	AR 0:31^2	DP 0:36^2

5 MIN

^{2}DENOTES HALF-MINUTES.

NOTE: Stop at future station (MP7.1) included.

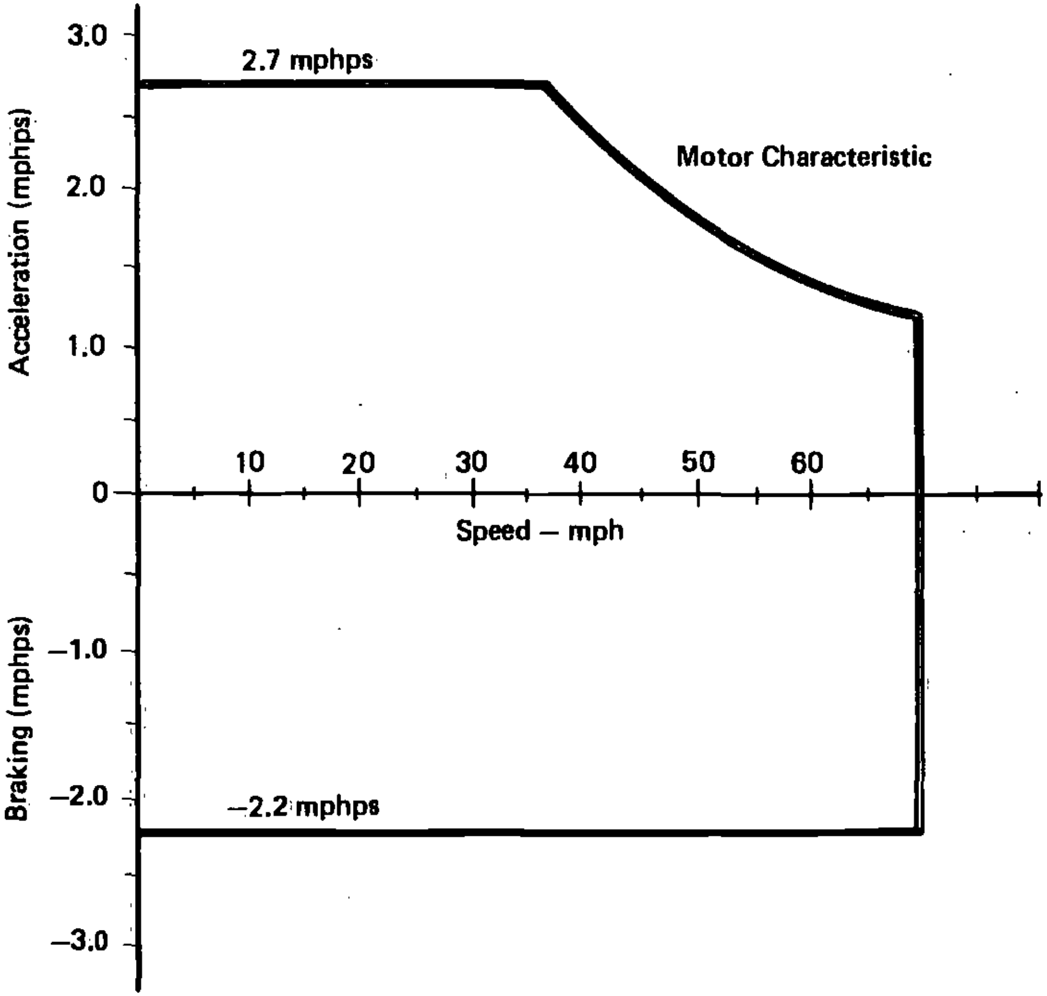
EXHIBIT III-3
PRELIMINARY ROUTE PROFILE



Source: SCRTD Sketch, Preliminary Grade Allocations.
Modified by Booz, Allen to include speed restrictions of horizontal curves.

MAXIMUM SPEED = 70 MPH

EXHIBIT III-4
VEHICLE PERFORMANCE CHARACTERISTICS FOR AUTOMATIC TRAIN OPERATION



Source: BART Specification modified by Booz·Allen.

EXHIBIT III-5
SPEED/DISTANCE CHARACTERISTICS
(LEVEL TRACK)

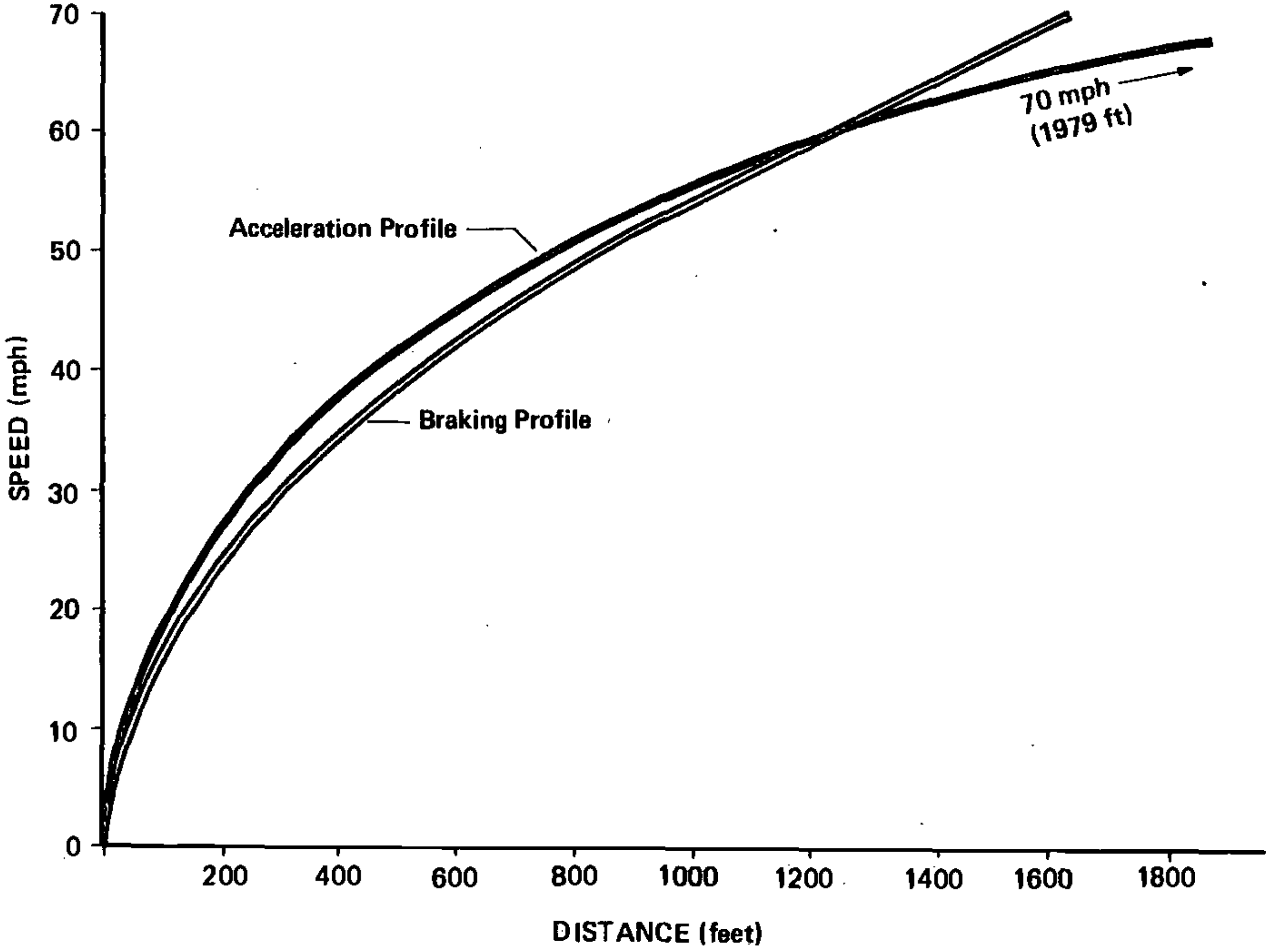
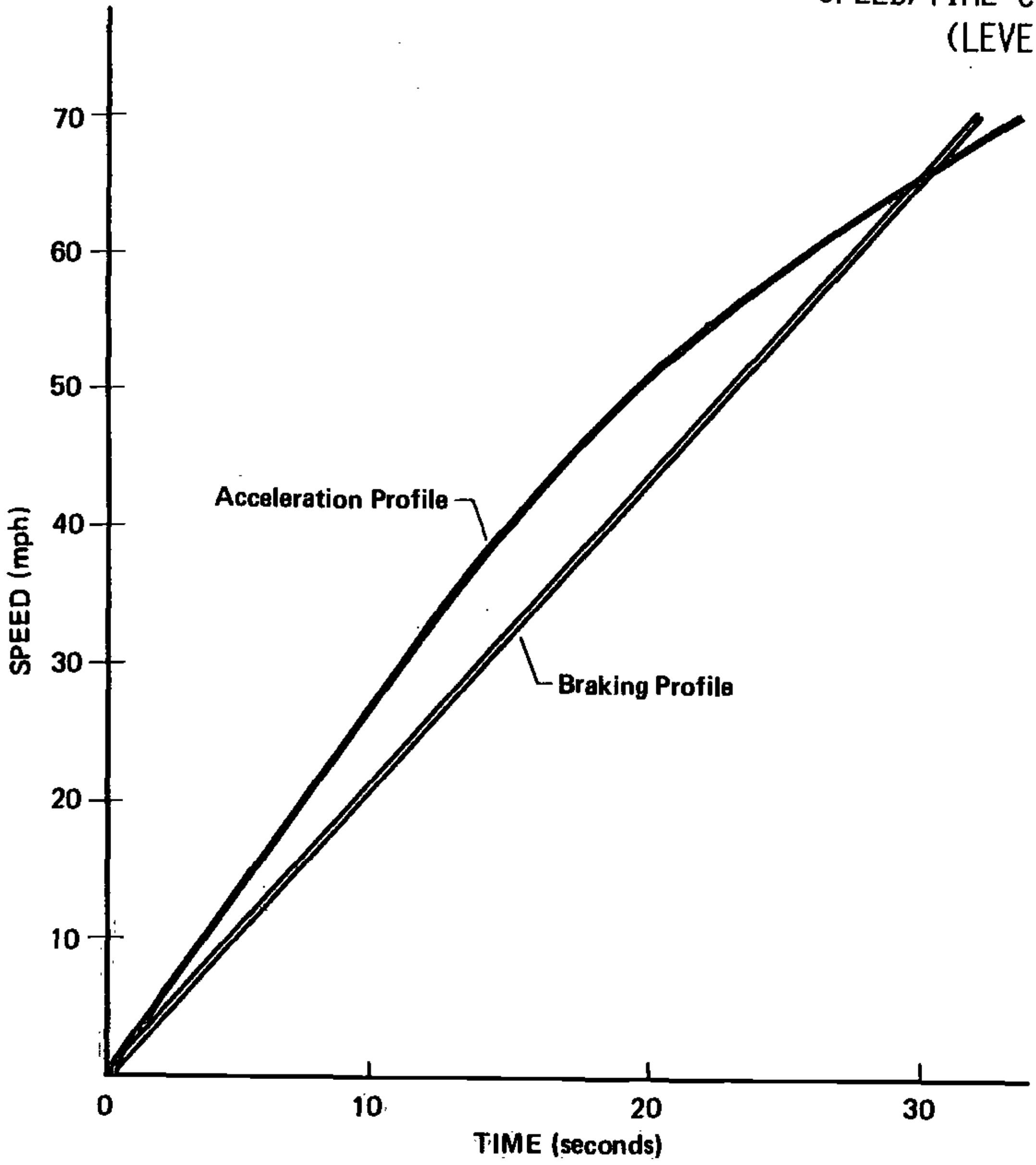


EXHIBIT III-6
SPEED/TIME CHARACTERISTICS
(LEVEL TRACK)



6. WITH SIX-CAR CONSISTS, 3-1/2 MINUTE SERVICE HEADWAYS ARE REQUIRED TO PROVIDE ADEQUATE CAPACITY FOR MAXIMUM LOAD POINT RIDERSHIP AT THE HEIGHT OF THE PEAK PERIOD

- A SERVICE SCHEDULE FOR THE AM PEAK HOUR (INBOUND) IS PRESENTED IN EXHIBIT III-7.
- THE EFFECTIVE HEADWAY BETWEEN TWO PEAK PERIOD TRAINS WILL VARY DUE TO STATION STOPS AND SPEED RESTRICTIONS, AS DEPICTED IN EXHIBIT III-8. SIMILAR EXHIBITS WILL PROVIDE THE BASES FOR OVERLAYING SAFE BRAKING DISTANCES, MAKING PRELIMINARY SIGNAL BLOCK ALLOCATIONS, AND HENCE DETERMINING MINIMUM DESIGN HEADWAYS.

A SUMMARY OF SERVICE IS PRESENTED IN EXHIBIT III-9. TO OPERATE THIS SERVICE, 114 CARS WOULD BE NEEDED, EXCLUDING AVAILABILITY AND RELIABILITY CONSIDERATIONS.

EXHIBIT III-7
A.M. PEAK HOUR SERVICE-INBOUND
MAXIMUM SIX-CAR CONSIST

TRAIN NO.	ARRIVE UNION STATION	HEADWAY
⋮	⋮	⋮
1	7:05	5 MIN
2	7:10	
3	7:14	4 MIN
4	7:18	
5	7:22	
6	7:26	
7	7:30	
8	7:33[2]	3½ MIN
9	7:37	
10	7:40[2]	
11	7:44	
12	7:47[2]	
13	7:51	
14	7:55	4 MIN
15	7:59	
16	8:03	
17	8:07	
18	8:11	
19	8:16	5 MIN
1	8:21	
⋮	⋮	

[2] DENOTES HALF-MINUTES.

EXHIBIT III-8
EFFECTIVE HEADWAY WITH A 3½-MINUTE SERVICE HEADWAY

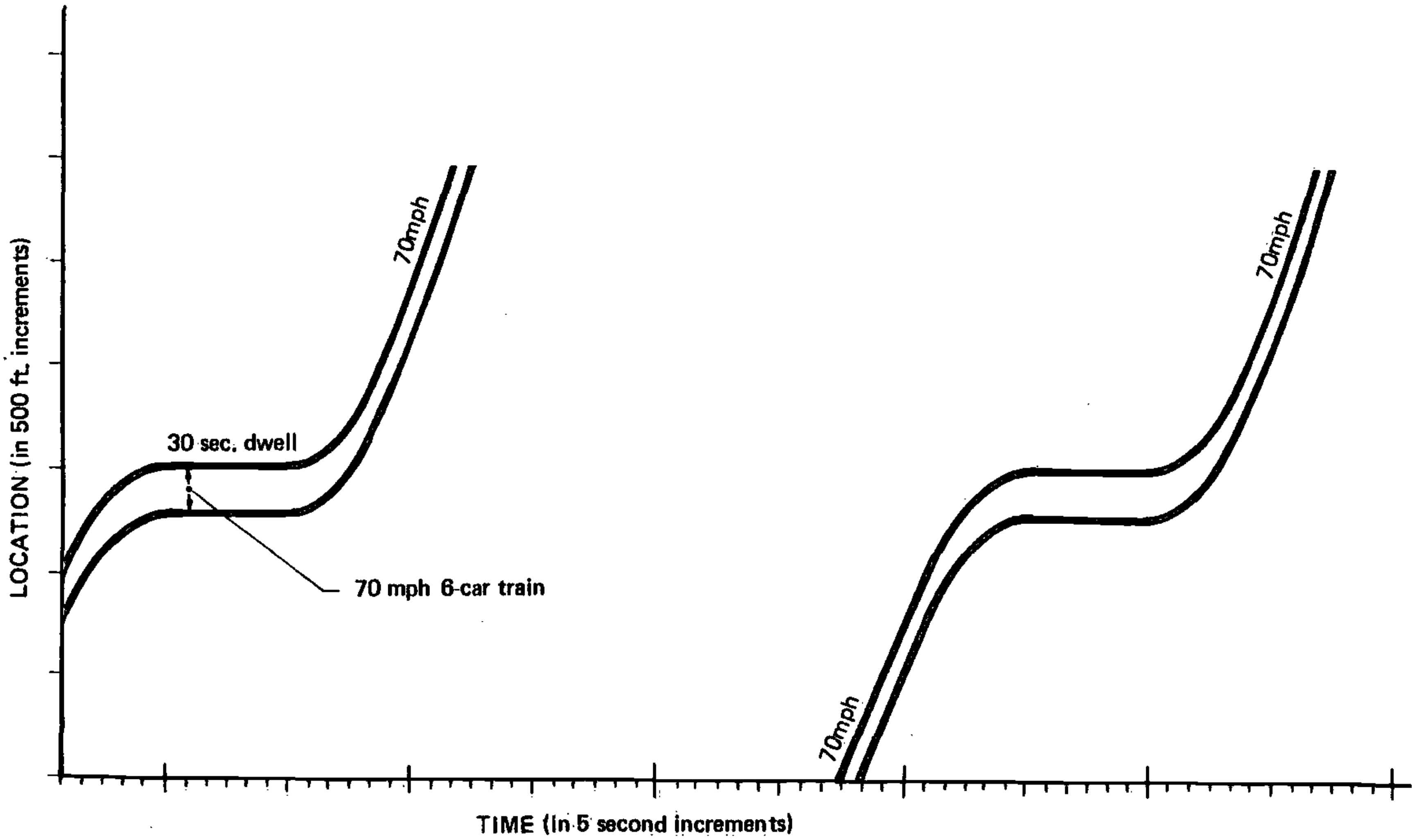


EXHIBIT III-9
SUMMARY OF SERVICE
SIX-CAR TRAIN OPERATION

PERIOD	# PSGRS-IN	# PSGRS-OUT	# CARS	# TRAINS	CONSIST	HEADWAY	TOTAL CAPACITY	TRAIN SERVICE HOURS	REVENUE CAR MILES
								(74)	(37.4)
5:30A-6:00A	411	411	12	2	6	15	1,980	148	448.8
6:00A-6:30A	3,287	2,054	24	4	6	7½	3,960	296	897.6
6:30A-7:00A	5,341	2,876	36	6	6	5	5,940	444	1,346.4
7:00A-7:30A	7,396	2,465	48	8	6	3½-4	7,920	592	1,795.2
7:30A-8:00A	7,396	2,054	48	8	6	3½-4	7,920	592	1,795.2
8:00A-8:30A	5,341	2,054	36	6	6	5	5,940	444	1,346.4
8:30A-9:00A	3,287	2,054	20	5	4	6	3,300	370	748.0
9:00A-3:00P	26,648	24,648	192	48	4	7½	31,680	3,552.0	7,180.8
3:00P-3:30P	2,465	2,465	16	4	4	7½	2,640	296	598.4
3:30P-4:00P	2,876	3,287	20	5	4	6	3,300	370	748.0
4:00P-4:30P	3,287	5,341	36	6	6	5	5,940	444	1,346.4
4:30P-5:00P	3,287	7,396	48	8	6	3½-4	7,920	592	1,795.2
5:00P-5:30P	2,876	7,396	48	8	6	3½-4	7,920	592	1,795.2
5:30P-6:00P	2,054	5,341	36	6	6	5	5,940	444	1,346.4
6:00P-6:30P	1,644	3,287	20	5	4	6	3,300	370	748.0
6:30P-7:00P	822	2,465	16	4	4	7½	2,640	296	598.4
7:00P-7:30P	822	822	8	2	4	15	1,320	148	299.2
7:30P-1:30A	4,932	4,932	48	24	2	15	7,920	1,776	1,795.2
			712	159				11,766 MIN = 191.6 HRS	26,628.8 MILES

7. <u>A FOUR-CAR MAXIMUM CONSIST IS A KEY ALTERNATIVE BECAUSE OF THE POTENTIAL FOR SUBSTANTIAL CAPITAL COST SAVINGS. A 2-MINUTE HEADWAY WOULD BE NECESSARY TO MOVE "PEAK-OF-THE-PEAK" RIDERSHIP USING FOUR-CAR CONSISTS</u>

- A SERVICE SCHEDULE FOR THE AM PEAK HOUR (INBOUND) IS PRESENTED IN EXHIBIT III-10.

