FRA/ORD-80/82.II

DUAL-MODE LOCOMOTIVE SYSTEMS ENGINEERING

VOLUME 2

DETAILED DESCRIPTION AND ANALYSIS

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FINAL REPORT

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Dual Mode Locomotive Systems Engineering

16. Abstract
This report, Volume II, provides a detailed description of the analysis of the dual mode locomotive (DML) systems engineering study undertaken as Phase I of a proposed five-phase program. The intent of the overall DML program is the development, in-service demonstration, and ultimate deployment of dual-mode locomotives. This study has confirmed the technical viability of the DML based on a modified diesel-electronic locomotive model SD40-2, which can operate from either a high voltage catenary electrified at 60 Hz or from an onboard diesel engine. The DML can be made available in either 50- or 25-kv versions and could have a regenerative electric brake capability if required. The weight of a 50-kv, regenerative DML (the heaviest option) is under 398,000 lb, with normal options included. The space requirements for the electric components are compatible with installation on existing locomotive platforms without interfering with the diesel power equipment.

The cost of the conversion of an SD40-2 to the DML configuration at locomotive rebuild ranges from $367,014 to $414,097. This conversion will make possible an initial electrification project that will result in a return on investment that is superior to conventional electrification for a fraction of the initial cost. The DML permits incremental electrification, which allows the reduced dependence on imported petroleum products associated with electrification to be achieved at a rate compatible with the available capital funds.

This report comprises two volumes as follows: Volume I - Summary and Volume II - Detailed Description and Analysis.

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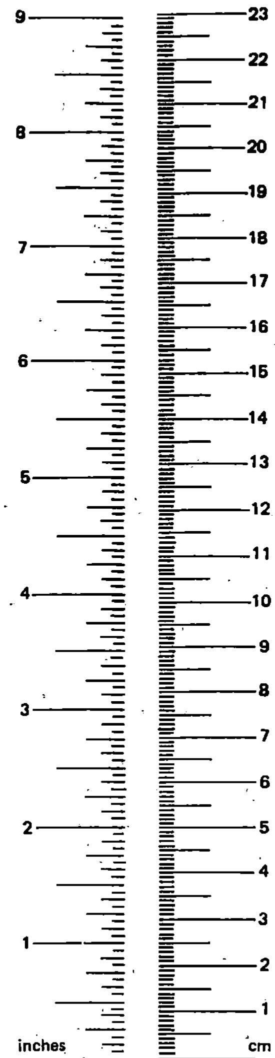
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

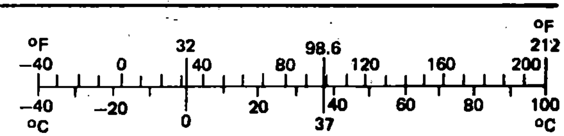
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This final report summarizes the results of the dual-mode locomotive (DML) systems engineering study. It is submitted to the Federal Railroad Administration (FRA) by the AiResearch Manufacturing Company of California, a division of the Garrett Corporation, in accordance with U.S. Department of Transportation (DOT) Contract No. DTFR53-80-C-00010. This final report comprises two volumes:

Volume No.	Title
I	Summary
II	Detailed Description of Analysis

This DML study represents the joint efforts of Garrett; GEC Traction (U.K.) Ltd., who assisted in the determination of component sizes; and Morrison-Knudsen, who conducted an equipment installation analysis.

The continued assistance and guidance of the FRA Contracting Officer's Technical Representative, Mr. John Koper, Program Manager, Energy/Environment, and several members of the FRA, Transportation Systems Center (TSC), and Department of Energy (co-sponsor) staffs were invaluable to the success of the program.

The interest and support for the DML concept given by Mr. Peter Eggleton, Director General, Transport Canada Research and Development Centre, and his staff have contributed to the likelihood of DML deployment throughout North America.

Major contributions were made by the Association of American Railroads and by many individual U.S. railroads, who provided comprehensive information that was used to establish and maintain the necessary data base. Many of these railroads also acted as sounding boards in the formulation and review of the DML concept. Their comments and suggestions have been incorporated into the final recommendations of this report, with the result that the concept favored for preprototype construction and for ultimate fleet deployment is representative of equipment that railroads would consider for future procurement. The following railroads have given substantial assistance or have expressed interest in the DML concept to Garrett during the study:

Amtrak
Atchison, Topeka, and Santa Fe
Burlington Northern
Chessie
Chicago and North Western
Chicago Milwaukee St. Paul and Pacific
Consolidated Rail Corporation
Denver and Rio Grand Western
Duluth Missabe and Iron Range
Louisville and Nashville
Missouri Pacific
Norfolk and Western
Seaboard Coast Line
Soo
Southern
Southern Pacific
Union Pacific

In addition, many equipment suppliers were helpful in defining the equipment that would be required to achieve the locomotive modification and in the review of the proposed modification. The suppliers contributing to the study were:

Dow Corning
Faiveley
General Electric Industrial Sales Division
General Motors (Electro-Motive Division)
Ingersoll Rand
Kim Hotstart
Matra Electric Inc.
Power Energy Industry
Ringsdorf
Southern California Edison
Vapor Corporation
Western Compressor Service (Sullair)

CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

TABLES (Continued)

TABLES (Continued)

TABLES (Continued)

TABLES (Continued)

SECTION 1

INTRODUCTION

The concept of the dual-mode locomotive (DML) was first identified during the Wayside Energy Storage Study (Reference 1)* performed under Contract No. DOT-TSC-1349 sponsored by DOT/FRA. A DML is a locomotive capable of operation from either the existing onboard diesel engine, or from a catenary using electric mode equipment added either at build or as a retrofit. Maintaining the full diesel capability enables the electrification to proceed at a pace compatible with available funding, thereby avoiding the massive initial investment normally associated with, and hindering, railroad electrification.