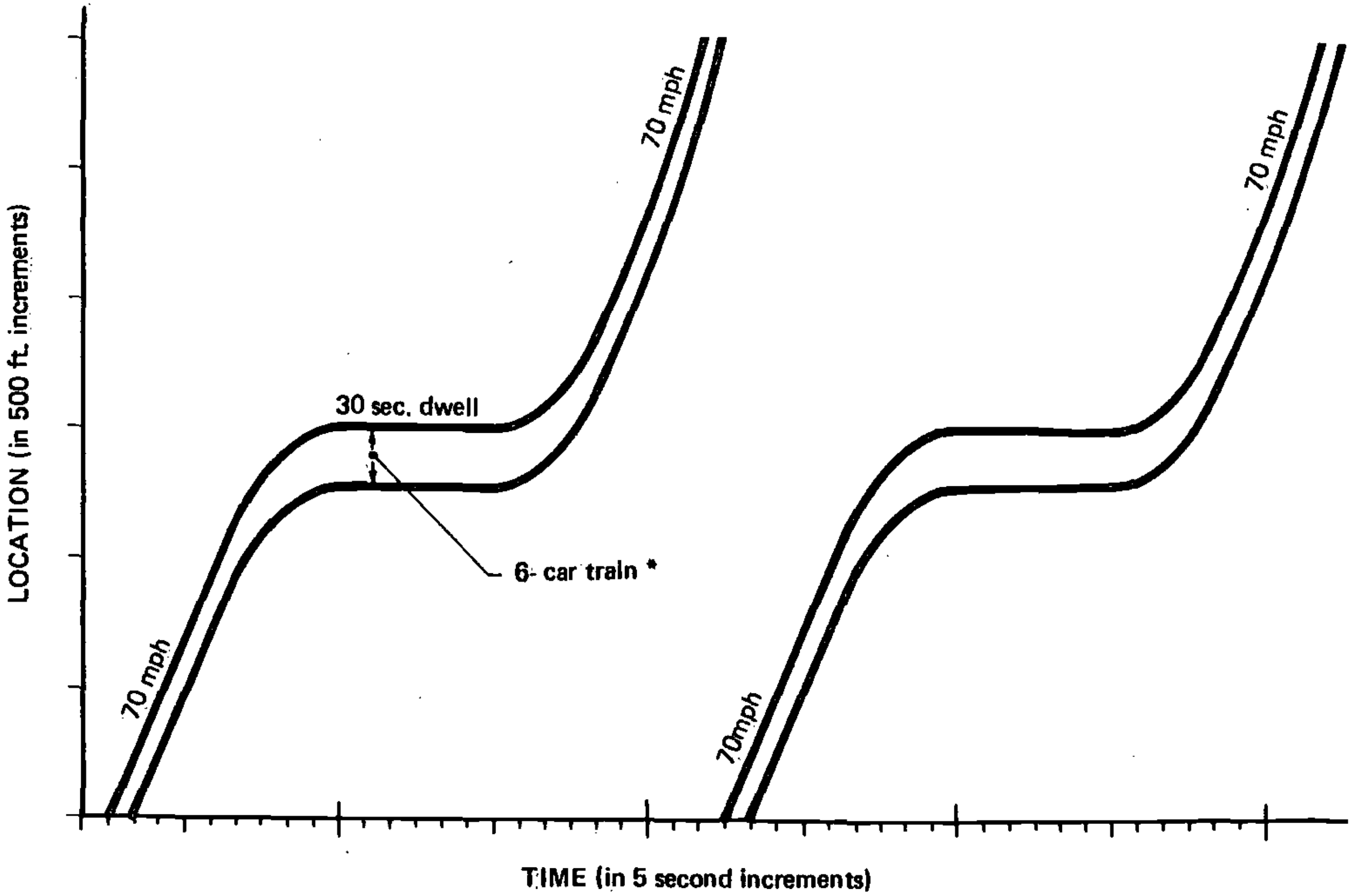
- THE EFFECTIVE HEADWAY BETWEEN TWO PEAK PERIOD TRAINS IS DEPICTED IN EXHIBIT III-11.

A SUMMARY OF SERVICE IS PRESENTED IN EXHIBIT III-12. TO OPERATE THIS SERVICE, 116 CARS WOULD BE NEEDED, EXCLUDING AVAILABILITY AND RELIABILITY CONSIDERATIONS.

EXHIBIT III-10
A.M. PEAK HOUR SERVICE-INBOUND
MAXIMUM FOUR-CAR CONSIST

TRAIN NO.	ARRIVE UNION STATION		HEADWAY
1	7:04		3
2	7:07		
3	7:10		
4	7:13		
5	7:16		
6	7:19		
7	7:21[2]		2½
8	7:24		
9	7:26[2]		
10	7:29		
11	7:31[2]		
12	7:34		
13	7:36[2]		
14	7:38		
15	7:40[2]	PEAK HOUR	2
16	7:42[2]		
17	7:44[2]		
18	7:46[2]		2
19	7:49		2½
20	7:51[2]		
21	7:54		
22	7:56[2]		
23	7:59		
24	8:01[2]		
25	8:04		
26	8:07		3
27	8:10		
28	8:13		
29	8:16		
1	8:19		

EXHIBIT III-11
EFFECTIVE HEADWAY WITH A 2-MINUTE SERVICE HEADWAY



* signal system to accomodate 6-car trains

EXHIBIT III-12
SUMMARY OF SERVICE WITH FOUR-CAR TRAIN OPERATION

PERIOD	# PSGRS-IN	# PSGRS-OUT	# CARS	# TRAINS	CONSIST	HEADWAY	TOTAL CAPACITY	TRAIN SERVICE HOURS (74 MIN)	REVENUE CAR MILES (37.4)
5:30A-6:00A	411	411	8	2	4	15	1,320	148.0	299.2
6:00A-6:30A	3,287	2,054	20	5	4	6	3,300	370.0	748.0
6:30A-7:00A	5,341	2,876	32	8	4	3-6	5,280	592.0	1,196.8
7:00A-7:30A	7,396	2,465	48	12	4	2-3	7,920	888.0	1,795.2
7:30A-8:00A	7,396	2,054	48	12	4	2-3	7,920	888.0	1,795.2
8:00A-8:30A	5,341	2,054	32	8	4	3-6	5,280	592.0	1,196.8
8:30A-9:00A	3,287	2,054	20	5	4	6	3,300	370.0	748.0
9:00A-3:00P	24,648	24,648	192	48	4	7½	31,680	3,552.0	7,180.8
3:00P-3:30P	2,465	2,465	16	4	4	7½	2,640	296.0	598.4
3:30P-4:00P	2,876	3,287	20	5	4	6	3,300	370.0	748.0
4:00P-4:30P	3,287	5,341	32	8	4	3-6	5,280	592.0	1,196.8
4:30P-5:00P	3,287	7,396	48	12	4	2-3	7,920	888.0	1,795.2
5:00P-5:30P	2,876	7,396	48	12	4	2-3	7,920	888.0	1,795.2
5:30P-6:00P	2,054	5,341	32	8	4	3-6	5,280	592.0	1,196.8
6:00P-6:30P	1,644	3,287	20	5	4	6	3,300	370.0	748.0
6:30P-7:00P	822	2,465	16	4	4	7½	2,640	296.0	598.4
7:00P-7:30P	822	822	8	2	4	15	1,320	148.0	299.2
7:30P-1:30A	4,932	4,932	48	24	2	15	7,920	1,776.0	1,795.2
				184				13,616.0 MIN = 226.9 HRS	25,731.2 MILES

* * * * *

IN SUMMARY, BASED ON OUR ASSUMPTIONS ON THE BASELINE EQUIPMENT AND THE PATRONAGE PREDICTIONS:

O TWO-CARS CONSISTS WILL NOT PROVIDE ADEQUATE SERVICE FOR PEAK PERIODS; HOWEVER, THEY CAN BE CONSIDERED FOR OFF-PEAK OPERATIONS TO SAVE ENERGY COSTS OR TO REDUCE HEADWAYS (BUT NOT BOTH).

O FOUR-CAR CONSISTS PROVIDE ADEQUATE SERVICE AT 120-SECOND OPERATIONAL HEADWAYS, BUT WOULD REQUIRE 90-SECOND DESIGN HEADWAYS. SHORT HEADWAYS, HOWEVER, ARE CONSTRAINED BY THE SAFE BRAKING DISTANCE REQUIREMENTS WHICH ARE EXTREMELY GRADE-DEPENDENT. VERTICAL PROFILES MAY NOT BE AN OPTION AT 90-SECOND HEADWAYS.

O SIX-CAR CONSISTS PROVIDE ADEQUATE SERVICE AT 3.5-MINUTE (210-SECOND) HEADWAYS. THIS PROVIDES SUBSTANTIALLY MORE DESIGN MARGIN FOR A VERTICAL PROFILE ALTERNATIVE.

O EIGHT-CAR CONSISTS ARE NOT REQUIRED.

O FOR THE INITIAL PERIOD OF REVENUE SERVICE, AN OPERATING FLEET OF 114 CARS WILL BE REQUIRED TO MAINTAIN SERVICE SCHEDULE. MAINTENANCE AND SERVICE SPARES WILL ADD APPROXIMATELY 25 PERCENT FOR A TOTAL FLEET OF APPROXIMATELY 144 CARS.

IV. OPERATING PROBLEMS DURING VEHICLE EQUIPMENT FAILURE

IV. OPERATING PROBLEMS DURING VEHICLE EQUIPMENT FAILURE

1. DIPPED GUIDEWAYS AGGRAVATE THE CONSEQUENCES OF SOME TYPES OF EQUIPMENT FAILURE

- O BLOCKAGES DUE TO REDUCED-PROPULSIVE-EFFORT CONSISTS (WITH OR WITHOUT PUSHING) REQUIRE MORE TIME TO CLEAR ON DIPPED GUIDEWAYS, WITH SYSTEM IMPACT DEPENDING ON NUMBER AND PLACEMENT OF POCKET TRACKS.

- O REDUCTION IN RUN SPEEDS DUE TO PARTIAL PROPULSION FAILURES MAY BE LESS SEVERE ON DIPPED GUIDEWAYS SINCE ACCELERATION LEVELS CAN BE MAINTAINED UNDER CLOSED LOOP CONTROL.

- O HOWEVER, WHEN OPERATIONAL CIRCUMSTANCES REQUIRE STOPPING OR VERY SLOW RUNNING BETWEEN STATIONS, VULNERABILITY TO PARTIAL LOSS OF PROPULSION IS INCREASED SUBSTANTIALLY.

2. FOR DIPPED PROFILES, THE FREQUENCY OF OCCURRENCE WILL INCREASE FOR IMPEDED OPERATIONS AND FOR THE NEED TO PUSH OUT

   - O A SMALLER PROPORTION OF TRACTIVE EFFORT LOSS WILL RESULT IN SLOWING OR DISABLEMENT.

   - O IN TURN, THE INCREASED FREQUENCY OF OFFLOADS AND/OR PUSH-OUTS WILL INCREASE THE NEED FOR SPARE CONSISTS--IF THE SYSTEM CONFIGURATION PERMITS SUCH SPARES TO BE PUT TO EFFECTIVE USE.

3. PROPULSION RELIABILITY FOR PROVEN SUBSYSTEMS CAN BE EFFECTIVELY PREDICTED FROM INDUSTRY DATA

   - O EXHIBIT IV-1 SUGGESTS SOME TYPICAL VALUES OF PROPULSION RELIABILITY:

     - THE ESTIMATES ARE BASED PRIMARILY ON TORONTO TRANSIT COMMISSION EXPERIENCE (POST-1960 CARS), COUNTING ONLY FAILURES REQUIRING "CHANGE-OFF" DURING REVENUE OPERATION.

     - THE ESTIMATES ARE SOMEWHAT MORE CONSERVATIVE THAN THOSE OF THE BUDD COMPANY'S RELIABILITY PREDICTION FOR MIAMI/BALTIMORE CARS.

EXHIBIT IV-1

PROPULSION RELIABILITY ESTIMATES

	TRACTION CONTROL & CUTOUT DESIGN	
COMPONENT	PER TRUCK BASIS	PER CAR BASIS
TRACTION MOTOR AND GEARBOX (4 PER CAR) (EACH)	MTBF = 3500 HRS	MTBF = 3500 HRS
TRACTION CONTROL PER CAR (1 PER CAR)		820
TRACTION CONTROL PER TRUCK (2 PER CAR) (EACH)	1000	
TRACTION CONTROL, COMMON (1 PER CAR)	4500	
FAILURE CONDITION		
LOSS OF ½ PROPULSION*	PROB. = 0.001569	N/A
LOSS OF ALL PROPULSION*	0.000112	0.001181

---

* PER CAR, PER ONE-WAY (30-MINUTE) TRIP.

N/A = NOT APPLICABLE.

SOURCE: TORONTO TRANSIT COMMISSION EXPERIENCE AND BUDD CO. RELIABILITY PREDICTION FOR MIAMI/BALTIMORE CARS.

- TWO TRACTION CONTROL AND CUTOUT DESIGNS ARE CONSIDERED:

    - CUTOUT CAPABILITY ON A PER-TRUCK BASIS, IMPLYING TWO DISCONNECTS AND TWO CHOPPERS PER CAR.

    - CUTOUT CAPABILITY ON A PER-CAR BASIS ONLY.

- THE EXHIBIT ALSO INDICATES THE CORRESPONDING PROBABILITIES OF PARTIAL (WHERE APPLICABLE) OR TOTAL PROPULSION LOSS FOR EACH CAR ON A SINGLE ONE-WAY TRIP.

4. <u>THE PER-CAR PROBABILITIES ARE READILY TRANSLATED TO PER-TRIP PROBABILITIES OF SINGLE OR MULTIPLE TRUCK CUT-OUTS ON MULTI-CAR CONSISTS</u>

- CONSIST IMPAIRMENT PROBABILITIES ARE SHOWN IN EXHIBIT IV-2.

- THE PROBABILITIES INCREASE ALMOST LINEARLY WITH CONSIST SIZE.

- BECAUSE THE PER-TRUCK BASIS INVOLVES MORE EQUIPMENT, IT RESULTS IN A HIGHER PROBABILITY THAT SOME PROPULSION IMPAIRMENT WILL OCCUR--BUT A SUBSTANTIALLY LOWER PROBABILITY OF MULTIPLE-TRUCK CUT-OUT.

EXHIBIT IV-2
PROBABILITY OF OCCURRENCE OF PROPULSION IMPAIRMENT

		TRACTION CONTROL & CUTOUT DESIGN	
CARS IN CONSIST	TRUCKS CUT OUT	PER TRUCK BASIS	PER CAR BASIS
2	1	PROB. = 0.003133	PROB. = N/A
	2	0.000226	0.002357
	3	0.0000004	N/A
	4	NEGLIGIBLE	0.0000014
4	1	0.006266	N/A
	2	0.00046	0.004703
	3	0.0000021	N/A
	4	0.00000008	0.000008
	5 OR MORE	NEGLIGIBLE	NEGLIGIBLE
6	1	0.009335	N/A
	2	0.000703	0.007038
	3	0.0000053	N/A
	4	0.0000002	0.000021
	5 OR MORE	NEGLIGIBLE	NEGLIGIBLE

BASIS: PER CONSIST, PER ONE-WAY (30-MINUTE) TRIP.

5. TO ASSESS THE SIGNIFICANCE OF THE IMPAIRED-PROPULSION PROBABILITIES, IT IS NECESSARY TO EXAMINE THE EFFECTS OF IMPAIRMENT ON GRADE-CLIMBING CAPABILITY

O THE GRADE-CLIMBING CAPABILITIES, SHOWN IN EXHIBIT IV-3, ARE BASED ON PROPULSIVE EFFORT EQUIVALENT TO THAT EXERTED IN ACCELERATION AT 3 MPHPS ON LEVEL TANGENT TRACK.

- HIGHER MOTOR CURRENTS ARE NOT ALLOWED.
- INTERNAL HEATING OF SELF-VENTILATED MOTORS AT LOW SPEEDS IS NOT CONSIDERED.

O WITH AN ADHESION COEFFICIENT OF 0.25, WHICH SHOULD BE SUSTAINABLE IN THE STARTER LINE ENVIRONMENT, THE ADHESION LIMIT IS SUBSTANTIALLY HIGHER THAN THE TORQUE LIMIT.

O TRUCK GEOMETRY AND ITS EFFECT ON AXLE WEIGHT TRANSFER HAVE NOT BEEN TAKEN INTO ACCOUNT HERE.

O FIFTY-PERCENT PROPULSION IMPAIRMENT LIMITS THE MAXIMUM GRADE TO AT MOST 7 PERCENT FOR UNASSISTED CLIMBING.

O NOTE THAT A TWO-CAR CONSIST WITH THREE TRUCKS CUT OUT HAS A MARGINAL CAPABILITY TO ASCEND A 3.5-PERCENT GRADE (FROM A STOP); THIS IS THE MAXIMUM GRADE ON THE STARTER LINE PROFILE WITHOUT DIPPING.

EXHIBIT IV-3
MAXIMUM GRADE FOR UNASSISTED CLIMB BY CONSIST WITH IMPAIRED PROPULSION

CARS IN CONSIST	2	4	6
TRUCKS CUT OUT			
1	10%	10%	10%
2	7*	10	10
3	3.5*	8	10
4	-	7*	8

* MARGINAL AT THIS GRADE.

BASIS: TORQUE-LIMITED PROPULSION (FORCE EQUIVALENT TO 3 MPHPS ACCELERATION).

6. THE REQUIREMENT FOR PUSH-OUT DURING PEAK PERIODS MUST BE MADE EXTREMELY INFREQUENT

- EXHIBIT IV-4 COMBINES THE RESULTS OF EXHIBITS IV-2 AND IV-3, SHOWING THE PROBABILITIES AND BORDERLINE EFFECTS OF THE VARIOUS IMPAIRMENTS FOR THE THREE CONSIST SIZES AND THE TWO DESIGN APPROACHES.

- THE RESULTS SUGGEST THAT PUSH-OUT REQUIREMENTS CAN BE HELD TO TOLERABLE OCCURRENCE FREQUENCIES BY LIMITING THE MAXIMUM GRADE TO SOME VALUE LESS THAN 7 PERCENT AND/OR BY AVOIDING THE USE OF TWO-CAR CONSISTS.

- FOR TWO-CAR CONSISTS, GRADE-CLIMBING PERFORMANCE WITH TWO TRUCKS CUT OUT IS MARGINAL EVEN ON GRADES OF LESS THAN 7 PERCENT. IF CONSISTS OF THIS SIZE AND THE PER-CAR BASIS DESIGN WERE USED IN PEAK PERIODS, THE 0.27 VALUE IMPLIES THAT THIS KIND OF OUTAGE SHOULD BE EXPECTED TO OCCUR ALMOST THREE TIMES PER WEEK.

- IT SHOULD BE NOTED THAT THE OCCURRENCE OF "DEAD" CONSISTS FOR OTHER REASONS, SUCH AS TRAINLINE AND HEAD-END CONTROL FAILURES, IS NOT REFLECTED IN THESE ESTIMATES.

EXHIBIT IV-4
EXPECTED NUMBER OF OCCURRENCES OF PROPULSION IMPAIRMENT PER 2-HOUR PEAK PERIOD

Cars in Consist	**2**		**4**		**6**	
Design Basis	**T**	**C**	**T**	**C**	**T**	**C**
Trucks Cut Out						
1	0.36	NA	0.36	NA	0.35	NA
2	0.03	0.27	0.03	0.27	0.03	0.27
3	0.00005	NA	0.0001	NA	0.0002	NA
4	neg.	0.0002	0.000005	0.0005	0.000008	0.0008

POOR
Grade Capability
(Less than 4%)

GOOD
Grade Capability
(Greater than 7%)

T = TRACTION CONTROL & CUTOUT DESIGN ON PER TRUCK BASIS.
C = TRACTION CONTROL & CUTOUT DESIGN ON PER CAR BASIS.

7. <u>IF CONSISTS FROM STORAGE ARE USED TO PUSH OUT DISABLED TRAINS, THE RELATIVE PASSENGER LOADING WILL AFFECT THE MAXIMUM PUSH-OUT CAPABILITY</u>

- O THE DISABLED TRAIN MUST BE PUSHED BY AN UNLOADED TRAIN TO THE NEXT STATION PLATFORM, WHERE THE PASSENGERS WILL BE OFFLOADED

- O TRACTION CAPABILITY OF THE UNLOADED CONSIST WILL BE LIMITED BY THE LOAD WEIGHING COMPENSATION

- O EXHIBIT IV-5 SHOWS THE MAXIMUM GRADE FOR PUSH-OUT FOR CONSISTS OF EQUAL SIZE BUT DIFFERENT LOADING.

* * * * *

IN SUMMARY:

- O TWO-CAR CONSISTS WILL REQUIRE FREQUENT PUSH-OUT.

- O BOTH FOUR-CAR AND SIX-CAR CONSISTS HAVE GOOD GRADE CLIMBING CAPABILITY AND CAN MANAGE GRADES UP TO 7 PERCENT FOR THE MORE LIKELY LEVELS OF PROPULSION DEGRADATION.

EXHIBIT IV-5
MAXIMUM GRADE FOR PUSH OF DEAD CONSIST BY CONSIST OF EQUAL SIZE

DEAD CONSIST LOAD	AW0	AW1	AW2	AW3
PUSHER LOAD				
AW0	7%*	6%	5%	5%
AW1	7	7*	6	6*
AW2	8	7	7*	6
AW3	9	8*	8	7*

---

* MARGINAL AT THIS GRADE

BASIS: TORQUE-LIMITED PROPULSION (FORCE EQUIVALENT TO 3 MPHPS ACCELERATION).

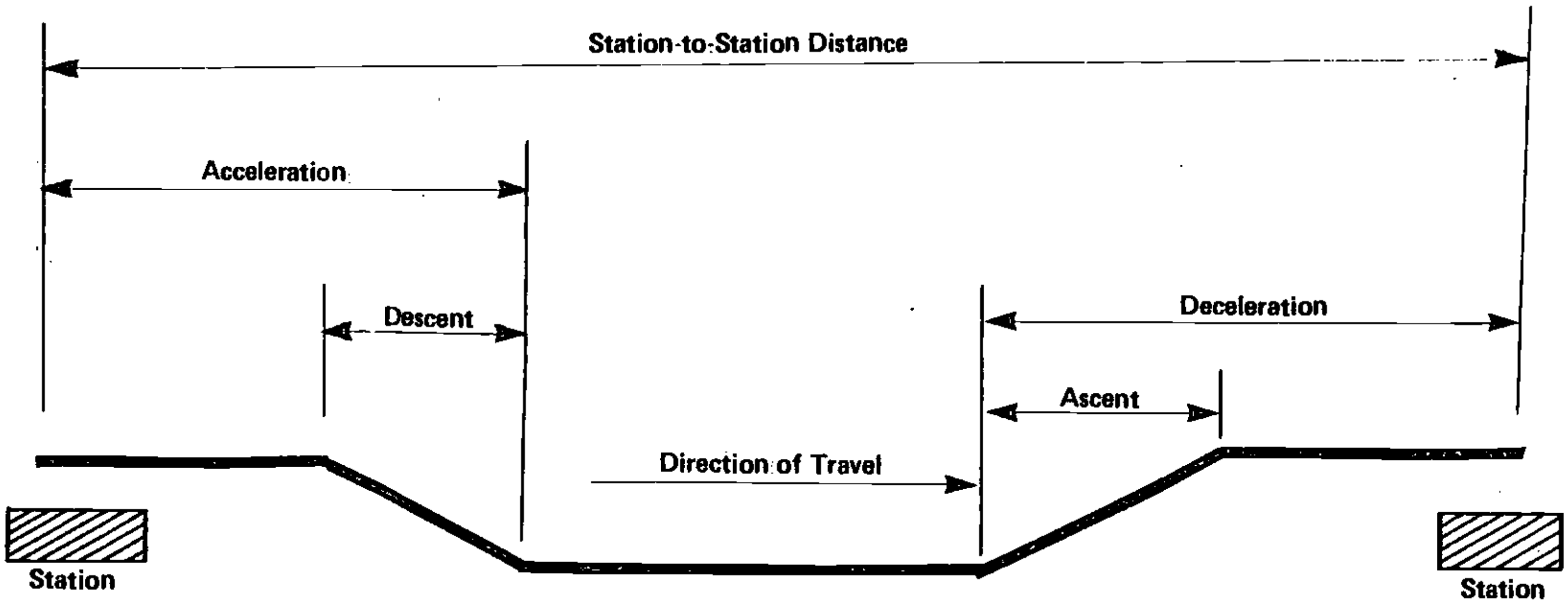
V. ENERGY SAVINGS ANALYSIS

V. ENERGY SAVINGS ANALYSIS

1. IN ORDER TO ILLUSTRATE THE PRINCIPLES INVOLVED, AND TO ASSESS THE POTENTIAL WORTH OF GRAVITY-ASSIST PROFILING, A SIMPLIFIED ENERGY SAVINGS ANALYSIS WAS PERFORMED USING THE FOLLOWING ASSUMPTIONS:

- POINT MASS IS ASSUMED FOR THE PHYSICAL DYNAMICS AND RELATED ENERGY CALCULATIONS.
- CLOSED-LOOP ACCELERATION CONTROL IS ASSUMED, THEREBY GIVING:
  - PREDETERMINED ACCELERATION RATE INDEPENDENT OF DOWNGRADE.
  - SIMILAR STATION-TO-STATION RUN TIMES WHICH IN TURN SIMPLIFY COMPARISONS.
- FRICTION EFFECTS ARE CALCULATED FOR AN EMPTY SIX-CAR TRAIN.
- FULL ACCELERATION UP TO MAXIMUM SPEED IS FEASIBLE.
- ACCELERATION IS COMPLETE AT END OF DESCENT, AND DECELERATION STARTS AT BEGINNING OF ASCENT, AS SHOWN IN EXHIBIT V-1.

EXHIBIT V-1
SEGMENTS OF THE VERTICAL PROFILE



2. <u>THERE ARE BOUNDS ON THE AMOUNT OF ENERGY WHICH CAN BE EXTRACTED FROM A GRAVITY-ASSIST PROFILE</u>

O THE FRACTION OF THE ENERGY ATTAINABLE FROM GRAVITY, COMPARED WITH THE TOTAL PROPULSIVE ENERGY REQUIRED, MAY BE EXPRESSED AS A PRODUCT OF:

- THE FRACTION OF THE ENERGY <u>USED FOR MOTION</u>
- THE FRACTION OF THAT ENERGY DEVELOPED <u>DURING DESCENT</u>
- THE FRACTION OF THAT ENERGY <u>DUE TO GRAVITY</u>.

THE LIMITATIONS ON EACH OF THESE COMPONENTS, THEREFORE, CONTROL THE NET CONTRIBUTION OF GRAVITY TO THE TOTAL PROPULSIVE ENERGY REQUIRED:

$$\frac{\text{ENERGY}_{\text{GRAVITY}}}{\text{ENERGY}_{\text{TOTAL}}} = \frac{\text{ENERGY}_{\text{MOTION}}}{\text{ENERGY}_{\text{TOTAL}}} \times \frac{\text{ENERGY}_{\text{DESCENT}}}{\text{ENERGY}_{\text{MOTION}}} \times \frac{\text{ENERGY}_{\text{GRAVITY}}}{\text{ENERGY}_{\text{DESCENT}}}$$

O BY SEPARATING OUT THE ENERGY CONTRIBUTIONS IN THIS MANNER, THE VARIOUS ISSUES AFFECTING DESIGN CAN BE SEGREGATED AND ASSESSED FOR INDIVIDUAL IMPACT ON ENERGY CONSUMPTION AND POSSIBLE SAVINGS.

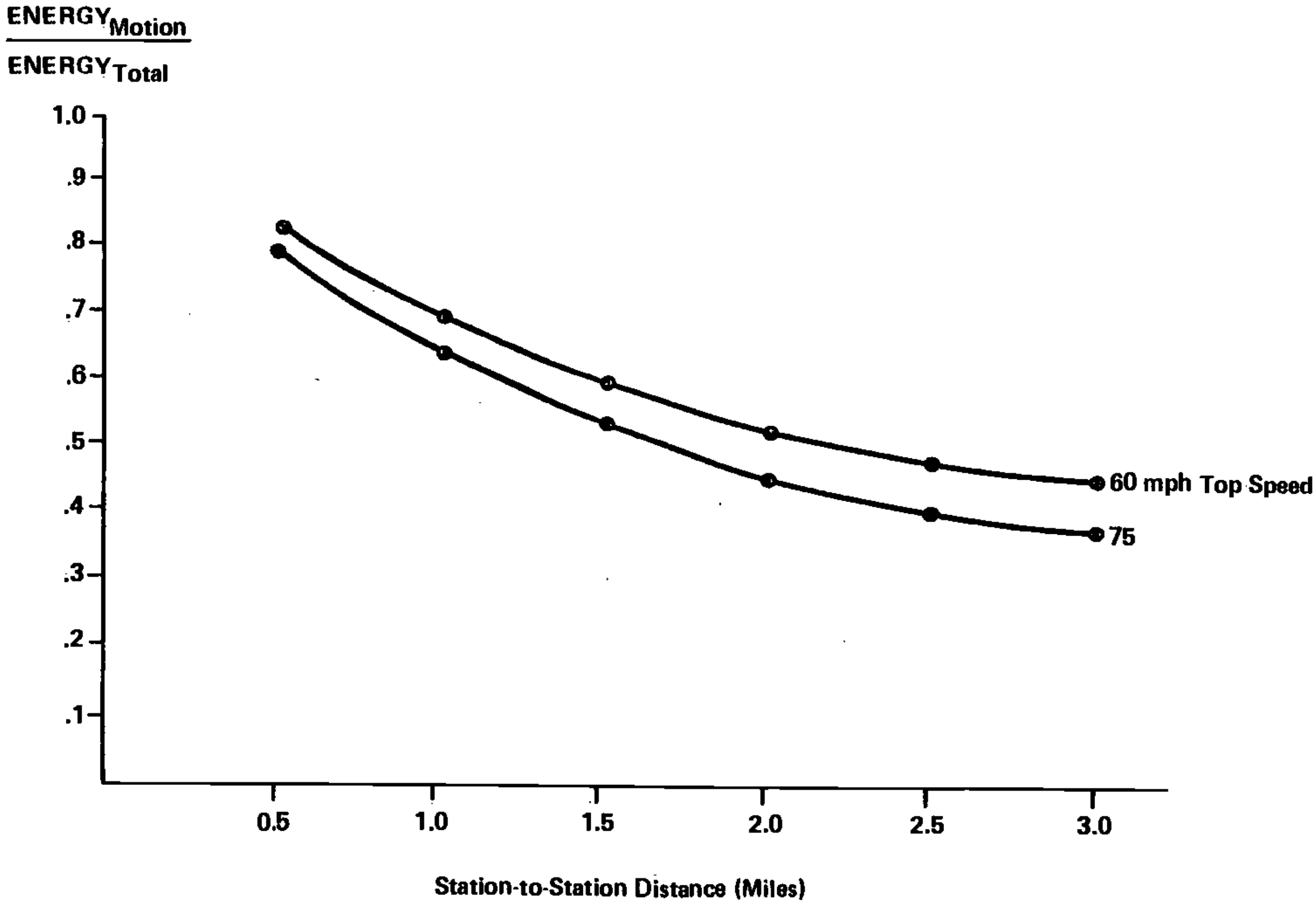
- IN EXHIBITS V-2, V-3 AND V-4, THE FRACTIONS OF ENERGY CONTRIBUTION ILLUSTRATE DIFFERENT ENERGY PENALTIES:

  - FRICTIONAL PENALTY (EXHIBIT V-2)--TRACTIVE EFFORT BEYOND THAT NEEDED FOR MOTION MUST BE SUPPLIED TO COMPENSATE FOR FRICTION. THIS IS NOT RECOVERABLE.

  - TRANSITION PENALTY (EXHIBIT V-3)--THERE ARE A NUMBER OF FACTORS WHICH PRECLUDE IMMEDIATE TRANSITION TO FULL GRADE. THESE INCLUDE: CROSSOVERS, POCKET TRACKS, HORIZONTAL CURVES, VERTICAL TRANSITIONS AND MOVEMENT ALONG LEVEL PLATFORMS.

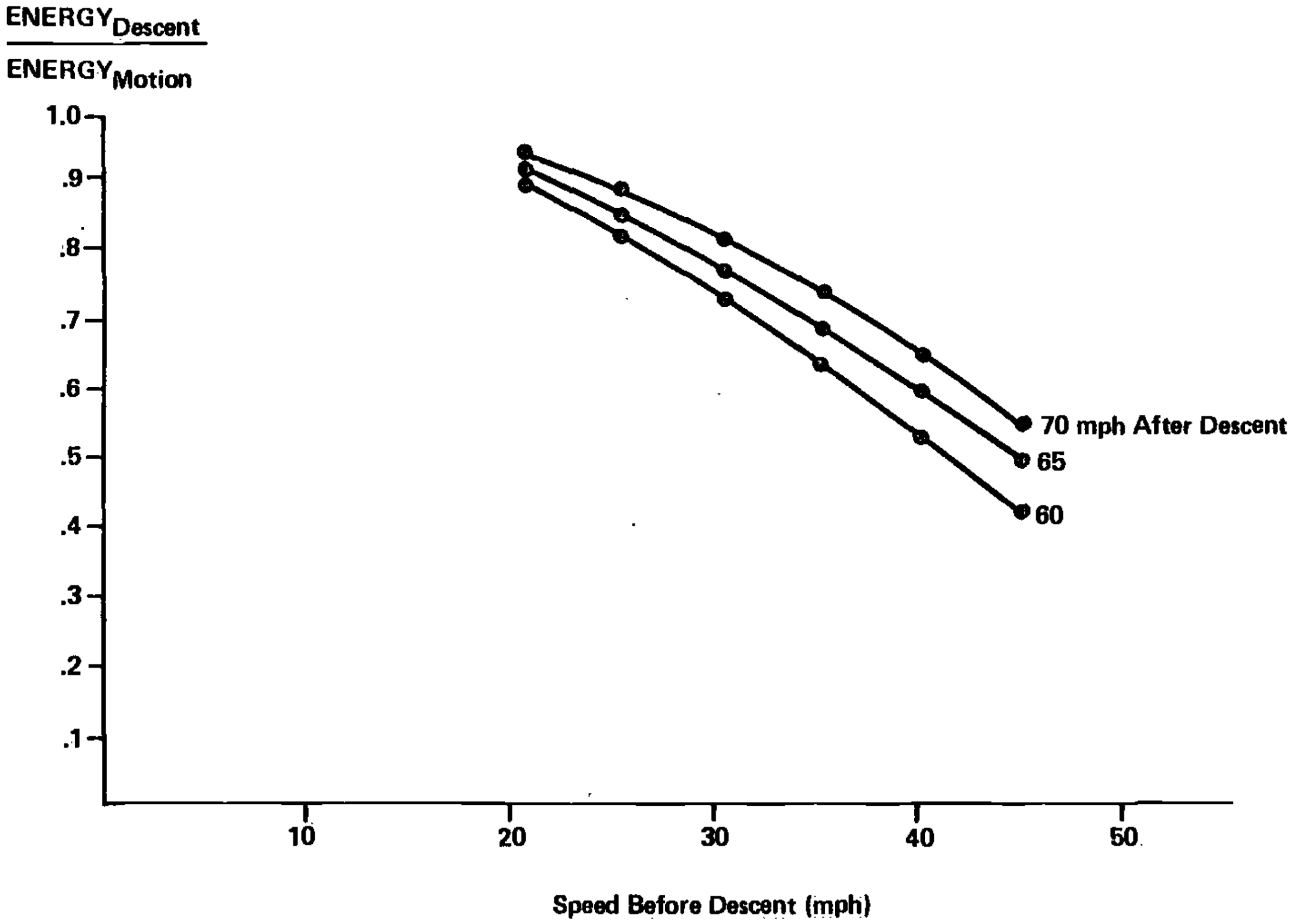
  - GRADE PENALTY (EXHIBIT V-4)--THE AMOUNT OF FORCE OBTAINABLE FROM GRAVITY ON A GRADED SECTION OF TRACK IS APPROXIMATELY 20 LB/TON/% GRADE. THIS FORCE WILL PROVIDE AN ACCELERATION OF 0.22 MPHPS PER PERCENT GRADE. ADDITIONAL TRACTIVE EFFORT IS REQUIRED TO MAINTAIN A DESIRED ACCELERATION RATE GREATER THAN THIS.

EXHIBIT V-2
FRICTIONAL PENALTY



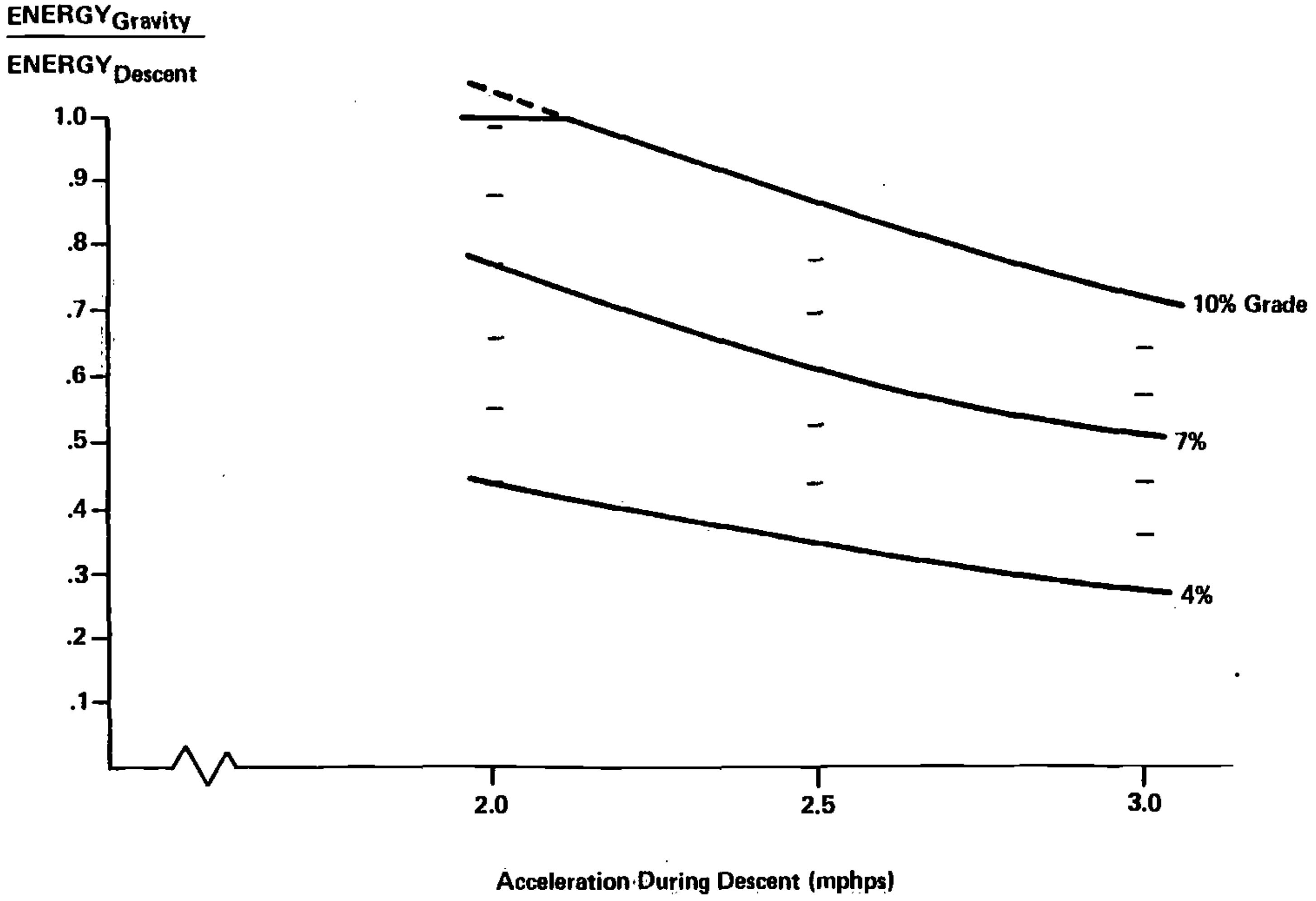
Source: Booz · Allen Calculations.