The DML is not intended to be in competition with conventional electrification, but is a short-term transitional locomotive (i.e., 10- to 20-yr) allowing railroad electrification to become established.

PROGRAM OUTLINE

The DML system engineering study was conducted by Garrett with the assistance of the program subcontractors, GEC Traction and Morrison-Knudsen. It is part of a five-phase program proposed by FRA as follows:

Phase I--System engineering study

Phase II--Detailed design

Phase III--Comprised of preparation of specifications and drawings, and modification and checkout of one or more locomotive(s) to dual-mode configuration

Phase IV--Test of dual-mode locomotive(s) in simulated service at the DOT Transportation Test Center (TTC) in Pueblo, Colorado

Phase V--Test of dual-mode locomotives in actual railroad service

It is thought that Phases II through V could be performed over a time frame of five years, following commencement of Phase II.

The Phase I effort comprises six work tasks, as specified in the contract statement of work. The specific tasks addressed during this phase are summarized in the following text.

Task 1 - Establish Technical and Economic Requirements

1-1 Analyze the applicability of the DML concept to various classes of railroad operations including but not limited to the following:

a. Drag freight operation (1 HP/ton approx.);
b. Medium-speed freight operation (1 to 2 HP/ton approx.);
c. Manifest freight operation (2 to 5 HP/ton approx.); and
d. Passenger operation (high speed, high power to weight ratio).

1-2 Analyze the population of locomotives (foreign and domestic) suitable for modification by major U.S. railroads. These locomotives would be used for various classes of service as indicated under Task 1-1.

1-3 Conduct an economic analysis of the application of dual-mode and conventional electric locomotives to selected railroad routes. This analysis shall test the sensitivity of the following factors as a minimum.

a. Traffic growth projections;
b. Percentage of route electrified;
c. Locomotive utilization;
d. Power to weight ratio;

*All references are listed in Section 10 of this report.

e. Locomotive life;
f. Capital cost factors; and
g. Energy cost projections, fuel savings and energy consumption.

1-4 Based on findings of 1-1, 1-2, and 1-3, select the candidate locomotive types for modification and testing to provide the maximum benefit to U.S. railroads.

<u>Task 2 - Establish Baseline Concept</u>

2-1 Develop baseline concepts making use of information regarding operational requirements and practices of representative U.S. railroads. Consideration shall include, but is not limited to, the following:

a. Catenary voltage;
b. Operational characteristics;
c. Power circuit;
d. Energy management;
e. Power enhancement;
f. Adhesion utilization;
g. Regenerative braking;
h. Auxiliaries;
i. Service life; and
j. Maintenance requirements.

<u>Task 3 - Preliminary Design Definition</u>

3-1 Prepare preliminary design definition of the dual-mode configuration for a selected candidate locomotive.

3-2 Define required modification to existing locomotive controls to provide DML capability. Modifications shall be such as to minimize adverse effects on the operational characteristics of the DML in diesel mode.

3-3 Define reliability and maintainability of the DML. Comparisons to be made with standard diesel and electric locomotives.

3-4 Prepare a set of preliminary designs including calculations, sketches, tables and specification sheets, suitable for installation studies of the complete set of components required to modify a diesel locomotive to a dual-mode configuration. Consideration shall be given to both 25 kV and 50 kV design voltages for the locomotive. The required components as a minimum shall include the following:

a. Pantograph;
b. Lightning arrestor;
c. Vacuum circuit breaker;
d. Grounding switch;
e. Main transformer;
f. High-voltage cable;
g. Regenerative power converter;
h. Smoothing choke;
i. Supply changeover switch;
j. Oil/air heat exchanger; and
k. Automatic power control.

<u>Task 4 - Develop System Performance Specifications</u>

4-1 Establish system operating parameters for DML application including, but not limited to, the following:

a. Catenary voltage variation for 25, 50 kV (nominal) systems;
b. Maximum axle load;
c. Adhesion limits;
d. Operational speed for various classes of service indicated under Task 1-1;
e. Ruling grade; and
f. Head-end braking limitation for resistive and regenerative braking.

4-2 Define DML performance specifications including, but not limited to, the following:

a. Tractive effort;
b. Speed;
c. Acceleration;
d. Braking effort;
e. Power and energy consumption;
f. Power factor;
g. Overall system efficiency;
h. Line current;
i. Environmental factors including temperature, shock, vibration, EMI; and
j. Power interruptions.