EXHIBIT V-3
TRANSITION PENALTY



Source: Booz·Allen Calculations.

EXHIBIT V-4
GRADE PENALTY



Source: Booz·Allen Calculations.

USING THESE CHARTS TO SEPARATELY ESTIMATE THE FRACTIONAL CONTRIBUTIONS OF THE VARIOUS ENERGY COMPONENTS, THE NET CONTRIBUTION OF GRAVITY TO THE TOTAL PROPULSIVE ENERGY REQUIREMENT CAN BE ESTIMATED. FOR EXAMPLE:

FOR STATION DISTANCE = 1 MILE $\quad \frac{\text{ENERGY}_{\text{MOTION}}}{\text{ENERGY}_{\text{TOTAL}}} = 0.70$

FOR INITIAL SPEED = 35 MPH
FOR FINAL SPEED = 65 MPH $\quad \frac{\text{ENERGY}_{\text{DESCENT}}}{\text{ENERGY}_{\text{MOTION}}} = 0.71$

FOR GRADE = 6%
FOR ACCELERATION = 2.5 MPHPS $\quad \frac{\text{ENERGY}_{\text{GRAVITY}}}{\text{ENERGY}_{\text{DESCENT}}} = 0.53$

$$\frac{\text{ENERGY}_{\text{GRAVITY}}}{\text{ENERGY}_{\text{TOTAL}}} = (0.70) \times (0.71) \times (0.53) = 0.26$$

IN THIS WAY, THE EFFECTS OF THE VARIOUS CONSTRAINTS (GRADE, DELAY IN TRANSITION TO DESCENT, ETC.) CAN BE INDIVIDUALLY EXAMINED BEFORE SELECTING ALTERNATIVE ALIGNMENT DESIGNS FOR MORE DETAILED ANALYSIS.

3. A MORE DETAILED ANALYSIS OF THE ENERGY CONSUMPTION OF TRAIN MOVEMENT IS PROVIDED BY CONSTRUCTING "ENERGY MAPS"

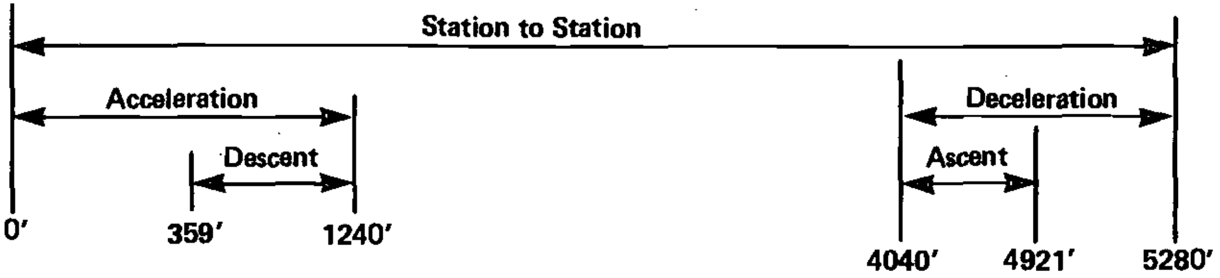
DISTANCE = VELOCITY vs. TIME

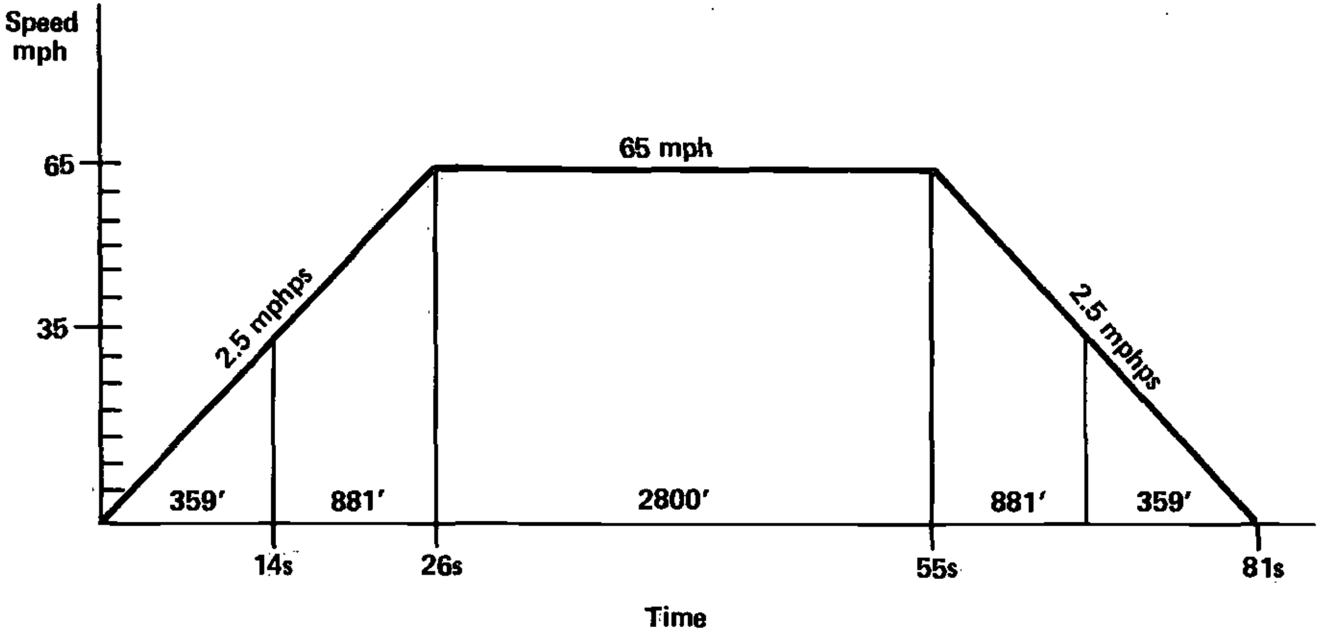
ENERGY = POWER vs. TIME

A VISUAL REPRESENTATION OF THE ENERGY CONSUMED DURING THE VARIOUS PORTIONS OF A STATION-TO-STATION TRIP IS PROVIDED BY LOOKING AT THE POWER LEVEL REQUIRED AS A FUNCTION OF TIME. THE AREA UNDER THE POWER/TIME CURVE REPRESENTS ENERGY. SIMILARLY, THE OPERATING CHARACTERISTICS OF A TRIP ARE REPRESENTED BY A VELOCITY/TIME PROFILE WHERE THE AREA UNDER THIS CURVE REPRESENTS DISTANCE TRAVELED.

THE VELOCITY PROFILE (EXHIBIT V-5) AND THE ENERGY MAPS (EXHIBITS V-6 THROUGH V-8) SHOW THE DISTANCE TRAVELED AND THE ENERGY CONSUMED FOR A STATION DISTANCE OF 1 MILE, TOP SPEED OF 65 MPH, AND ACCELERATION (AND DECELERATION) RATE OF 2.5 MPHPS. THREE INDIVIDUAL ENERGY MAPS ARE SHOWN TO SEPARATELY ILLUSTRATE THE TOTAL, THE EFFECTS OF FRICTION, AND THE EFFECTS OF 6-PERCENT GRADE PROFILING (STARTING IN THIS CASE WHEN THE TRAIN REACHES 35 MPH).

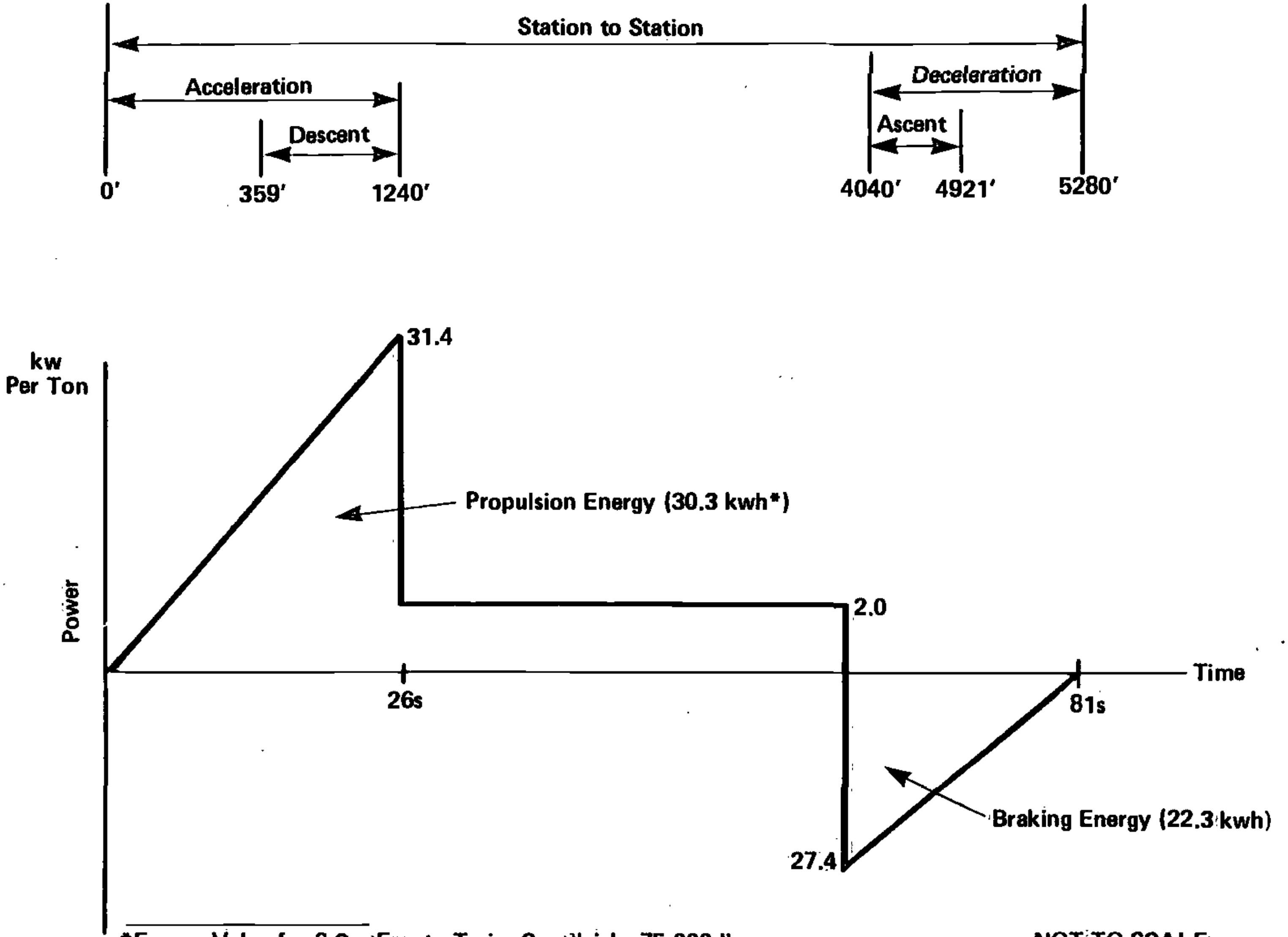
EXHIBIT V-5
VELOCITY PROFILE





NOT TO SCALE

EXHIBIT V-6
ENERGY MAP



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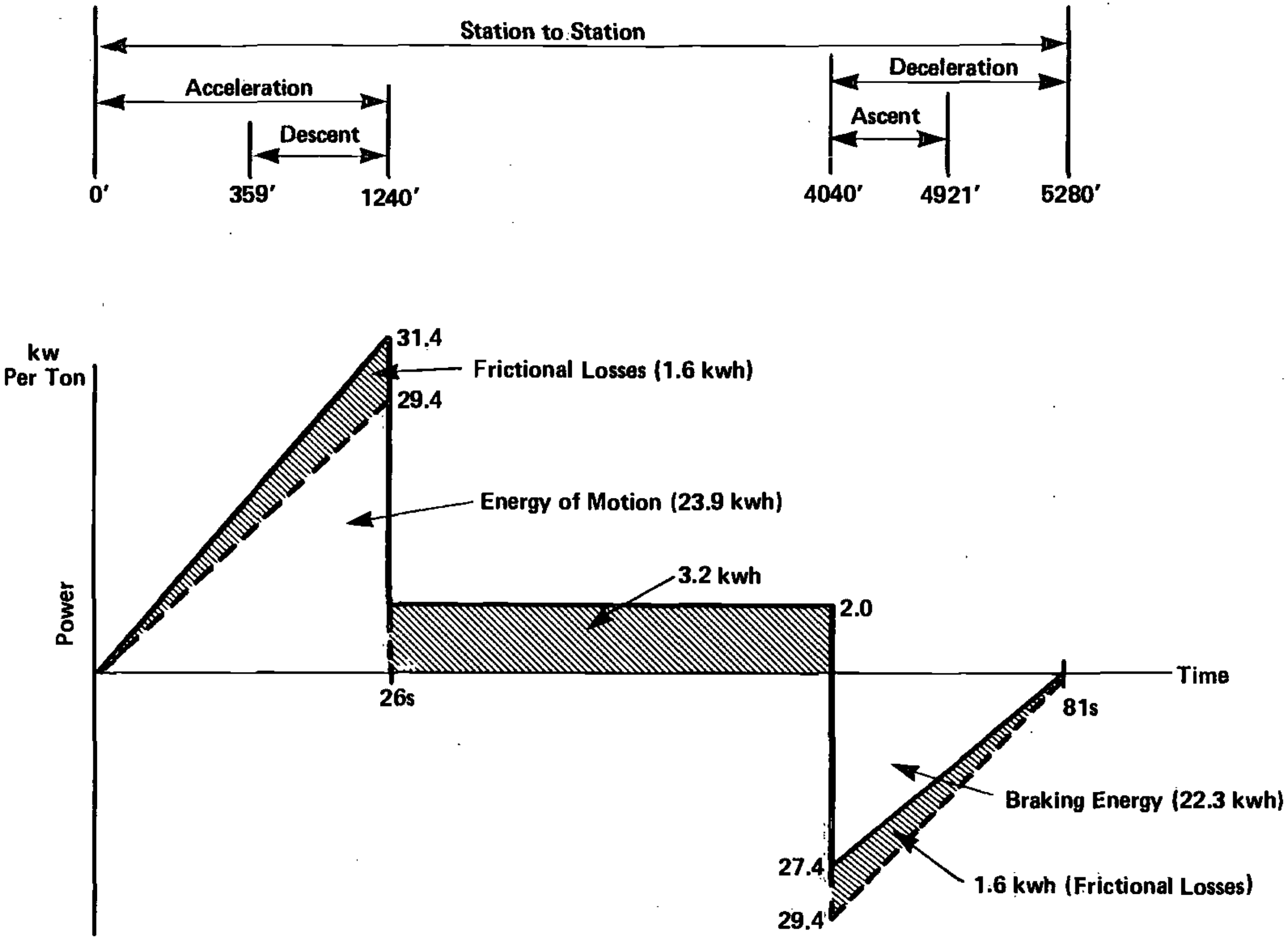
*Energy Value for 6-Car Empty Train; Car Weighs 75,000 lbs.

NOT TO SCALE

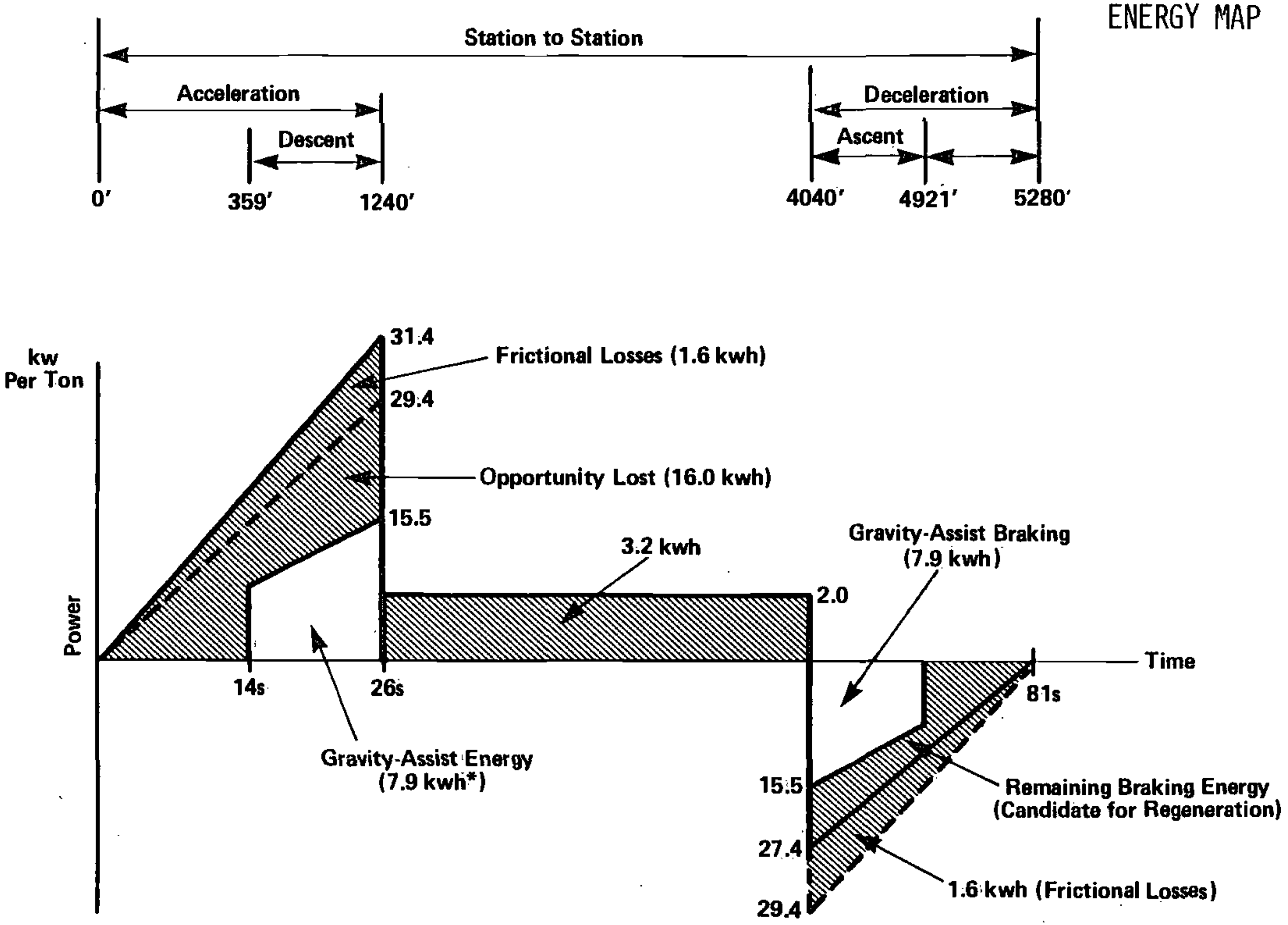
EXHIBIT V-7
ENERGY MAP



*Energy for 6-Car Train

NOT TO SCALE

EXHIBIT V-8
ENERGY MAP



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*Energy for 6-Car Train.

NOT TO SCALE

4. SYSTEM ENERGY COST SAVINGS CAN BE ESTIMATED USING THE ENERGY ANALYSIS AND PRELIMINARY OPERATING PLAN

- THE UPPER BOUND OF ANNUAL COST SAVINGS FROM VERTICAL PROFILING FOR THE CASE REPRESENTED BY THE PREVIOUS ENERGY MAPS IS:

	NORTHBOUND	SOUTHBOUND
ENERGY FOR SIX-CAR TRAIN (LEVEL)*	23.9	23.9
ENERGY FOR SIX-CAR TRAIN (PROFILE)	16.0	16.0
SAVINGS (PROFILE)	7.9 KWH	7.9 KWH

EQUIVALENT ONE-WAY TRIPS (FOR SIX-CAR TRAINS) PER WEEKDAY = 118.7 (FROM OPERATING PLAN)

COST OF ENERGY = $0.05 PER KWH

EQUIVALENT WEEKDAYS PER YEAR = 292.4

MAXIMUM ENERGY SAVINGS OF PROFILE (EMPTY CAR) = (7.9 + 7.9) X 118.7 X 292.4 X 0.05 = $27,419/ANNUM.

USING AN EQUIVALENT LOAD FACTOR OF 1.165 FOR PROPULSION ENERGY, THEN MAXIMUM ENERGY SAVINGS OF PROFILE (LOADED CAR) = $31,943/ANNUM.

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* "LEVEL" IMPLIES THAT GRADES ARE ONLY USED TO ACCOMMODATE DIFFERENT STATION ELEVATIONS.

O ANALYSIS OF THE ENERGY BENEFITS IS BEST MADE ON AN INDIVIDUAL STATION BASIS. EACH STATION PAIR HAS A DIFFERENT ENERGY SAVINGS POTENTIAL RESULTING FROM THE POSSIBILITIES AND RESTRICTIONS FOR VERTICAL PROFILING GEOMETRY.

FOR EXAMPLE, THE UPPER BOUND OF ANNUAL COST SAVINGS FROM VERTICAL PROFILING BETWEEN BEVERLY/FAIRFAX AND SANTA MONICA/FAIRFAX IS:

	NORTHBOUND	SOUTHBOUND
ENERGY FOR SIX-CAR TRAIN (LEVEL)	43.7	26.8
ENERGY FOR SIX-CAR TRAIN (PROFILE)	36.8	21.0
SAVINGS (PROFILE)	6.9 KWH	5.8 KWH

MAXIMUM ENERGY SAVINGS OF PROFILE (LOADED CAR) = (6.9 + 5.8) X 118.7 X 292.4 X 0.05 X 1.165 = $25,676/ANNUM.

O EXHIBIT V-9 SHOWS PROPULSION AND BRAKE ENERGY FOR EACH STATION-TO-STATION RUN CONSIDERING SEVERAL SETS OF RESTRICTIONS ON VERTICAL PROFILE GEOMETRY. THE ALTERNATIVES ANALYZED ARE:

- NO VERTICAL PROFILE OTHER THAN THAT REQUIRED BY DIFFERENCES IN STATION ELEVATIONS
- MAXIMUM GRADE OF 4% WITH THE DIP OF THE VERTICAL PROFILE RESTRICTED TO A MAXIMUM OF 30 FEET
- SIMILAR GRADE AND DEPTH RESTRICTIONS OF 6% AND 40 FEET, RESPECTIVELY
- SIMILAR GRADE AND DEPTH RESTRICTIONS OF 6% AND 50 FEET, RESPECTIVELY
- SIMILAR GRADE AND DEPTH RESTRICTIONS OF 6% AND 60 FEET, RESPECTIVELY

THE PROFILE THAT RESULTS IN THE LOWEST PROPULSION ENERGY OR "MINIMUM CASE" IS SHOWN IN THE EXTREME RIGHT HAND COLUMN OF EXHIBIT V-9.

O EXHIBIT V-10 SUMMARIZES PROPULSION ENERGY REQUIREMENTS AND UPPER BOUNDS ON SAVINGS FOR A COMPLETE ROUND TRIP OF A SIX-CAR EMPTY TRAIN. A LOAD FACTOR OF 1.165 (OR OTHERWISE) CAN BE APPLIED TO OBTAIN ENERGY VALUES FOR AVERAGE SYSTEM LOADS.

EXHIBIT V-9

PROPULSION AND BRAKE ENERGY FOR VARIOUS VERTICAL PROFILE GEOMETRIES

		No Profile		Max Grade 4% Max Depth 30 FT		Max Grade 6% Max Depth 40 FT		Max Grade 6% Max Depth 50 FT		Max Grade 6% Max Depth 60 FT		Minimum Case Propulsion Energy (kWH)
Station Run	Direction	Propulsion Energy (kWH)	Brake Energy (kWH)	Propulsion Energy (kWH)	Brake Energy (kWH)	Propulsion Energy (kWH)	Brake Energy (kWH)	Propulsion Energy (kWH)	Brake Energy (kWH)	Propulsion Energy (kWH)	Brake Energy (kWH)	
North Hollywood												
	In	29.2	35.5	27.2	33.7	26.9	33.4	27.8	34.3	29.2	35.7	26.9
	Out	57.9	26.3	55.6	24.6	54.8	23.8	56.0	26.0	57.3	26.3	54.0
Studio City												
	In	29.3	29.7	25.9	24.5	23.6	22.4	22.4	21.2	21.7	20.7	21.7
	Out	56.7	26.5	50.7	22.2	40.8	20.2	47.6	18.9	46.3	17.6	46.3
Hollywood												
	In	25.5	37.7	23.2	34.9	21.0	32.6	21.4	33.0	22.2	33.9	21.0
	Out	38.8	19.2	33.2	14.3	30.9	12.1	30.1	11.2	30.3	11.5	30.1
Cahuenga/Hollywood												
	In	28.6	35.7	26.2	33.4	24.8	32.0	24.8	32.0	24.8	32.1	24.8
	Out	44.6	26.2	40.9	22.3	39.1	20.5	38.7	20.1	38.9	20.3	38.7
Fountain/La Brea												
	In	31.9	29.3	27.3	25.6	26.6	24.9	26.0	24.5	27.0	25.5	26.0
	Out	36.4	27.2	34.4	24.4	33.7	23.6	33.4	23.4	33.3	23.3	33.3
Fairfax/Santa Monica												
	In	26.8	36.3	28.2	34.6	21.2	32.5	21.0	32.4	21.0	32.5	21.0
	Out	43.7	24.4	41.0	19.6	38.5	17.1	37.5	16.1	36.8	15.4	36.8
Fairfax/Beverly												
	In	30.9	28.2	30.0	27.4	30.6	28.1	31.5	28.9	33.1	30.6	30.0
	Out	37.5	27.6	34.2	24.4	33.7	23.8	33.1	23.3	33.0	23.2	33.0
Wilshire/Fairfax												
	In	36.0	27.6	30.4	22.0	29.2	20.8	26.8	18.4	26.0	17.4	26.0
	Out	31.1	29.5	25.7	24.0	24.3	22.7	22.2	20.7	21.6	20.1	21.6
Wilshire/La Brea												
	In	38.5	28.4	33.5	23.3	32.2	22.0	30.0	19.8	29.3	19.0	29.3
	Out	40.3	28.4	34.6	22.8	33.4	21.5	31.7	19.8	30.4	18.5	30.4
Wilshire/Western												
	In	26.1	19.1	23.6	16.4	23.6	16.4	23.6	16.4	23.6	16.4	23.6
	Out	23.0	26.1	20.6	23.9	20.6	23.9	20.6	23.9	20.6	23.9	20.6
Wilshire/Normandie												
	In	25.8	19.6	23.2	16.9	23.2	16.9	23.2	16.9	23.2	16.9	23.2
	Out	23.2	25.5	20.8	23.2	20.8	23.2	20.8	23.2	20.8	23.2	20.8
Wilshire/Vermont												
	In	34.5	28.2	28.5	22.5	27.3	21.2	25.6	19.4	24.3	18.2	24.3
	Out	32.7	28.1	27.9	23.5	25.6	21.3	23.9	19.6	23.2	19.0	23.2
Alvarado												
	In	35.8	27.5	31.5	22.3	30.5	21.0	27.9	18.6	26.6	17.4	26.6
	Out	31.8	28.8	29.0	26.9	28.6	26.5	28.4	26.3	27.9	25.9	27.9
7th/Flower												
	In	19.0	16.0	17.2	15.1	17.2	15.1	17.2	15.1	17.2	15.1	17.2
	Out	16.9	15.7	15.9	14.0	15.9	14.0	15.9	14.0	15.9	14.0	15.9
5th/Broadway												
	In	26.3	19.2	23.6	16.4	23.6	16.4	23.6	16.4	23.6	16.4	23.6
	Out	23.0	26.1	20.8	24.0	20.8	24.0	20.8	24.0	20.8	24.0	20.8
Civic Center												
	In	21.7	20.6	19.7	16.9	19.7	16.9	19.8	17.0	21.0	18.3	19.7
	Out	24.8	18.7	19.7	15.3	18.5	15.1	19.4	15.1	20.7	16.4	19.4
Union Station												
TOTALS (kWH)		1028.3	843.4	919.3	735.4	890.2	705.9	872.7	689.2	871.5	688.7	858.6

EXHIBIT V-10
PROPULSION ENERGY AND SAVINGS PER TRAIN PER ROUND TRIP

	MAXIMUM GRADE - MAXIMUM DEPTH					MINIMUM CASE
	NO PROFILE	4%, 30 FT	6%, 40 FT	6%, 50 FT	6%, 60 FT	
TOTAL ENERGY (KWH)	1028.3	919.3	890.2	872.7	871.5	858.6
SAVINGS (KWH)	--	109.0	138.1	155.6	156.8	169.7
PERCENTAGE SAVINGS	--	10.6%	13.4%	15.1%	15.2%	16.5%*

ASSUMPTIONS:

- TRAINS OPERATE AT MAXIMUM PERFORMANCE WITHOUT OPERATIONAL DISTURBANCES
- LOSSES FROM SUBSTATION INPUT TO VEHICLE TRACTION OUTPUT NOT INCLUDED
- MINOR DIFFERENCES IN RUN TIMES NOT FULLY CORRECTED.

* NOT FULLY ACHIEVABLE WITH TWIN TUNNELS FOLLOWING SAME VERTICAL PROFILE.

5. <u>THE ANNUAL COSTS FOR PROPULSION ENERGY CAN BE REDUCED SUBSTANTIALLY BY VERTICAL PROFILING</u>

- EXHIBIT V-11 INDICATES ANNUAL COST SAVINGS OF $339,600. HOWEVER, SEVERAL OTHER FACTORS MUST BE CONSIDERED BEFORE A PRACTICAL UPPER LIMIT ON COST SAVINGS CAN BE DETERMINED.

- MAJOR FACTORS WHICH DECREASE VERTICAL PROFILE COST SAVINGS ARE:

  - OPERATIONAL PERTURBATIONS THAT REQUIRE A TRAIN TO MAKE ADDITIONAL BRAKE APPLICATIONS BETWEEN STATIONS

  - REQUIREMENTS FOR CROSSOVER LOCATIONS AND POCKET TRACKS

- FACTORS WHICH MAY INCREASE VERTICAL PROFILE COST SAVINGS ARE:

  - IMPLEMENTATION OF A CONTROL STRATEGY TO MINIMIZE BRAKE APPLICATIONS ON DOWNGRADES AND POWER APPLICATIONS ON UPGRADES

  - A PERFORMANCE MODIFICATION STRATEGY THAT REDUCES ACCELERATION LEVELS AND TOP SPEEDS WHEN MAXIMUM PERFORMANCE IS NOT REQUIRED.

EXHIBIT V-11
PROPULSION ENERGY AND SAVINGS PER STATION PAIR

	No Profile[1] Energy (kWH)		Minimum Case								With Profile[2] Energy (kWH)		Annual Energy[3] Cost ($000)		Annual Savings ($000)	Percentage Savings
			4% 30ft		6% 40ft		6% 50ft		6% 60ft							
Station Run	Inbound	Outbound	In	Out	In	Out	In	Out	In	Out	Inbound	Outbound	No Profile	With Profile		
North Hollywood																
Studio City	29.2	57.9			*	*					26.9	54.8	176.1	165.2	10.9	6.2
Hollywood Bowl	29.3	56.7							*	*	21.7	46.3	173.8	137.4	36.4	20.9
Cahuenga/Hollywood	25.5	38.8			*		o	*			21.4	30.1	130.0	104.1	25.9	19.9
Fountain/La Brea	28.6	44.6					*	*			24.8	38.7	148.0	128.4	19.6	13.2
Fairfax/Santa Monica	31.9	36.4					*	o		*	26.0	33.4	138.1	120.1	18.0	13.0
Fairfax/Beverly	26.8	43.7							*	*	21.0	36.8	142.5	116.8	25.7	18.0
Wilshire/Fairfax	30.9	37.5	*	o						*	30.0	34.2	138.3	129.8	8.5	6.1
Wilshire/La Brea	36.0	31.1							*	*	26.0	21.6	135.6	96.2	39.4	29.0
Wilshire/Western	38.5	40.3							*	*	29.3	30.4	159.3	120.7	38.6	24.2
Wilshire/Normandie	26.1	23.0	*	*							23.6	20.6	99.3	89.5	9.8	9.9
Wilshire/Vermont	25.8	23.2	*	*							23.2	20.8	99.1	88.9	10.2	10.3
Alvarado	34.5	32.7							*	*	24.3	23.2	135.8	96.0	39.8	29.3
7th/Flower	35.8	31.8							*	*	26.6	27.9	136.7	110.2	26.5	19.4
5th/Broadway	19.0	16.9	*	*							17.2	15.9	72.6	66.9	5.7	7.9
Civic Center	26.3	23.0	*	*							23.6	20.8	99.6	89.8	9.8	9.8
Union Station	21.7	24.8			*	o	*				19.7	19.5	94.0	79.2	14.8	15.7
TOTALS	1028.3										860.4		2078.8	1739.2	339.6	16.34

Assumptions:

1. Power distribution losses not included.
2. Profile resulting in minimum energy selected.
3. Five cents per kWH (no charge for peak loads or low power factor); trips per annum.

6. OPERATIONAL PERTURBATIONS WHICH CAUSE INTERFERENCE IN MOVEMENT OF FOLLOWING TRAINS SUBTRACT FROM THE UPPER BOUND OF ENERGY SAVINGS

O A WORST CASE IS REPRESENTED BY A TRAIN HAVING TO STOP AT THE BOTTOM OF THE PROFILE. AS SHOWN IN EXHIBIT V-8, 23.9 KWH OF ENERGY WILL BE LOST ASSUMING NO REGENERATION. IN ORDER TO REACH THE NEXT STATION FROM THE STOPPED POSITION, ENERGY MUST BE USED FOR:

- OVERCOMING THE VERTICAL HEIGHT--7.9 KWH
- ACCELERATING UP TO SPEED--7.35 KWH (ASSUMING SPEED IS LIMITED TO 32.5 MPH)
- FRICTION LOSSES--APPROXIMATELY 0.5 KWH

THEREFORE, TOTAL ADDIIONAL ENERGY REQUIRED FOR STATION-TO-STATION RUN IS 15.75 KWH.

O SIMILARLY, IF THE MAXIMUM EFFECT ON A FOLLOWING TRAIN IS A SPEED REDUCTION TO 32.5 MPH BEFORE REACHING THE ASCENDING GRADE, AND ASSUMING THAT SPEED IS MAINTAINED AT 32.5 MPH UP THE GRADE AND INTO THE STATION STOP PROFILE, THEN THE ADDITIONAL ENERGY REQUIRED IS:

- OVERCOMING THE VERTICAL HEIGHT--7.9 KWH
- FRICTION LOSSES--APPROXIMATELY 1.0 KWH

AND TOTAL ADDITIONAL ENERGY REQUIRED FOR STATION-TO-STATION RUN IS APPROXIMATELY:

7.9 + 1.0 - 1.6 = 7.5 KWH.

O THE TWO EXAMPLES ABOVE INDICATE THAT FREQUENT PERTURBATIONS OF TRAIN MOVEMENT MUST OCCUR BEFORE NET ENERGY SAVINGS OF THE VERTICAL PROFILE ARE REDUCED TO ZERO. IF THE SYSTEM PERTURBANCE IS NOT REFLECTED BACK DOWN THE LINE AND SLOWDOWN IS ONLY IMPOSED ON ONE TRAIN, THEN TWO INTERFERENCE-FREE RUNS ARE REQUIRED TO RECOVER THE ADDITIONAL ENERGY USED BY THE TRAIN THAT STOPS AND ONE INTERFERENCE-FREE RUN FOR THE TRAIN THAT IS SLOWED TO 32.5 MPH.

7. <u>ENERGY COST SAVINGS MUST BE COMPARED WITH THE ESTIMATED INCREASE IN CAPITAL COSTS OF VERTICAL PROFILING</u>

- O INCREMENTAL TUNNEL AND GUIDEWAY COSTS FOR THE DIPPED SYSTEM HAVE NOT BEEN IDENTIFIED.

- O IF VERTICAL VENTILATION SHAFTS ARE REQUIRED BETWEEN STATIONS THEN TYPICAL COSTS MAY BE ESTIMATED:

  - INCREMENTAL COST OF VERTICAL SHAFT IS $5000* PER FOOT

  - ASSUMING ONE SHAFT BETWEEN EACH STATION PAIR, THEN FROM EXHIBIT V-11, ADDITIONAL SHAFT LENGTHS ARE (5 X 30) + (2 X 40) + (3 X 50) + (6 X 60) FEET. TOTAL ADDITIONAL DEPTH = 740 FEET.

ESTIMATED ADDITIONAL COST = $3.7 MILLION.

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* SOURCE: JPL REPORT.

8. REGENERATIVE ELECTRICAL BRAKING IS AN ALTERNATIVE MEANS OF SAVING PROPULSIVE ENERGY. ALTHOUGH ITS TOTAL EFFECTIVENESS MAY BE REDUCED BY VERTICAL PROFILING, THE SPECIFICATION OF REGENERATIVE EQUIPMENT MAY STILL BE COST-EFFECTIVE

- O ONCE A D.C. CHOPPER IS SPECIFIED, THE EXTRA CAPITAL EXPENSE TO ADD THE REGENERATIVE BRAKE FUNCTION INVOLVES THE FOLLOWING ITEMS:
  - ADDITIONAL CONTACTORS OR SOLID STATE SWITCHES TO CONNECT THE POWER CIRCUITS IN THE ELECTRIC BRAKE CONFIGURATION
  - ADDITIONAL CONTROL ELECTRONICS AND CONTROL FUNCTIONS
  - OTHER COMPONENTS REQUIRED FOR THE PARTICULAR CIRCUIT DESIGN UTILIZED, SUCH AS POWER RESISTORS AND DIODES.

  HOWEVER, THE INCREMENTAL COST AND WEIGHT ARE LOW.