Task 5 - Develop Preliminary Equipment Performance Specifications

5-1 Define preliminary performance requirements of at least the following components of the selected DML in 25 kV and 50 kV versions:

a. Pantograph
b. Lightning arrestor;
c. Vacuum circuit breaker:
d. Grounding switch;
e. Main transformer;
f. High-voltage cable;
g. Regenerative power converter;
h. Smoothing choke;
i. Supply changeover switch;
j. Oil/air heat exchanger; and
k. Automatic power control

Task 6 - Develop Preliminary Cost Estimate

6-1 Develop a preliminary cost estimate for the modification of the selected candidate locomotive based on the preliminary DML definition and performance specifications of the preceding tasks and reassess the economic analysis of Task 1 based on this estimate. Identify the cost impact of 25-kV or 5-kV catenary voltage and the addition of regenerative braking.

6-2 Reassess the technical feasibility and operational benefits based on the results of the preceding tasks.

PHASE I METHODOLOGY

A logic diagram showing the methodology followed by Garrett and its subcontractors in performing the systems engineering study is shown in Figure 1-1. As the study proceeded, the work was reviewed not only with FRA and DOE, but also with major railroads, including:

Amtrak
Burlington Northern
Conrail
Missouri Pacific
Southern Pacific
Union Pacific

TRAIN PERFORMANCE CALCULATOR (TPC)

The journey times and energy calculations required for this study were performed using the Garrett TPC. The original version of the TPC developed during the Wayside Energy Storage Study (WESS) was documented in Reference 1. Since the completion of that program, major modifications have been made to the TPC to make it compatible with DML operation. During the performance of the study, which was documented in the "Application of WESS Concepts to Canadian Railways" (Reference 2), the TPC was determined to have an energy (fuel) consumption accuracy of 7.4 percent, and a time accuracy of 1.7 percent. Other data have since shown greater energy accuracy and indicate that there may be a variation due to type of terrain encountered. In any event, the energy calculations are used to derive differences, and therefore the worst case 7-percent accuracy is considered adequate.

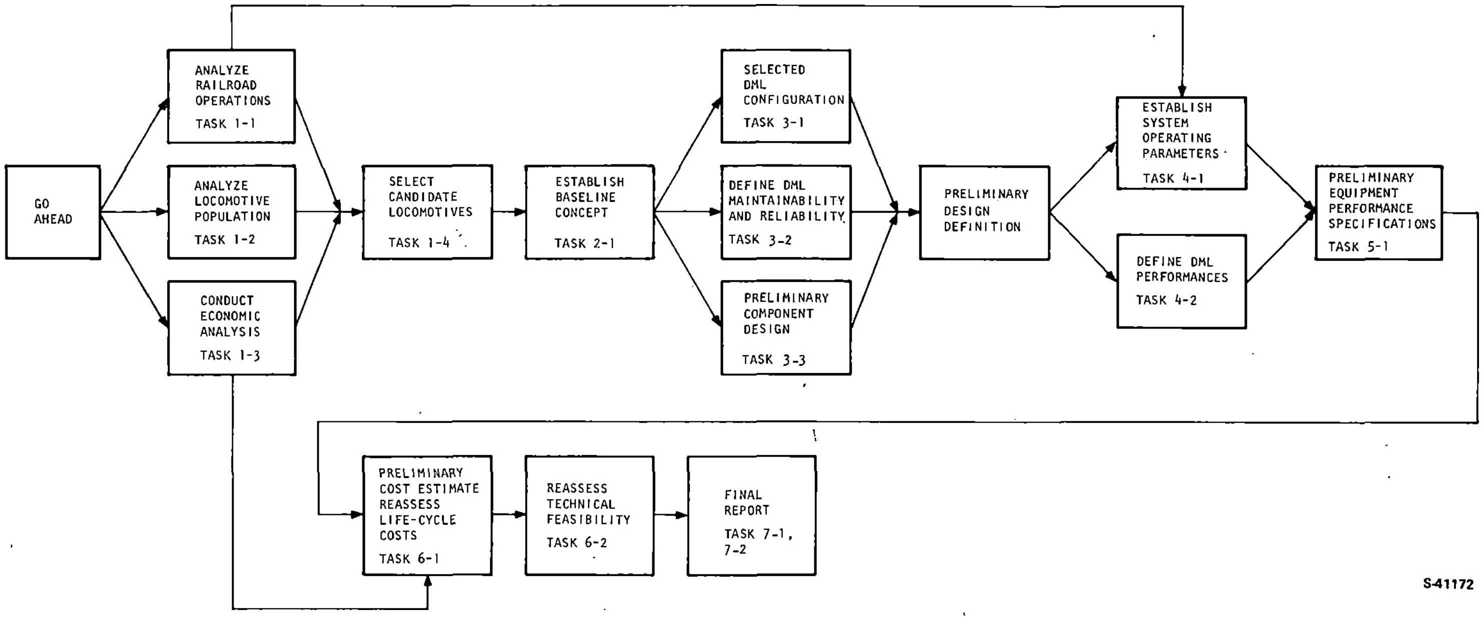


Figure 1-1. DML Phase I System Engineering Methodology

FORMAT OF FINAL REPORT

This final report has been organized so that each section specifically addresses the similarly named task in the contract statement of work. The sheer volume of material generated during this 8-1/2 month study period has necessitated publishing this report in two volumes. Volume 1 briefly describes work conducted, results achieved, the conclusions, and specifically the basic characteristics of the dual-mode locomotive. The main body of the technical data, options considered, and backup cost data, together with proposed future program plans, are presented in this volume of the report.

SECTION 2

TECHNICAL AND ECONOMIC REQUIREMENTS

RAILROAD OPERATING CLASSIFICATIONS

Railroad operations are often categorized by the gross horsepower per trailing ton (hp/ton) ratio at which dispatch takes place. The terms used to describe these trains vary from railroad to railroad and from division to division. One dispatcher may identify a 2-hp/ton train as manifest or hot-shot, while another would not term it hot-shot unless it was dispatched above 4 hp/ton. Similarly, a train dispatched at 1.5 hp/ton may be termed a drag operation by one railroad, but as a medium speed train by another.

The hp/ton ratio and, therefore, the number of locomotives required on a given train is influenced by two basic considerations:

- Minimum speed on the ruling grade
- Overall journey time

Ruling Grade

To simplify the method of dispatch on a given route, it is common to identify the steepest grade of significant length and then calculate permissible train loadings based on the required performance on that grade. A ruling grade is usually relatively short when compared with the overall route; for example, the 780-mile route considered in this study has a 26-mile ruling grade, and the 250-mile route has a 10-mile ruling grade.

The major concern when considering operation on the ruling grade is the protection of the locomotive power equipment under the following two conditions:

1. Starting--If the train has been compelled to stop on the ruling grade, can it restart without causing damage to the equipment. Railroads usually avoid stopping trains on ruling grades by the judicious siting of passing sidings and signals. If, as a matter of course, stops are not usually required on the ruling grade, a railroad may take advantage of short-term equipment ratings to get the train restarted. Another course of action is to take slack in the train to enable the initial tractive effort requirement to be eased. Many railroads, however, do not allow this practice.

2. Balancing speed--This is the speed at which the tractive effort available matches the forces resisting forward motion on a constant grade. If full engine power is maintained, i.e., notch-8 operation, while the locomotive speed drops so low that the alternator is able to deliver more than the continuous-rating current to each traction motor, it is probable that damage to the traction motors, alternator, and/or cables will occur through prolonged operation at the minimum continuous speed of the locomotive. Therefore, a dispatcher will assign sufficient locomotives for a given train, ensuring that the train negotiates the ruling grade at the highest of the minimum continuous speeds of the different locomotives in the consist. The minimum continuous speeds of some common locomotives are given in Table 2-1. This policy also enables the short-term rating to be used in such unforeseen circumstances as traction motor cutout or locomotive failure.

Once it is established that the train must negotiate the ruling grade at a minimum speed, it is then necessary to consider whether it is desirable to run up that grade at a speed significantly higher than the minimum continuous speed. The main influence on this decision is line capacity (see Reference 3), which is defined as follows:

$$\text{Capacity} = \frac{\text{Speed} \times \text{time}}{\text{Signal block distance} \times \text{number of signal blocks apart}}$$

$$\text{or} \quad C = \frac{V \times T}{D \times N} \quad \text{trains}$$

$$\text{i.e.,} \quad C = V/(DN) \quad \text{trains/hr}$$

TABLE 2-1

MINIMUM CONTINUOUS SPEED OF
COMMON ROAD LOCOMOTIVES

Locomotive Model	Minimum Continuous Speed, mph
GP30	12.0
GP35	12.0
GP40	11.0
GP40-2	11.3
SD35	9.5
SD39	7.5
SD40-2	7.2 to 11.1
SD45	7.7 to 11.0
SD45-2	7.2
U25B	12.0
B30-7	7.8
U30C	7.5
U33C	7.8

NOTE: See Reference 2.

The capacity of a line is determined by the lowest capacity of each segment comprising that route. For single-track, bidirectional operation, the ruling grade could impose severe restrictions on the ability of that route to handle traffic. Therefore, these railroads tend to (1) keep speeds relatively high on the ruling grade, (2) reduce block distances, and (3) sometimes double track.

Journey Time

The journey time required for a certain train over a given route is determined by a number of independent factors, including:

Commercial--The transportation of perishables, such as fruit, requires a speedy delivery from the point of origin to the destination. However, even a trainload of nonperishables requires speedy delivery if another delivery system is available (such as highway trucks). Therefore, a railroad must examine the nature of the commodity for each route, the status of the competition, and the requirements of the customer in determining the commercially prudent journey time required.

Technical--It has been established that line capacity is proportional to train speed, and therefore to maintain an acceptable line capacity, it is necessary to maintain a relatively high average speed, particularly on single-track railroads.

Variation of Power/Weight Ratio

An investigation of the effect of varying the hp/ton was conducted out on two markedly different railroad routes--Harrisburg-Pittsburgh (Conrail) and Los Angeles-Salt Lake City (UP), with both using average-size trains for each route.

1. Harrisburg-Pittsburgh

The Conrail Harrisburg-Pittsburgh route (Figure 2-1) is the most intensely used route in the United States, having an annual traffic level of 56 millions of gross trailing tons (MGTT) in each direction, and is a prime candidate for electrification. It is essentially a slow speed route having a maximum speed of 50 mph. Route capacity is maintained by having three and four tracks as shown in Figure 2-2. The route is dominated by the Horseshoe Curve, which has grades between 1.75 and 1.17 percent and a curvature of up to 6 deg.