- O EXHIBIT V-9 SHOWS THE TOTAL BRAKING ENERGY FOR A SINGLE ROUND TRIP OF A SIX-CAR TRAIN AS 843 KWH. THIS IS REDUCED TO 688 KWH FOR A 6% GRADE, 60-FOOT DIP PROFILE DESIGN, WHICH IS A REDUCTION OF 18.4%. THUS, 81.6% OF THE BRAKING ENERGY REMAINS A CANDIDATE FOR REGENERATION.

O ENERGY SAVINGS DUE TO REGENERATIVE BRAKES ARE EXPECTED TO BE IN THE RANGE OF 10-15% WITHOUT VERTICAL PROFILING.

- OPERATING RESULTS IN HANOVER, GERMANY, SHOW 22% SAVINGS FOR AN AVERAGE STATION SPACING OF 0.38 MILES.

- OPERATING RESULTS IN SAO PAULO, BRAZIL, SHOW 18% SAVINGS WITH AN AVERAGE STATION SPACING OF 0.56 MILES.

THE AVERAGE STATION SPACING OF THE SCRTD STARTER LINE IS 1.1 MILES AND LOWER REGENERATION EFFICIENCY WILL RESULT.

O FOR 12.5% ENERGY SAVINGS WITHOUT VERTICAL PROFILING, THE ANNUAL COST SAVINGS WILL BE $259,850 (12.5% OF $2,078,800).

WITHOUT FURTHER SIMULATION, THE EFFECT OF VERTICAL PROFILING ON REGENERATION EFFICIENCY IS UNCLEAR. IF A DIRECT RATIO, HOWEVER, IS ASSUMED BETWEEN SAVINGS AND CANDIDATE BRAKING ENERGY, THE ANNUAL SAVINGS WOULD BE $223,750.

FOR A FLEET SIZE OF 114 CARS, THE ANNUAL SAVINGS CORRESPOND TO $1,963 PER CAR.

9. INDIVIDUAL STATION-TO-STATION RUNS MUST BE EXAMINED TO DETERMINE THE UPPER BOUNDS ON ADDITIONAL ENERGY SAVINGS THAT CAN BE REALIZED FROM COAST AND PERFORMANCE MODIFICATION STRATEGIES

- EXHIBITS V-12 AND V-13 ILLUSTRATE THE POTENTIAL FOR ADDITIONAL ENERGY SAVINGS FOR A SIX-CAR TRAIN RUN FROM CAHUENGA/HOLLYWOOD TO FOUNTAIN/LA BREA.

- AT A DISTANCE OF 900 FEET, BRAKE APPLICATION OCCURS ON THE PROFILE DOWNGRADE BECAUSE OF THE 55-MPH HORIZONTAL CURVE RESTRICTION. THIS MAY BE AVOIDED BY A COAST STRATEGY AS SHOWN IN EXHIBIT V-12. EXHIBIT V-13 SHOWS THAT:

  - ADDITIONAL RUN TIME IS 1 TO 2 SECONDS.

  - UP TO 5 KWH OF ADDITIONAL PROPULSION ENERGY CAN BE SAVED BY THE VERTICAL PROFILE.

- AT 3,200 FEET THE HORIZONTAL CURVE RESTRICTION IS LIFTED, AND FOR MAXIMUM PERFORMANCE THE TRAIN IS ACCELERATED UP TO 70 MPH. IF THE SPEED LIMIT IS CONTINUED AT 55 MPH, EXHIBIT V-13 SHOWS THAT:

  - ADDITIONAL RUN TIME IS APPROXIMATELY 3 SECONDS.

  - 8 KWH OF PROPULSION ENERGY CAN BE SAVED.

EXHIBIT V-12
TRAIN PERFORMANCE BETWEEN CAHUENGA/HOLLYWOOD AND FOUNTAIN/LA BREA

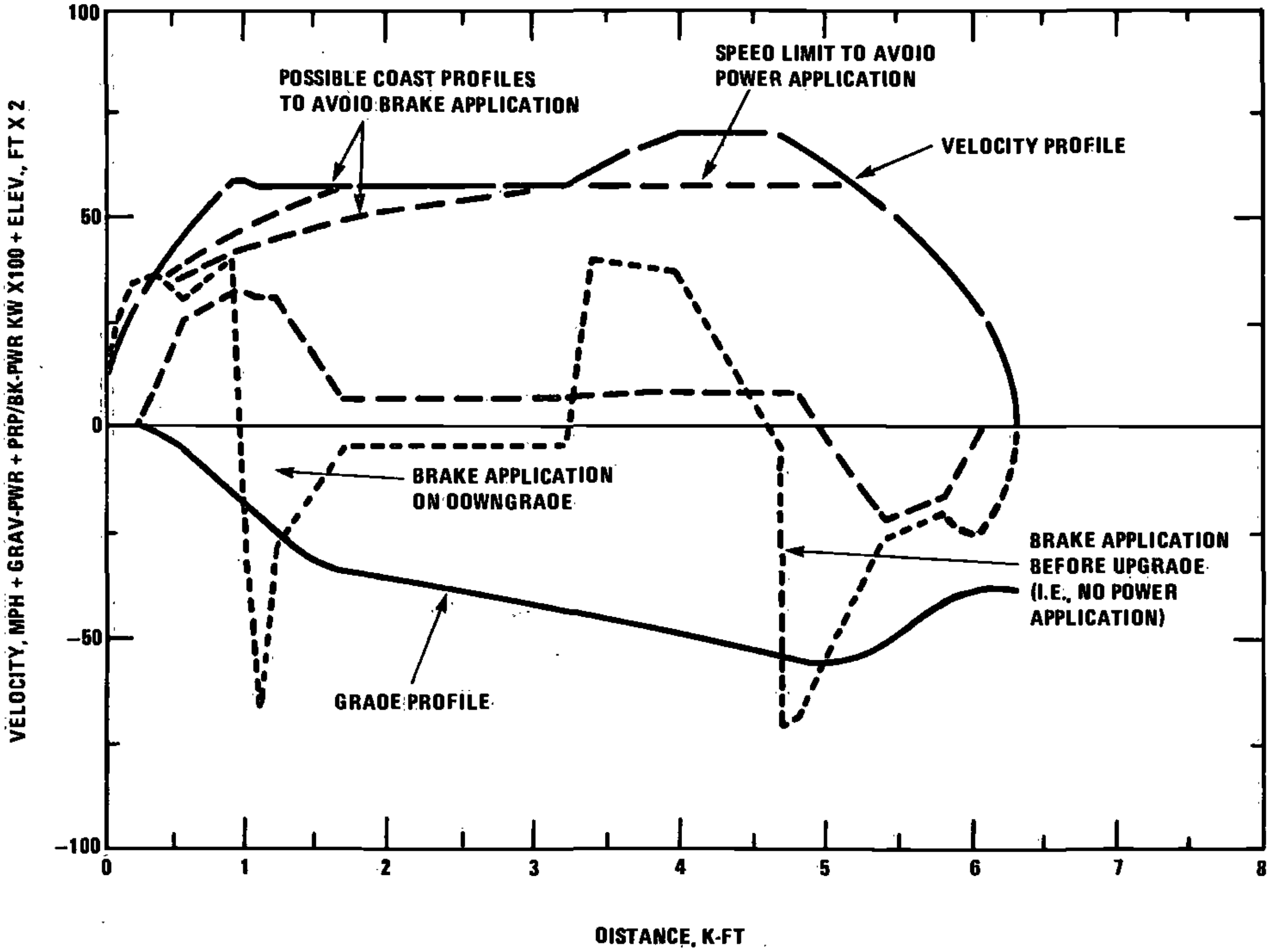
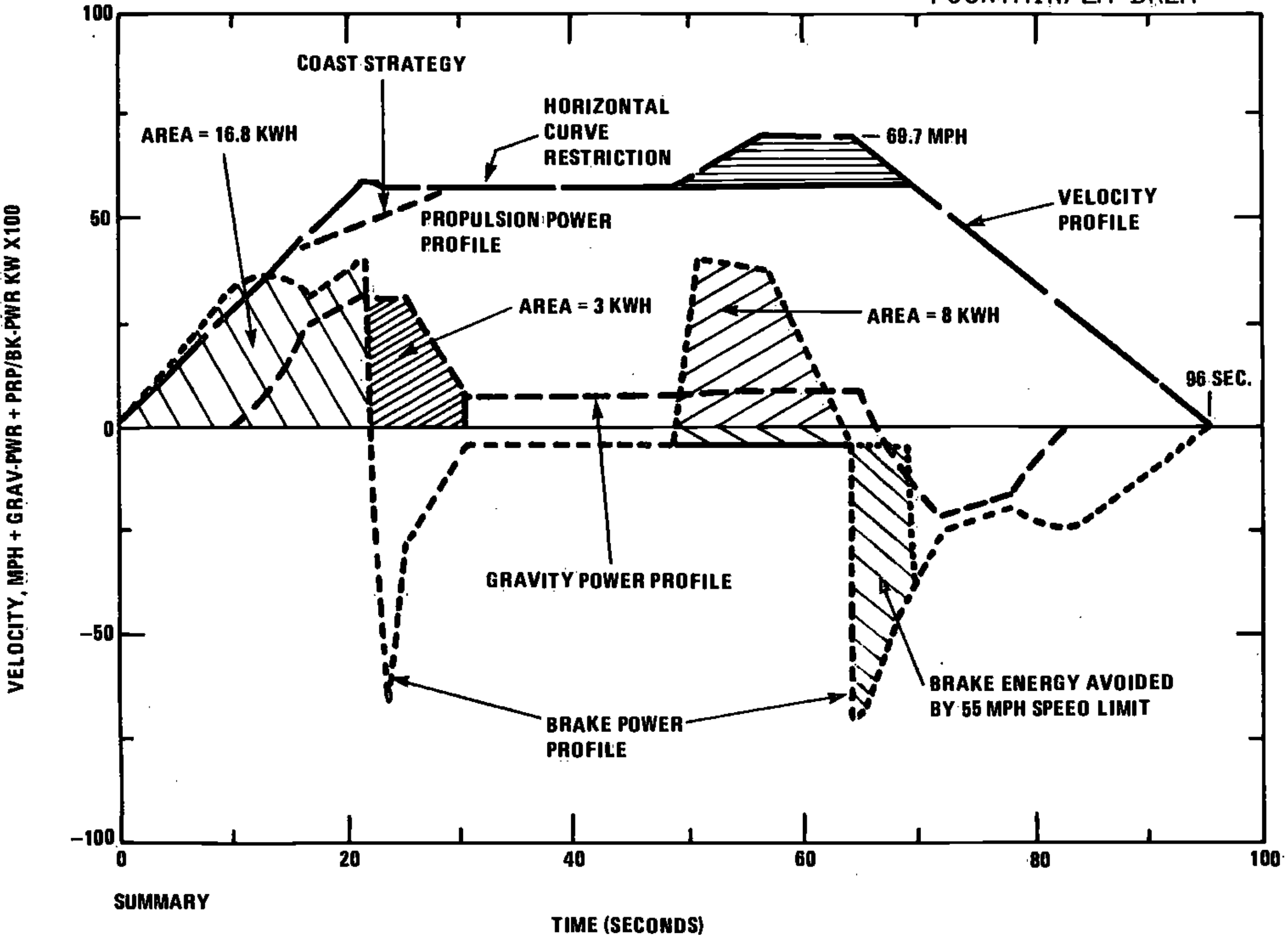


EXHIBIT V-13

TRAIN PERFORMANCE BETWEEN CAHUENGA/HOLLYWOOD AND FOUNTAIN/LA BREA



SUMMARY

	WITH PROFILE	WITHOUT PROFILE
RUN TIME	96 SEC.	SAME
MAX. SPEED	69.7 MPH	SAME
AVR. SPEED	45.0 MPH	SAME
PROP^L ENERGY	24.8 KWH	28.6 KWH
BRAKE ENERGY	32.0 KWH	35.7 KWH

THIS ENERGY SAVING IS INDEPENDENT OF THE VERTICAL PROFILE.

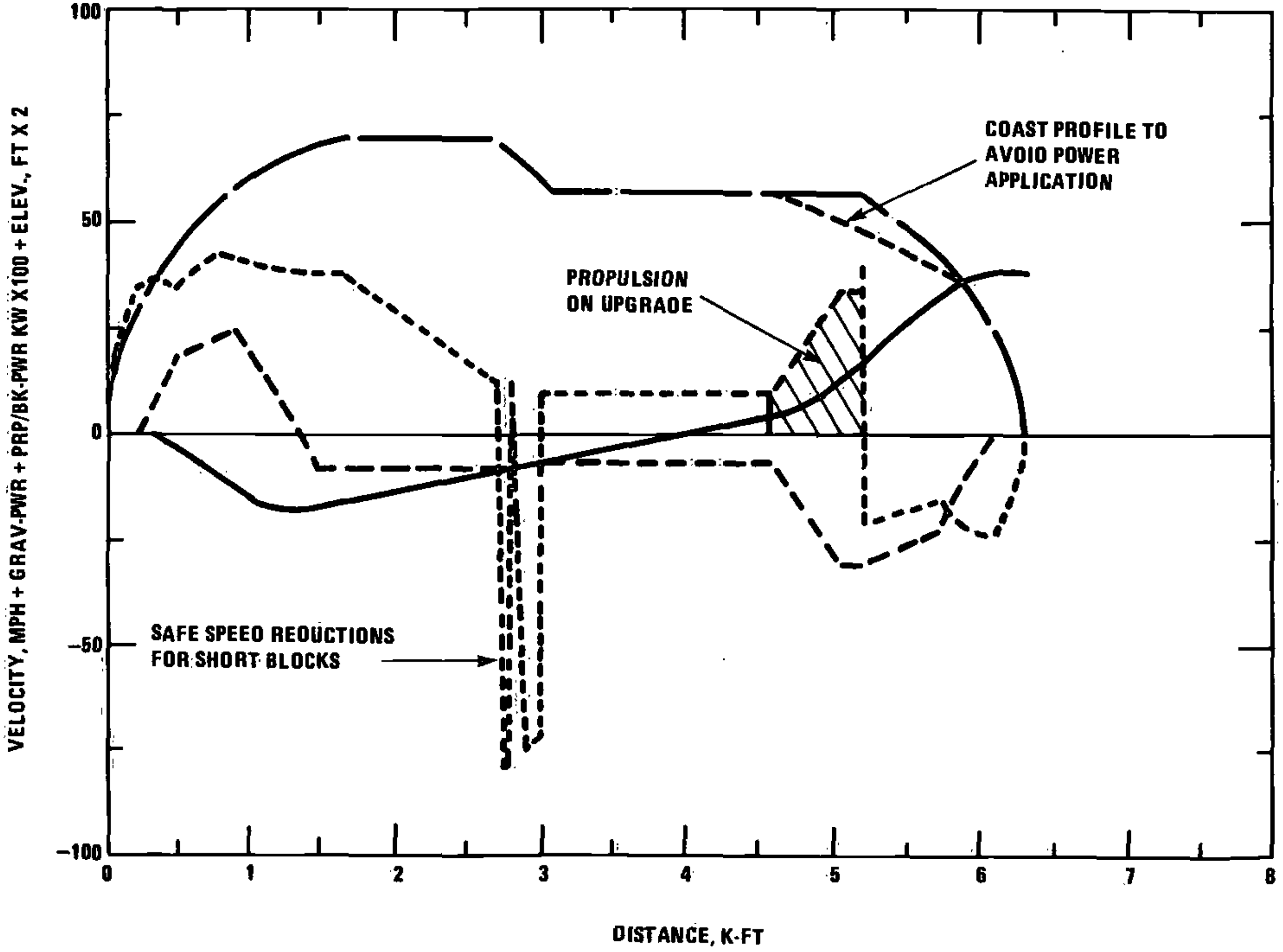
IN SUMMARY, PROPULSION ENERGIES AND RUN TIMES ARE APPROXIMATELY:

	WITH CONTROL STRATEGY	WITHOUT CONTROL STRATEGY
WITH VERTICAL PROFILE	15.6 KWH 101 SEC.	24.8 KWH 96 SEC.
WITHOUT VERTICAL PROFILE	20.6 KWH 99 SEC.	28.6 KWH 96 SEC.

THEREFORE, FOR THIS CASE, A COMBINATION OF VERTICAL PROFILING AND AN OPTIMAL CONTROL STRATEGY CAN GIVE ENERGY SAVINGS OF UP TO 45% FOR A 5% INCREASE IN RUN TIME.

O EXHIBIT V-14 ILLUSTRATES A POWER APPLICATION ON A PROFILE UPGRADE FOR THE RUN FROM FOUNTAIN/LA BREA TO CAHUENGA/HOLLYWOOD. A COAST PROFILE IS SHOWN THAT WILL MINIMIZE THE POWER APPLICATION.

EXHIBIT V-14
TRAIN PERFORMANCE BETWEEN FOUNTAIN/LA BREA AND CAHUENGA/HOLLYWOOD



VI. SUMMARY

VI. SUMMARY

THIS CHAPTER SUMMARIZES OUR FINDINGS, CONCLUSIONS AND RECOMMENDATIONS.

1. FINDINGS: BASELINE EQUIPMENT DEFINITION AND OPERATING PLAN

- THE CAPACITY REQUIREMENTS AND SERVICE OBJECTIVES OF THE SCRTD METRO RAIL PROJECT CAN BE SATISFIED BY APPLYING CONVENTIONAL RAIL RAPID TRANSIT TECHNOLOGY BASED ON SUBSYSTEMS PREVIOUSLY DEMONSTRATED IN REVENUE SERVICE.

- TRAINS OF SIX CARS OPERATING ON A HEADWAY OF 3 1/2 MINUTES WILL PROVIDE SUFFICIENT CAPACITY TO MEET THE PROJECTED RIDERSHIP, WITH EXPANSION UP TO 30,000 PASSENGERS PER HOUR (ONE-WAY PEAK LINK) BY REDUCING HEADWAYS TO 2 MINUTES.

- SIX-PERCENT GRADE IS THE MAXIMUM GRADE THAT SHOULD BE CONSIDERED FOR FURTHER VERTICAL PROFILE ANALYSIS. THIS IS BASED ON AN ANALYSIS OF TRACTION DEGRADATION RESULTING FROM PROPULSION SUBSYSTEM FAILURES. GRADES OF 7 PERCENT OR MORE WILL RESULT IN SYSTEM BLOCKAGES AT A FREQUENCY OF OCCURRENCE THAT IS LIKELY TO BE UNACCEPTABLE.

2. FINDINGS: RESULTS OF ENERGY MANAGEMENT ANALYSIS

- ENERGY SAVINGS WERE ANALYZED FOR VERTICAL PROFILING, REGENERATION AND PERFORMANCE CONTROL.

  - VERTICAL PROFILES DESIGNED TO CONSERVATIVE CRITERIA WILL REDUCE PROPULSION ENERGY COSTS BY UP TO 16 PERCENT, AN ANNUAL COST SAVINGS IN EXCESS OF $300,000, BASED ON A RATE OF 5 CENTS PER KILOWATT-HOUR. IT IS ESTIMATED THAT ENERGY COSTS WILL INCREASE BY 50-100 PERCENT BY THE TIME THE STARTER LINE IS PUT INTO REVENUE SERVICE.

  - FOR REGENERATING PROPULSION EQUIPMENT, AN ADDITIONAL COST SAVINGS OF $250,000 PER ANNUM IS ANTICIPATED (BASED ON 5 CENTS PER KILOWATT-HOUR). AN ADDITIONAL BENEFIT IS THE SIGNIFICANT REDUCTION OF PEAK ELECTRICAL LOAD DURING PEAK OPERATING PERIODS.

  - SUBSTANTIAL SAVINGS WILL RESULT FROM REDUCTION OF TOP SPEEDS, FROM EFFECTIVE CONTROL OF ACCELERATION RATES AND FROM COASTING CAPABILITIES. HOWEVER, THESE SAVINGS MUST BE EVALUATED AGAINST INCREASED TRIP TIMES AND REDUCED THROUGHPUT.