The year-round average size train on this route is 5220 trailing tons, with the average power/weight ratio 2.26 hp/ton for westbound and 1.47 hp/ton for eastbound. Table 2-2 shows the trains dispatched on a single day in October. These data do not reflect the yearly average data but do illustrate the type of operation over the route being considered. This results in 3.9 SD40 locomotives for the average westbound train, and 2.55 SD40 locomotives for the average eastbound train, with 21,456 average trains/yr.

TABLE 2-2

SAMPLE OF TRAIN CONSIST DATA FOR
HARRISBURG-PITTSBURGH OPERATION

Eastbound		Westbound	
Trailing Tons	Number Locomotives	Trailing Tons	Number Locomotives
5258	4	3194	3/5*
7280	4/6*	3000	2/4*
5371	2	3900	2/4*
3607	2	6564	4/6*
6829	4/6*	4242	4/6*
5894	4/6*	3559	2/4*
3750	2	3500	3/5*
2808	2/4*	3256	2/4*
7680	3/5*	3684	2/4*
13000	3/5*	3945	5
6860	4	3475	4
4299	2	4412	2/4*
7052	3	2508	2
5457	3/5*	7210	3/7*
10410	4/6*	6781	3/7*
13530	3/5*	3350	4
3210	4	3520	4
6010	3/5*	1590	2
4200	3/5*	5385	3/5*
5000	2	4263	5
5016	3/5*	4493	3/7*
3505	3	3040	3/5*
136,029	67/89*	88,871	67/103
2030/locomotive = 1.47 hp/ton		1326/locomotive = 2.26 hp/ton	

*Helper operation

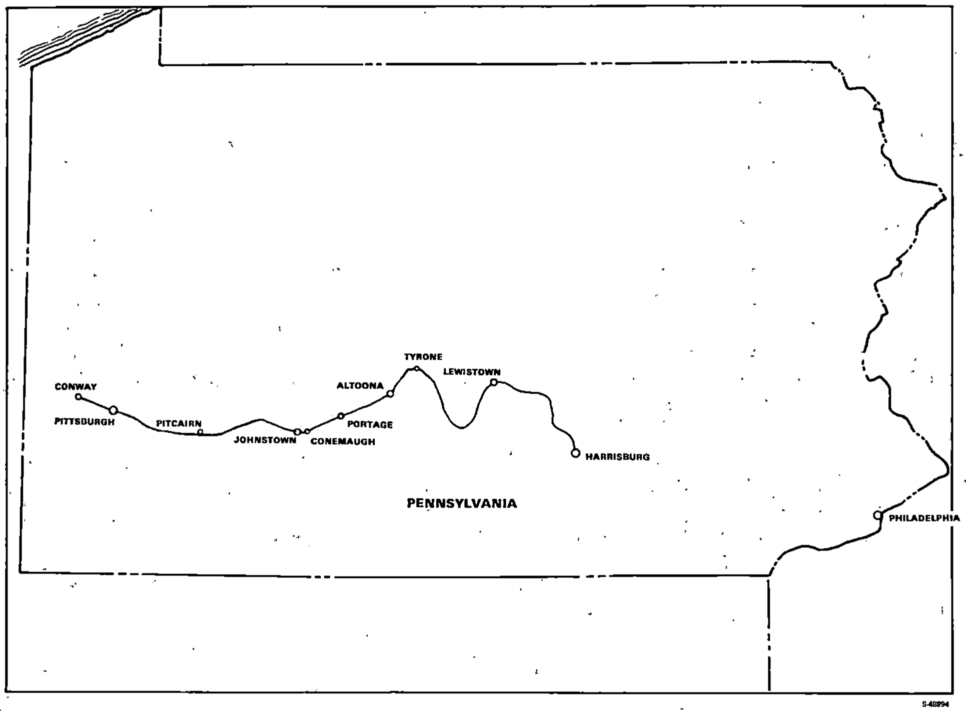


Figure 2-1. Harrisburg-Pittsburgh Route of Conrail

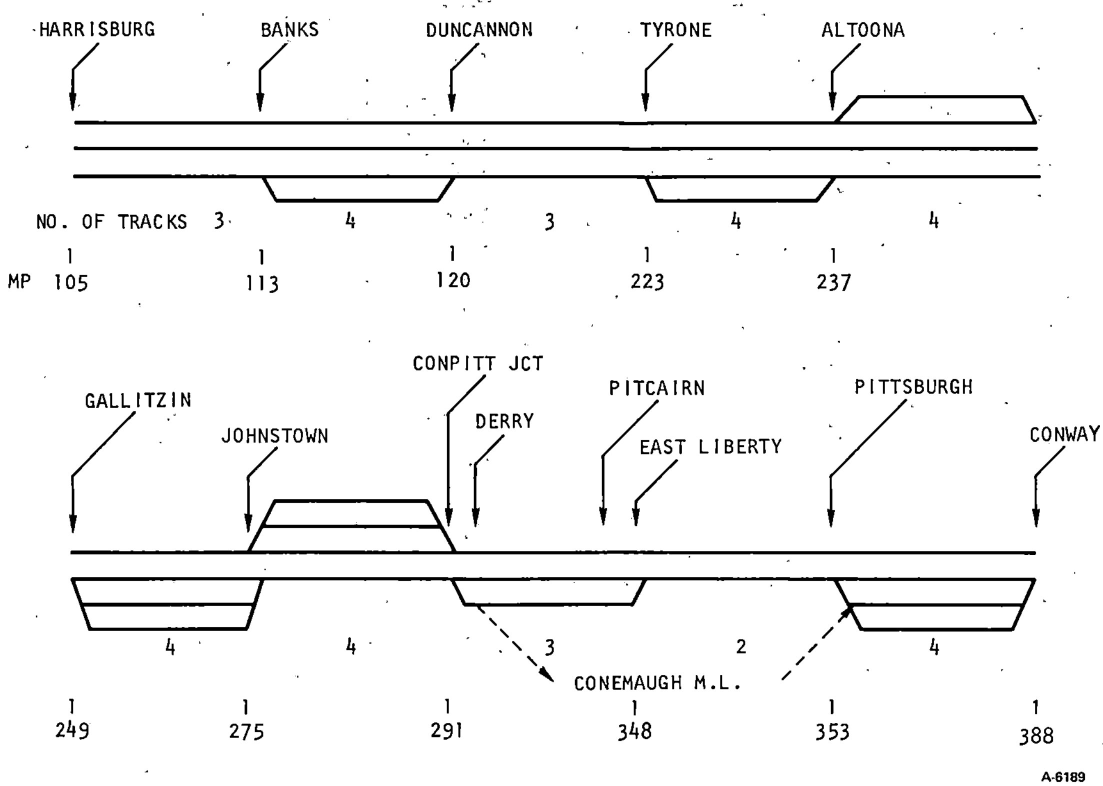


Figure 2-2. Harrisburg-Pittsburgh Track Configuration

a. TPC Output

The 5,220 trailing ton train was run over the route with varying numbers of locomotives but without helpers on the ruling grade, using the Garrett train performance calculator (TPC). The variation in journey time is shown in Table 2-3, and is shown graphically in Figures 2-3 and 2-4.

TABLE 2-3

HARRISBURG-PITTSBURGH JOURNEY TIME
(5220 TRAILING TONS)

Number of SD40 Locomotives	Journey Time, min.		
	WB	EB	Round Trip
9	337	392	729
7	339	398	737
5	348	407	755
3	382	455	837
2	463*	498	961

*Train speed drops below minimum continuous speed of locomotives.

To achieve the reduced journey time associated with the larger number of locomotives, a fuel consumption penalty is incurred as shown in Table 2-4, and is shown graphically in Figures 2-5 and 2-6.

TABLE 2-4

HARRISBURG-PITTSBURGH DIESEL LOCOMOTIVE FUEL CONSUMPTION
(5220 TRAILING TONS)

Number of Locomotives	Fuel, gal		Annual, mgal	
	WB	EB	WB	EB
9	3321	3036	35.65	32.22
7	3135	2728	33.65	29.25
5	2602	2412	27.9	25.9
3	2208	2030	23.7	21.8
2	2021	1848	21.7	19.85

This relationship is almost a straight line within the variation analyzed. However, the use of helpers would be required for certain cases because the train speed falls below the minimum continuous speed for SD40 operation when on the ruling grade. This is not reflected in Tables 2-3 or 2-4, but is clearly illustrated in Figures 2-7 and 2-8.

To determine the optimum locations for the electrified sections of the route, and to test the sensitivity of the return on investment to the percent of route electrified, all sections of significant notch 8 operation were identified for each train. This is shown in Table 2-5, which also shows the proposed electrified section derived from operation at each power/weight ratio. These electrified