- AN INTEGRATED APPROACH TO THE INDIVIDUAL APPLICATION OF ENERGY MANAGEMENT ALTERNATIVES IS REQUIRED TO MAXIMIZE BENEFITS.

3. FINDINGS: COST OF ENERGY MANAGEMENT OPTIONS

- O VERTICAL PROFILES - THE INCREMENTAL TUNNEL AND VENTILATION SHAFT COSTS WERE NOT ANALYZED.

- O REGENERATION - THE INCREMENTAL COSTS APPEAR TO BE VERY SMALL.

- O PERFORMANCE CONTROL - SIGNIFICANT COSTS ARE LIKELY TO BE INCURRED FOR PRODUCT DEVELOPMENT AND EQUIPMENT PROCUREMENT. THE ADVERSE IMPLICATIONS OF INEFFECTIVE DEVELOPMENT INCREASE IF VERTICAL PROFILES ARE IMPLEMENTED.

4. CONCLUSIONS

O VERTICAL PROFILES

- ANNUAL SAVINGS OF $300,000 REPRESENT A PRESENT VALUE OF $2,240,000 AT A DISCOUNT RATE OF 12 PERCENT. A MORE DETAILED ANALYSIS OF THE INCREMENTAL CAPITAL COST IS REQUIRED TO JUDGE WHETHER THE ANNUAL OPERATIONAL COST SAVINGS MIGHT BE JUSTIFIED.

- THE VERTICAL PROFILE POSSIBILITIES MUST BE ESTABLISHED ON A STATION-TO-STATION BASIS, BUT THE RESULTS MUST BE EVALUATED ON A SYSTEMWIDE BASIS.

O REGENERATION - REGENERATION SHOULD BE INCORPORATED REGARDLESS OF OTHER ENERGY MANAGEMENT ALTERNATIVES.

O PERFORMANCE CONTROL - PERFORMANCE CONTROL SHOULD BE INCORPORATED REGARDLESS OF OTHER ENERGY MANAGEMENT ALTERNATIVES, BUT ITS COMPLEXITY WILL INCREASE IF VERTICAL PROFILES ARE ADAPTED.

5. RECOMMENDATIONS

- O VERTICAL PROFILES - TO MAKE A FINAL DECISION, DESIGN VERTICAL PROFILES WITH MAXIMUM GRADES IN THE RANGE OF 4 TO 6 PERCENT FOR EACH INDIVIDUAL STATION-TO-STATION ALIGNMENT. ASSESS THE INCREMENTAL CONSTRUCTION COST OF THESE PROFILES. MAJOR CONSIDERATIONS ARE THE INCREMENTAL COSTS FOR:

  - MID-LINE VENTILATION SHAFTS
  - ADDITIONAL CHANGES IN THE TUNNELING MEDIUM DUE TO THE VERTICAL PROFILE
  - ADDITIONAL TUNNELING BELOW THE WATER TABLE DUE TO THE VERTICAL PROFILE.

  EVALUATE INCREMENTAL COSTS AGAINST ENERGY COST SAVINGS ON A LIFE-CYCLE BASIS FOR EACH STATION-TO-STATION LINK, AND EVALUATE RESULTS ON A SYSTEMWIDE BASIS.

- O REGENERATION - SPECIFY A REGENERATIVE PROPULSION SUBSYSTEM DURING PRELIMINARY ENGINEERING.

- O PERFORMANCE CONTROL - CONDUCT FURTHER STUDIES TO ESTABLISH THE FUNCTIONAL REQUIREMENTS AND A COST ESTIMATE OF A PERFORMANCE CONTROL SUBSYSTEM.

APPENDIX A

LIST OF REFERENCES

APPENDIX A

LIST OF REFERENCES

	REPORT/PUBLICATION TITLE	AUTHOR/SOURCE/DATE
1.	SCRTD Design Criteria	SCRTD, November 1979
2.	Report of European Adhesion Utilization Survey Trip	Klauder, May 1981
3.	Costs of Dipped Guideway	Sperry
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5.	Gravity-Assisted Acceleration and Braking	Uher, December 1980
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9.	Design Criteria - Volume IV - (Systemwide Systems) - Part 1	SCRTD, June 1981 (Rev.)
10.	Elements of Railway Signaling	General Railway Signal, June 1979
11.	Alternatives Analysis and Environmental Impact Statement/Report - Appendix IV	SCRTD
12.	Final Alternatives Analysis/Environmental Impact Statement/Report	SCRTD, April 1980

	REPORT/PUBLICATION TITLE	AUTHOR/SOURCE/DATE
13.	Effects of Tunnel and Station Size on the Costs and Service of Subway Transit Systems	JPL, November 1979
14.	Assessment of the Impact of Dipped Guideways on Urban Rail Transit Systems Train Scheduling and Operation	Gibbs & Hill, July 1981
15.	Alternative Systems for Rapid Transit Propulsion and Electrical Braking	Krings, March 1973
16.	The Status of Advanced Propulsion Systems for Urban Rail Vehicles	MITRE Corp., May 1979
17.	Patronage Impact of Possible Future Line Extensions	SCRTD, June 1981
18.	Alternative Concepts for Underground Rapid Transit Systems	JPL, March 1977
19.	Drives and Power Trains for Rapid Transit Cars	Westinghouse
20.	Energy Storage Propulsion System for Rapid Transit Cars	MTA, October 1978
21.	Transit Industry Core Technical Specifications for the Procurement of Rapid Rail Cars	The Decision Group, October 1980

	REPORT/PUBLICATION TITLE	AUTHOR/SOURCE/DATE
22.	PREFERRED ALTERNATIVE REPORT	SCRTD, SEPTEMBER 1979
23.	ASSESSMENT OF THE IMPACT OF DIPPED GUIDEWAYS ON URBAN RAIL TRANSIT SYSTEMS	KLAUDER, JULY 1981
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25.	ALLEVIATION OF PRESSURE PULSE EFFECTS FOR TRAINS ENTERING TUNNELS	JPL, JUNE 1979
26.	ALTERNATIVE CONCEPTS FOR UNDERGROUND RAPID TRANSIT SYSTEMS, VOLUME I	JPL, MARCH 1977
27.	ALTERNATIVE CONCEPTS FOR UNDERGROUND RAPID TRANSIT SYSTEMS, VOLUME II	JPL, MARCH 1977
28.	SPECIAL STUDY OF THE APPROPRIATE FLEET SIZE, PARTS I AND III	BOOZ, ALLEN & HAMILTON, APRIL 1978
29.	THE EFFECTS OF THE DC-CHOPPER TECHNOLOGY IN PUBLIC RAPID TRANSIT PASSENGER TRANSPORT (PRTPT)	AMLER, JANUARY 1978
30.	RELIABILITY DATA AND ANALYSIS FOR TRANSIT VEHICLES	SINGH/KANKAM

APPENDIX B

ANALYTICAL AND SIMULATION PROGRAMS

APPENDIX B

ANALYTICAL AND SIMULATION PROGRAMS

SRI INTERNATIONAL, AS A SUBCONTRACTOR TO BOOZ, ALLEN & HAMILTON, WAS ASSIGNED SPECIFIC TASKS WITH REGARD TO THE VERTICAL PROFILE ALTERNATIVES ISSUE. SRI HAS ACCOMPLISHED THE FOLLOWING:

O IMPLEMENTED A PROFILE GENERATION PROGRAM THAT CAN GENERATE DIPPED PROFILES SUBJECT TO INPUT RESTRICTIONS ON MAXIMUM GRADES AND MAXIMUM DEPTHS OF TUNNELING BELOW GRADES WHICH WOULD BE REALIZED WITHOUT SPECIAL PROFILING. THIS PROGRAM IS CALLED PROGEN AND CAN BE RUN INTERACTIVELY.

O IMPLEMENTED A SPECIAL-PURPOSE, RAPID TRANSIT PERFORMANCE CALCULATOR TO PERMIT CALCULATIONS OF ENERGY THAT CAN BE USED TO COMPARE THE EFFECTS OF PROFILING STRATEGIES ON THE SCRTD NETWORK. THE PROGRAM IS RTENERGY AND CAN BE RUN INTERACTIVELY.

O IMPLEMENTED THE NOMINAL NETWORK CONFIGURATION WITH GRADES AND STATION LOCATIONS FROM SCRTD SKETCHES ON A COMPUTER.

O RUN THE PROFILE GENERATION PROGRAM TO GENERATE SEVERAL NETWORK PROFILING ALTERNATIVES.

- RUN THE RTENERGY PROGRAM FOR TRAINS OPERATING IN BOTH DIRECTIONS BETWEEN THREE SELECTED STATIONS WITH NOMINAL GRADES AND WITH 6 PERCENT PROFILES. ONE CASE WAS ALSO RUN WITH THE START OF THE PROFILE MOVED DOWN TO A STATION.
- COMPARED THE RESULTS OF THE PROFILE ANALYSIS.
- DERIVED A METHODOLOGY FOR LOOKING AT PROFILE COSTS.

THESE ACTIVITIES WILL BE DISCUSSED IN GREATER DETAIL IN THE FOLLOWING SECTIONS.

1. PROFILE GENERATOR (PROGEN)

THIS PROGRAM CALCULATES AND CREATES THE VERTICAL PROFILE AND SPEED LIMITS FOR ALL THE STATION PAIRS OF THE SCRTD FUTURE GUIDEWAY TRANSIT SYSTEM. THE INPUTS TO THE PROGRAM ARE:

- O THE MAXIMUM DIP GRADE IN PERCENT
- O THE TUNNEL DEPTH IN FEET.

THE STATION NAMES, STATION LENGTH, THE PARAMETER TO COMPUTE VERTICAL CURVE LENGTH, AND SPEED LIMITS FOR STARTING AND STOPPING OF TRAINS ARE ALL DEFINED IN INTERNAL DATA STATEMENTS IN THE PROGRAM.

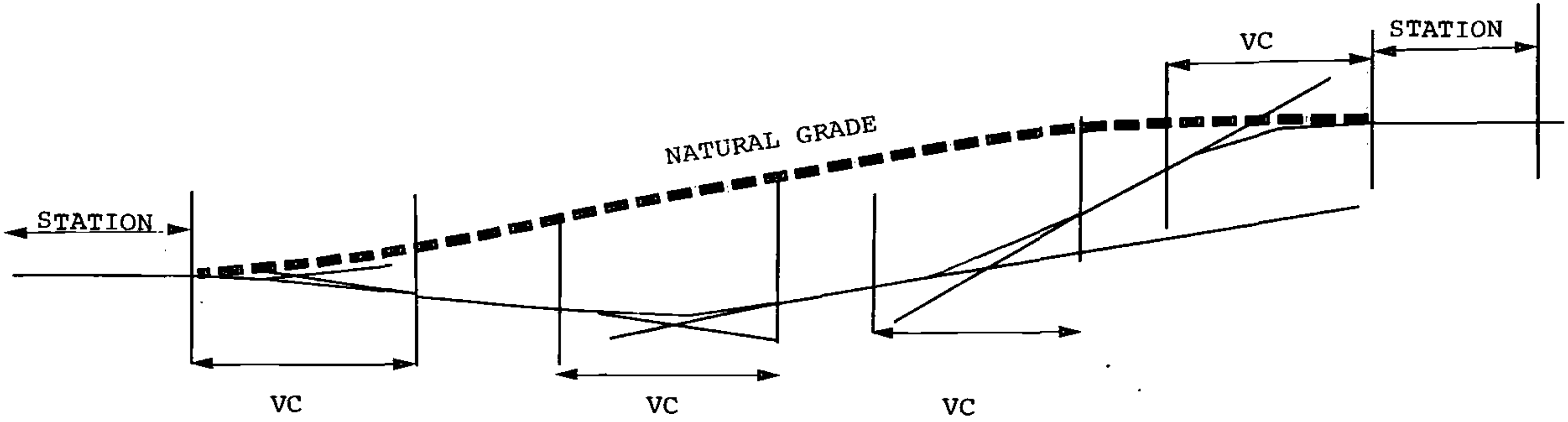
THE MAJOR ASSUMPTIONS ADOPTED IN THIS PROGRAM ARE:

- O THE GRADE OF THE STRAIGHT SEGMENT IN THE MIDSECTION OF THE TUNNEL IS PARALLEL TO THE NATURAL GRADE. (SEE EXHIBIT B-1.)

- O THE STRAIGHT SEGMENT IN THE MIDSECTION MUST BE AT LEAST A TRAIN LENGTH.

WHEN THE STATION SPACING IS SHORT, IT MAY NOT BE POSSIBLE TO ATTAIN EITHER THE SPECIFIED DEPTH OR THE GRADE. IN THAT CASE, THE PROGRAM WILL AUTOMATICALLY REDUCE THE TUNNEL DEPTH AND/OR GRADE SO THAT A DIP CAN BE ACCOMMODATED IN THE PROFILE. THE PROGRAM CAN ALSO HANDLE THE CASE WHERE THERE ARE NO DIPS IN THE PROFILE.

EXHIBIT B-1
SCHEMATIC REPRESENTATION OF
VERTICAL PROFILE WITH A DIP



VC = Vertical Curve.

2. RAPID TRANSIT ENERGY CALCULATION (RTENERGY)

THIS PROGRAM CALCULATES THE ENERGY AND TIME REQUIRED TO MOVE A TRAIN POINT MASS BETWEEN STATIONS. THE DAVIS EQUATION IS USED TO CALCULATE DRAG. ENERGY IS COMPUTED AS THE F'DX WHERE F IS THE APPLIED TRACTION FORCE. TRACTION FORCE AVAILABLE IS BASED ON A MOTOR CURVE OF FORCE AVAILABLE VERSUS TRAIN VELOCITY TYPICAL OF BART MOTORS WHICH TYPIFY MOST SYSTEMS. THE PROGRAM WILL ACCEPT SPEED RESTRICTION AND CALCULATE BLOCKS (IF REQUIRED) TO ASSURE THAT THE TRAIN WILL HIT ANY SPECIFIED ZONES AT A SPEED AT OR BELOW THE INPUT SPEED. A FLARE LOGIC IS ASSURED FOR STATION STOPS SO THEY WILL OCCUR AT A PRESPECIFIED DECELERATION RATE. A TRAIN LOGIC WHICH APPLIES A CONSTANT BRAKE FORCE IN THE CASE OF OVERSPEED IS ASSUMED.

PROGRAM RUNS ARE MADE BY SELECTING A GRADE PROFILE AND SPEED PROFILE GENERATED BY PROGEN AND EXECUTING THE PROGRAM. A TYPICAL OUTPUT FILE IS ATTACHED. OUTPUTS INCLUDE THE PROFILE AND VELOCITY RESTRICTIONS USED, ANY SPECIAL BLOCKS CREATED TO MEET SPEED RESTRICTIONS, THE STOPPING PROFILE (VELOCITY VERSUS POSITION), ENERGIES, AND APPLIED FORCES.

THE PROGRAM IS IN STANDARD FORTRAN AND IS PRESENTLY IMPLEMENTED ON THE VAX MACHINE AT SRI INTERNATIONAL.

APPENDIX C

COMPUTER PROGRAM TO EVALUATE OPERATING ALTERNATIVES DURING FAILURE MANAGEMENT

APPENDIX C

COMPUTER PROGRAM TO EVALUATE OPERATING ALTERNATIVES DURING FAILURE MANAGEMENT

BOOZ, ALLEN HAS ADAPTED AN EXISTING COMPUTER PROGRAM FOR USE IN DEVELOPING PEAK-PERIOD SCHEDULING ALTERNATIVES FOR THE SCRTD STARTER LINE. THE PROGRAM IS CAPABLE OF DISPLAYING THE EFFECTS OF A VARIETY OF OPERATIONAL PERTURBATIONS, AND THUS CAN AID IN EVALUATING ALTERNATIVES (E.G., IN HEADWAYS AND CONSIST SIZES) FROM THE VIEWPOINT OF FAILURE MANAGEMENT. THIS IN TURN ASSISTS IN DETERMINING FLEET SIZE REQUIREMENTS.

THIS PROGRAM, LABELED SCF1, IS WRITTEN IN CDC NOS BASIC AND IS INTENDED TO BE USED IN AN INTERACTIVE MODE. COSTS ARE ON THE ORDER OF $1-$2 PER RUN.

1. BASIC CHARACTERISTICS

SCF1 IS BASED ON CURRENT PATRONAGE ESTIMATES INBOUND DURING THE A.M. PEAK. THE PEAK IS REPRESENTED BY A SMOOTHED, SYMMETRICAL CURVE EXTENDING OVER TWO HOURS WITH APPROXIMATELY 26,000 PASSENGERS ON THE PEAK LINK. OF THIS TRAFFIC, 41.2 PERCENT OCCURS IN THE FIRST AND LAST 30 MINUTES COMBINED; 36.4 PERCENT IN THE INTERVALS 30-50 MINUTES AND 70-90 MINUTES INTO THE PEAK; AND THE REMAINING 22.4 PERCENT IN THE MIDDLE 20 MINUTES. VOLUMES ON OTHER LINKS ARE SCALED USING THE 1995 OPTION I DAILY VOLUME ESTIMATES, WITH ALL EXITING/ENTERING PASSENGERS SHOWN FOR WILSHIRE/CRENSHAW INCORPORATED IN THE WILSHIRE/WESTERN VOLUMES.

THE BASELINE SCHEDULE INCORPORATED IN SCF1 PROVIDES SIX-CAR CONSISTS AT 5, 10, 15, 20, 25, 30, 34, 38, 42, 46, 50, 53-1/2, 57, 60-1/2, 64, 67-1/2, 71, 75, 79, 83, 87, 91, 96, 101, 106, 111 AND 116 MINUTES AFTER THE START OF THE 2-HOUR PEAK PERIOD AND AN ADDITIONAL TRAIN AT 121 MINUTES. THE MODEL DISREGARDS RUN TIMES, IMPLYING THAT THE PEAK PERIOD IS OFFSET AMONG STATIONS BY THE NOMINAL STATION-TO-STATION RUN TIMES. THE EFFECT IS A WORST-CASE LOAD AT THE PEAK OF THE PEAK.

2. FEATURES

THE MOST COMMON VARIATIONS ADDRESSED BY SCF1 ARE ACCOMMODATED BY PROMPTED INPUTS. THESE INCLUDE:

- O VARIATIONS IN PATRONAGE. THE PROGRAM REQUESTS AN INPUT BY THE QUERY "% OF AVG. PATRONAGE=?." THE RESPONSE "100" RESULTS IN USE OF THE 1995 ESTIMATES; ANY OTHER RESPONSE CAUSES VOLUMES AT ALL STATIONS (AND HENCE ON ALL LINKS) TO BE SCALED BY THE SAME FACTOR.

- O DELAYS. THE QUERY "HOW MANY DELAY INCIDENTS?" SOLICITS AN INPUT OF THE NUMBER OF DELAY-TYPE SCHEDULE PERTURBATIONS; A POSITIVE RESPONSE INDUCES DISPLAY OF THE FORMAT INDICATOR "RUN NO., STATION NO., AMOUNT" FOLLOWED BY THE APPROPRIATE NUMBER OF "?" QUERIES, EACH OF WHICH REQUIRES THE THREE-PARAMETER RESPONSE. THE EFFECT OF EACH RESPONSE IS TO DELAY THE IDENTIFIED RUN BEGINNING AT THE INDICATED STATION, AND ALL LATER RUNS AT ALL STATIONS, SO THAT SCHEDULED HEADWAYS AFTER THE INCIDENT ARE MAINTAINED. THE PROGRAM WILL ACCEPT NEGATIVE "DELAYS" TO ALLOW FOR OPERATIONAL STRATEGIES SUCH AS CLOSING UP HEADWAYS AFTER AN INCIDENT AND TO PERMIT MINOR SCHEDULE CHANGES WITHOUT CHANGES IN THE PROGRAM AS STORED. (ALL TIME INPUTS, SUCH AS DELAY AMOUNTS, SHOULD BE IN MULTIPLES OF 1/2 MINUTE.)