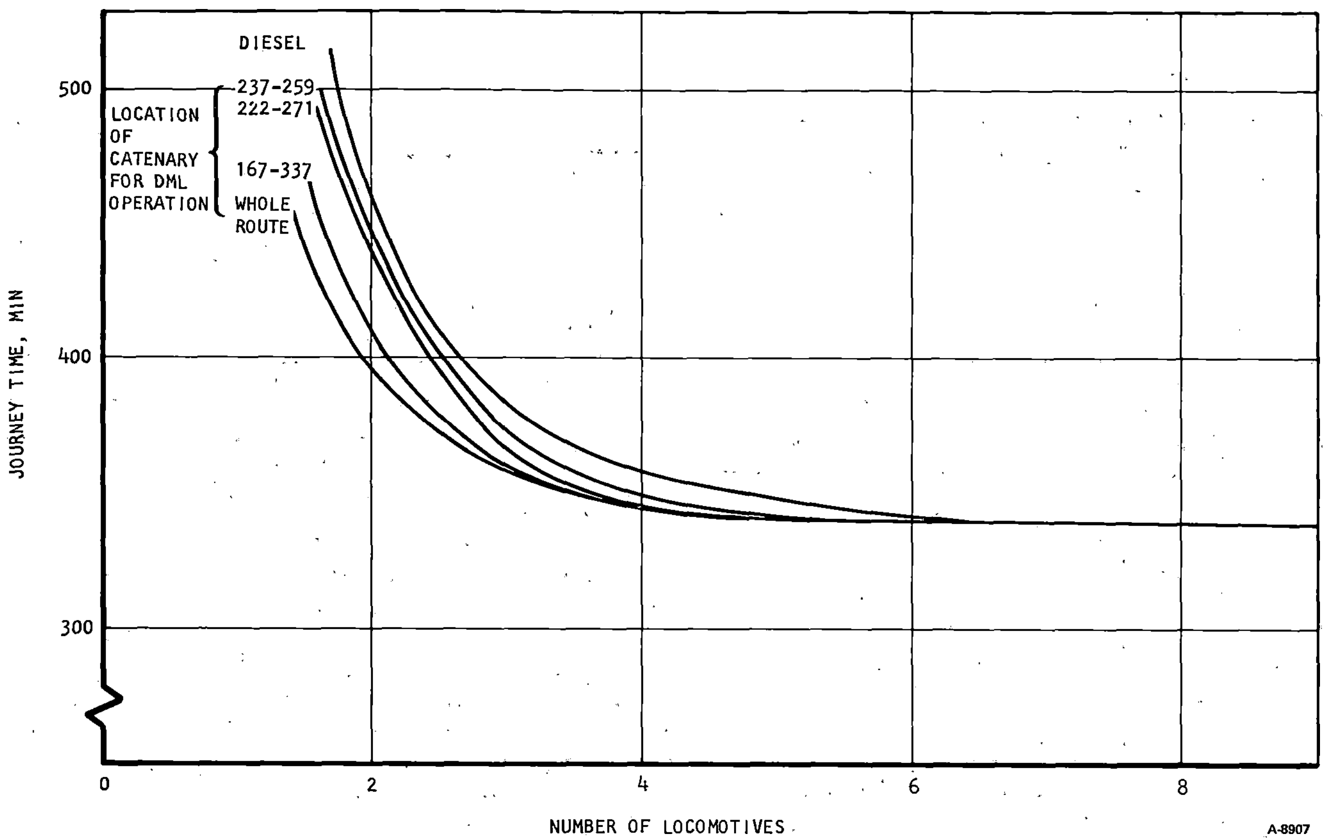


Figure 2-3. Harrisburg- Pittsburgh Route Journey Time

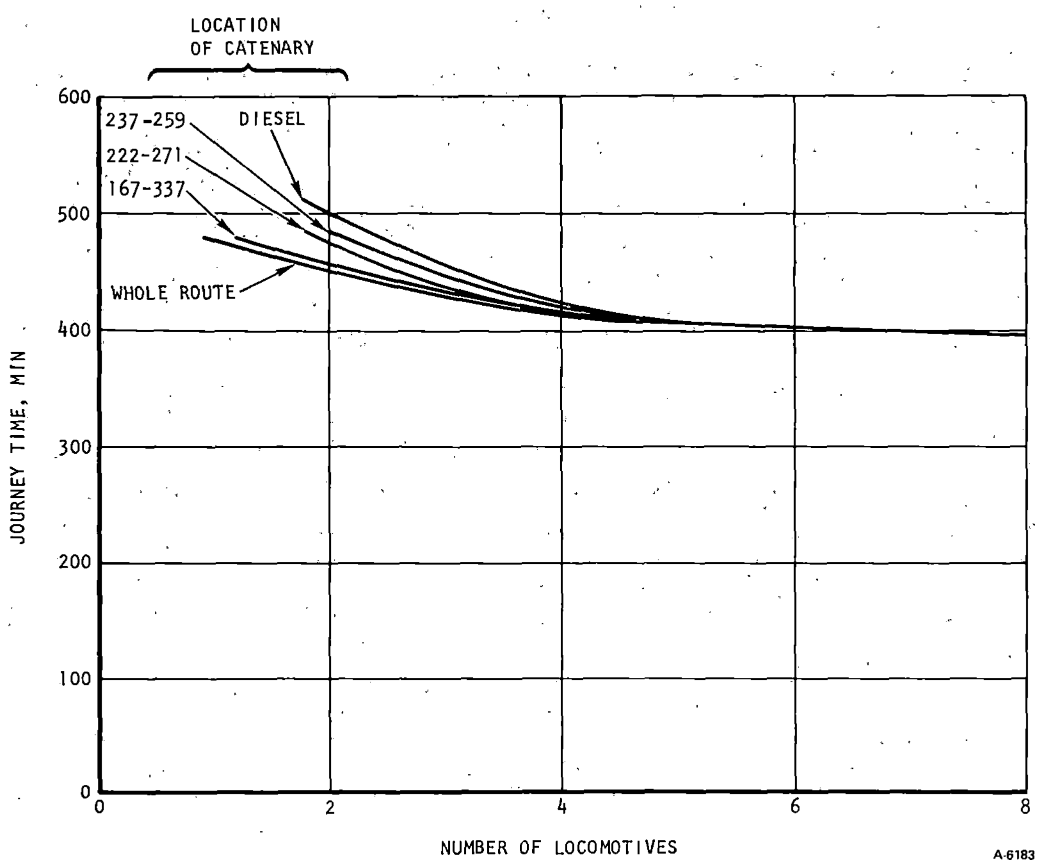


Figure 2-4. Pittburgh-Harrisburg Route Journey Time