- O CONSIST SIZE. THE QUERY "NOMIN. CARS PER CONSIST?" ORDINARILY SHOULD BE ANSWERED "6" FOR THE BASELINE (1995) SCHEDULE; A DIFFERENT SIZE MAY BE APPROPRIATE IF THE PATRONAGE INPUT DIFFERS SUBSTANTIALLY FROM 100 PERCENT.

- PERTURBATIONS OTHER THAN DELAYS. THE QUERY "HOW MANY UNUSUAL CONSISTS/OFFLOADS/ANNULLED TRAINS?" IS FOLLOWED BY ADDITIONAL PROMPTS AND FORMAT INDICATIONS IF A POSITIVE RESPONSE IS GIVEN. THE POSSIBILITIES ARE SOMEWHAT COMPLICATED AND WILL BE UNDERSTOOD MORE READILY VIA EXAMPLES OR HANDS-ON USE OF SCF1. SOME PERTURBATIONS--ESPECIALLY OFFLOADS--ARE LIKELY TO BE ACCOMPANIED BY DELAYS; DELAYS MUST BE SPECIFIED SEPARATELY, UNDER THE EARLIER HEADING.

3. EXAMPLES

EXHIBIT C-1 IS A REPRODUCTION OF SCF1 PROMPTS, INPUTS AND OUTPUT FOR NOMINAL CONDITIONS--100 PERCENT PATRONAGE, SIX-CAR CONSISTS, WITH NO DELAYS OR OTHER PERTURBATIONS. THE OUTPUT INDICATES PER-CAR PASSENGER LOADING ON THE 15 SUCCESSIVE (INBOUND) SEGMENTS, CORRESPONDING TO THE RUN NUMBER IDENTIFIED ON THE FOLLOWING LINE. THE ABSENCE OF A LETTER SUFFIX INDICATES THAT THE PER-CAR LOAD IS WITHIN NOMINAL SEATING CAPACITY; THE SUFFIX "S" IS A REMINDER THAT THE LOAD IS WITHIN NORMAL SEATED-PLUS-STANDING CAPACITY, WHILE "C" INDICATES THAT CRUSH LOAD IS BEING APPROACHED. IT CAN BE SEEN THAT THE MAXIMUM LOAD IN THIS BASELINE CASE OCCURS IN RUN 11, ON THE 11TH SEGMENT (WILSHIRE/VERMONT TO WILSHIRE/ALVARADO).

EXHIBIT C-2 REPRODUCES THE RESULTS UNDER THE SAME PATRONAGE AND SCHEDULE CONDITIONS, BUT WITH PERTURBATIONS. A GLANCE AT THE "UNUSUAL CONSISTS" PORTION OF THE INPUT REVEALS THAT RUN 14 IS TO ENCOUNTER AN OFFLOAD AT STATION 8. THE "0" RESPONSE TO "REPLACEMENT CONSIST SIZE (0=NONE)?" IS UNIMPORTANT IN THIS INSTANCE. BECAUSE THE SCHEDULE IS BASED ON 19 CONSISTS IN SERVICE, THE NEXT AFFECTED RUN WOULD BE 14 + 19 = 33, WHICH DOES NOT OCCUR WITHIN THE 2-HOUR PEAK. (IF RUN 33 EXISTED, THE "0" RESPONSE WOULD CAUSE IT TO BE EFFECTIVELY ANNULLED.) THE FIRST DELAY CORRESPONDS TO THE OFFLOAD EVENT; THE OPERATIONAL STRATEGY IS TO CLOSE UP THE GAPS, AND IS REFLECTED BY THE SIX NEGATIVE "DELAYS" THAT FOLLOW. THE DELAY RUN 27 IS INTRODUCED ONLY TO EXERCISE THE DISPLAY, AT THE END OF THE PRINTOUT, OF ANY DELAY EFFECTS PERSISTING TO THE END OF THE 2-HOUR PEAK.

EXHIBIT C-1
PASSENGER LOADING WITH UNPERTURBED SCHEDULE

```
 81/08/31. 14.14.33.
PROGRAM   SCF1

ALL TIMES TO NEAREST 1/2 MINUTE
% OF AVG. PATRONAGE=? 100
HOW MANY DELAY INCIDENTS? 0
NUMIN. CARS PER CONSIST ? 6
HOW MANY UNUSUAL CONSISTS/OFFLOADS/ANNULLED TRAINS? 0

  24   44   46   63   68   70  90S 103S 116S 122S 139S 137S 105S   69   48
 RUN  1

  25   45   47   65   70   72  96S 105S 119S 125S 142S 140S 108S   70   49
 RUN  2

  25   46   48   66   72   74  98S 108S 122S 128S 146S 144S 111S   72   50
 RUN  3

  26   47   49   68   74  76S 100S 110S 125S 131S 149S 147S 113S   74   51
 RUN  4

  26   48   51   70  75S  77S 103S 113S 128S 134S 153S 150S 116S  75S   53
 RUN  5

  27   50   52   71  77S  79S 105S 115S 130S 137S 156S 153S 118S  77S   54
 RUN  6

  23   42   44   60   65   67  88S  97S 110S 116S 132S 130S 100S   65   45
RUN  7

  25   46   48   66   71   73  97S 107S 120S 127S 144S 142S 109S   71   50
 RUN  8

  27   50   52   71  77S  79S 105S 116S 131S 137S 156S 154S 118S  77S   54
 RUN  9

  29   53   56  77S  83S  85S 113S 125S 141S 148S 168C 166C 128S  83S   58
 RUN 10

  31   57   60  82S  89S  92S 121S 134S 151S 159S 181C 178C 137S  89S   62
RUN 11

  29   52   55  75S  82S  84S 111S 122S 138S 145S 165C 163S 125S  81S   57
 RUN 12

  29   54   56  77S  83S  86S 113S 125S 141S 149S 169C 166C 128S  83S   58
 RUN 13

  30   55   57  79S  85S  86S 116S 128S 144S 152S 172C 170C 131S  85S   59
RUN 14
```

```
  30   54   57  78S  85S  87S 115S 127S 143S 151S 171C 169C 130S  85S   59
 RUN 15

  29   53   55  76S  83S  85S 113S 124S 140S 148S 168C 165C 127S  83S   56
 RUN 16

  28   52   54   75  81S  83S 110S 122S 137S 145S 164S 162S 124S  81S   57
 RUN 17

  31   56   59  81S  88S  90S 119S 131S 149S 156S 178C 175C 135S  88S   61
RUN 18

  29   52   55  75S  82S  84S 111S 122S 138S 146S 166C 163S 125S  82S   57
RUN 19

  27   49   51   70  75S  78S 103S 113S 128S 135S 153S 151S 116S  76S   53
RUN 20

  24   45   47   64   69   71  95S 104S 118S 124S 141S 139S 107S   70   49
 RUN 21

  22   41   43   59   64   65  87S  96S 108S 114S 129S 127S  98S   64   45
 RUN 22

  27   49   51   71  77S  79S 104S 115S 130S 137S 155S 153S 118S  77S   54
RUN 23

  26   48   50   69  75S  77S 102S 113S 127S 134S 152S 150S 115S  75S   52
 RUN 24

  26   47   49   68   73  75S 100S 110S 124S 131S 148S 146S 112S   73   51
RUN 25

  25   46   48   66   72   74  98S 108S 122S 128S 145S 143S 110S   72   50
RUN 26

  25   45   47   65   70   72  95S 105S 119S 125S 142S 140S 107S   70   49
RUN 27

   4    8    8   12   13   13   17   19   22   23   26   26   20   13    9
RUN 28
```

EXHIBIT C-2

PASSENGER LOADING WITH PERTURBATION: EXAMPLE

```
 81/09/01. 09.54.25.
PROGRAM   SCF1


ALL TIMES TO NEAREST 1/2 MINUTE
% OF AVG. PATRONAGE=? 100
HOW MANY DELAY INCIDENTS? 8
RUN NO.,STATION NO.,AMOUNT
? 14,8,6
? 15,7,-.5
? 16,6,-1
? 17,5,-1
? 18,4,-1
? 19,3,-1
? 20,2,-1.5
? 27,3,1
NOMIN. CARS PER CONSIST ? 6
HOW MANY UNUSUAL CONSISTS/OFFLOADS/ANNULLED TRAINS? 1
UNUSUAL SIZE=1,OFFLOAD=2,ANNULLED=3
(IF TRAIN UNAVAIL. THROUGHOUT PEAK, USE 1, SIZE 0)
ABNORMAL NO.  1
TYPE
? 2
RUN ... OFFLOADED AT STATION ...? 14,8
REPLACEMENT CONSIST SIZE (0=NONE) ? 0

  24   44   46   63   68   70  93S 103S 116S 122S 139S 137S 105S   69   48
 RUN  1

  25   45   47   65   70   72  96S 105S 119S 125S 142S 140S 108S   70   49
 RUN  2

  25   46   48   66   72   74  98S 108S 122S 128S 146S 144S 111S   72   50
RUN  3

  26   47   49   68   74  76S 100S 110S 125S 131S 149S 147S 113S   74   51
 RUN  4

  26   48   51   70  75S  77S 103S 113S 128S 134S 153S 150S 116S  75S   53
 RUN  5

  27   50   52   71  77S  79S 105S 115S 130S 137S 156S 153S 118S  77S   54
RUN  6

  23   42   44   60   65   67  88S  97S 110S 116S 132S 130S 100S   65   45
 RUN  7

  25   46   48   66   71   73  97S 107S 120S 127S 144S 142S 109S   71   50
 RUN  8

  27   50   52   71  77S  79S 105S 116S 131S 137S 156S 154S 118S  77S   54
 RUN  9

  29   53   56  77S  83S  85S 113S 125S 141S 148S 168C 166C 128S  83S   58
RUN 10

  31   57   60  82S  89S  92S 121S 134S 151S 159S 181C 178C 137S  89S   62
RUN 11

  29   52   55  75S  82S  84S 111S 122S 138S 145S 165C 163S 125S  81S   57
 RUN 12

  29   54   56  77S  83S  86S 113S 125S 141S 149S 169C 166C 128S  83S   58
RUN 13

  30   55   57  79S  85S  88S 116S
 667 PASS OFFLOADED AT STA.  8 AT  66.5 MINS..

STATION  8 AT  66.5 MINS.:  939 PASS. LEFT

STATION  9 AT  66.5 MINS.:  648 PASS. LEFT

STATION 10 AT  66.5 MINS.:  340 PASS. LEFT

STATION 11 AT  66.5 MINS.:  701 PASS. LEFT

STATION 12 AT  66.5 MINS.:  299 PASS. LEFT

STATION 13 AT  66.5 MINS.:  131 PASS. LEFT

STATION 14 AT  66.5 MINS.:  243 PASS. LEFT

STATION 15 AT  66.5 MINS.:    0 PASS. LEFT
 RUN 14
 80S 146S 153S 210C
STATION  5 AT  70.0 MINS.:   16 PASS. LEFT

STATION  6 AT  70.0 MINS.:   42 PASS. LEFT

STATION  7 AT  69.5 MINS.:  424 PASS. LEFT

STATION  8 AT  69.5 MINS.:  965 PASS. LEFT

STATION  9 AT  69.5 MINS.:  598 PASS. LEFT

STATION 10 AT  69.5 MINS.:  318 PASS. LEFT

STATION 11 AT  69.5 MINS.:  715 PASS. LEFT

STATION 12 AT  69.5 MINS.:  226 PASS. LEFT
191C 155S 109
 RUN 15

  24   43   45   62   70  76S 162S
STATION  8 AT  72.0 MINS.:  617 PASS. LEFT

STATION  9 AT  72.0 MINS.:  511 PASS. LEFT

STATION 10 AT  72.0 MINS.:  276 PASS. LEFT

STATION 11 AT  72.0 MINS.:  669 PASS. LEFT

STATION 12 AT  72.0 MINS.:  136 PASS. LEFT
168C 100S  70
 RUN 16

  19   34   36   49   49   51   70 181C
STATION  9 AT  74.5 MINS.:  203 PASS. LEFT

STATION 10 AT  74.5 MINS.:  231 PASS. LEFT

STATION 11 AT  74.5 MINS.:  656 PASS. LEFT

STATION 12 AT  74.5 MINS.:   43 PASS. LEFT
167C 100S  69
 RUN 17

  21   39   41   49   55   57  79S  86S 135S 176C
STATION 11 AT  77.5 MINS.:  399 PASS. LEFT
218C 163S  99S  69
 RUN 18

  20   37   38   53   56   59  79S  87S  99S 104S 185C 176C 132S  81S   57
 RUN 19

  19   27   28   40   44   46   61   68  77S  81S  93S  92S   70   46   32
 RUN 20

  15   36   38   57   63   66  90S 100S 114S 121S 138S 137S 105S   65   45
 RUN 21

  22   41   43   59   64   65  87S  96S 108S 114S 129S 127S  98S   64   45
RUN 22

  27   49   51   71  77S  79S 104S 115S 130S 137S 155S 153S 116S  77S   54
 RUN 23

  26   48   50   69  75S  77S 102S 113S 127S 134S 152S 150S 115S  75S   52
 RUN 24

  26   47   49   68   73  75S 100S 110S 124S 131S 148S 146S 112S   73   51
 RUN 25

  25   46   48   66   72   74  98S 108S 122S 128S 145S 143S 110S   72   50
RUN 26

  25   45   47   70  77S  80S 109S 121S 138S 146S 167C 165C 127S  83S   58
 RUN 27

   9   17   18   25   27   27   36   40   45   48   54   54   41   26 [illegible]
 RUN 28


PEAK SCHEDULE ENDED   1.0 MINS. LATE
```

THE OUTPUT DISPLAY PROCEEDS AS IN THE PRECEDING EXAMPLE UNTIL THE OFFLOAD EVENT OCCURS. THE OFFLOAD INDICATION IS FOLLOWED BY AN INDICATION FOR EACH REMAINING STATION ON RUN 14 OF THE PASSENGERS THAT WOULD OBSERVE THIS LIGHT, BAD-ORDER TRAIN PASSING BY IF IT CONTINUED TO THE END OF THE LINE WITHOUT FURTHER DELAY; AT STATION 8, THE COUNT INCLUDES THE OFFLOADED PASSENGERS.

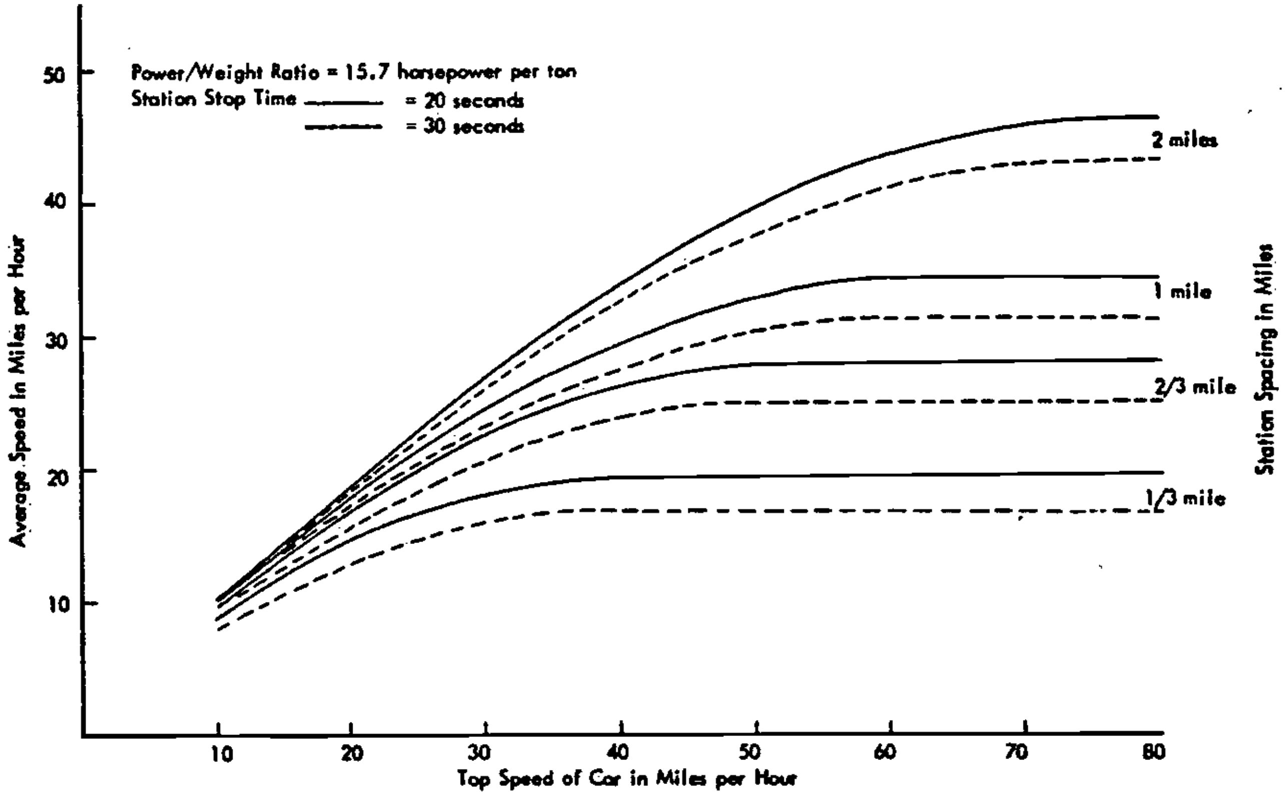
THE COMBINED EFFECTS OF THE DELAY AND THE LOSS OF RUN 14 PERSIST IN THE FORM OF THE INABILITY OF RUNS 15 THROUGH 18 TO ACCOMMODATE ALL ACCUMULATED PASSENGERS. ONE OBVIOUS USE OF SCF1 WOULD BE TO EXAMINE THE EFFECTS OF ALTERNATIVE CLOSE-UP STRATEGIES IN THIS SCENARIO.

APPENDIX D

MISCELLANEOUS TECHNICAL INFORMATION

EXHIBIT D-1

RELATIONSHIP BETWEEN TOP SPEED, STATION SPACING AND AVERAGE SPEED FOR RAIL TRANSIT



Source: Lang and Soberman (1964).

EXHIBIT D-2
SAFE STOPPING DISTANCES FOR WMATA*

GRADE	15 MPH	28 MPH	40 MPH	50 MPH	55 MPH	65 MPH	75 MPH
+4.0%	293	585	898	1194	1368	1775	2262
+3.0	315	628	965	1284	1474	1937	2480
+2.0	341	681	1047	1393	1601	2119	2744
+1.0	374	742	1143	2526	1758	2335	3058
0.0	413	821	1264	1690	1951	2609	3443
-1.0	464	923	1418	1896	2102	2964	3957
-2.0	532	1051	1626	2177	2528	3445	4670
-3.0	625	1231	1903	2563	2994	4136	5741
-4.0	762	1497	2315	3138	3691	5223	7528

SOURCE: IEEE SAFE HEADWAY STANDARDS WORKING GROUP

REACTION TIME

5.5 SEC TOTAL REACTION TIME:

- O 2 SEC SIGNALING DELAY
- O 2.75 SEC OVERSPEED DETECTOR AND POWER REMOVAL
- O 0.75 SEC BRAKE APPLICATION

BRAKE RATE

MINIMUM RATE OF 1.65 MPH/SEC:

- O FULL SERVICE RATE OF 2.2 MPHPS MINIMUM ON LEVEL
- O ONE TRUCK FAILURE (OR CUT-OUT) ON TWO-CAR TRAIN

---

* INCLUDES 20 FEET FOR COUPLER OVERHANG AND 10 FEET FOR THE FINAL FLARE OUT.

SOURCE: IEEE SAFE HEADWAY STANDARDS WORKING GROUP