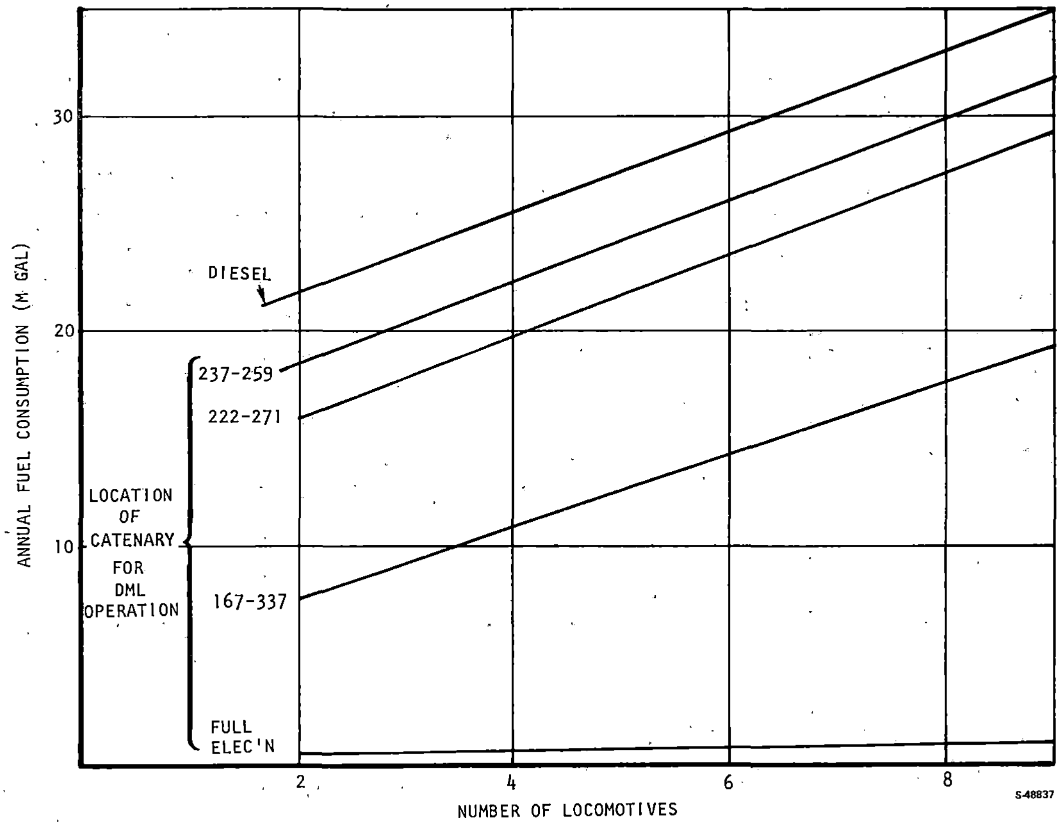


Figure 2-5. Harrisburg-Pittsburgh Route Fuel Consumption

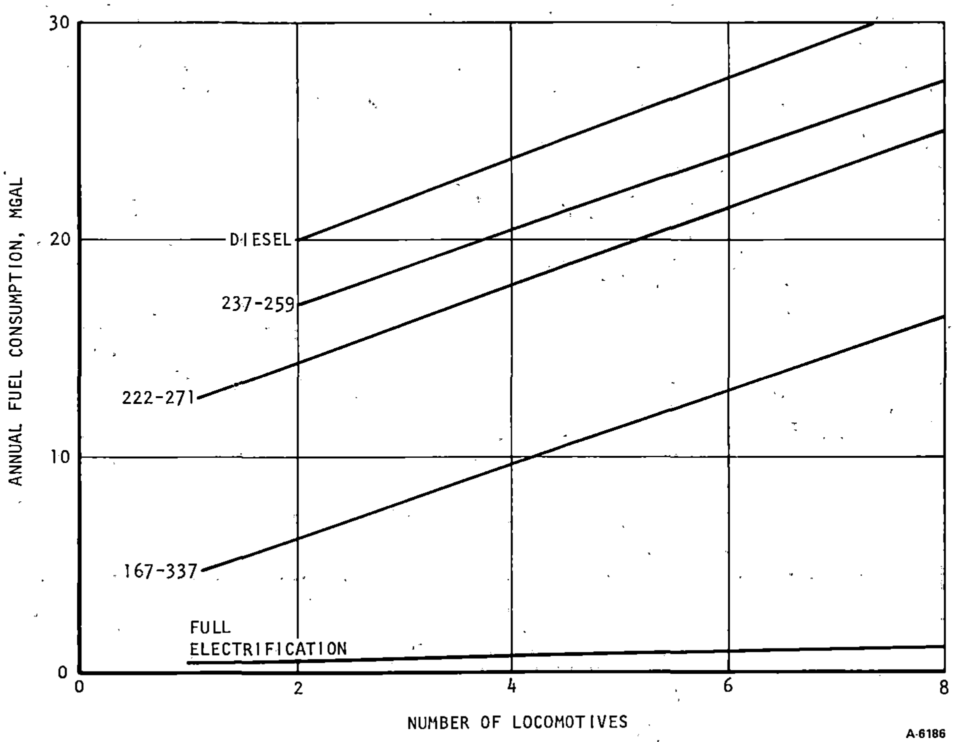


Figure 2-6. Pittburgh-Harrisburg Route Fuel Consumption

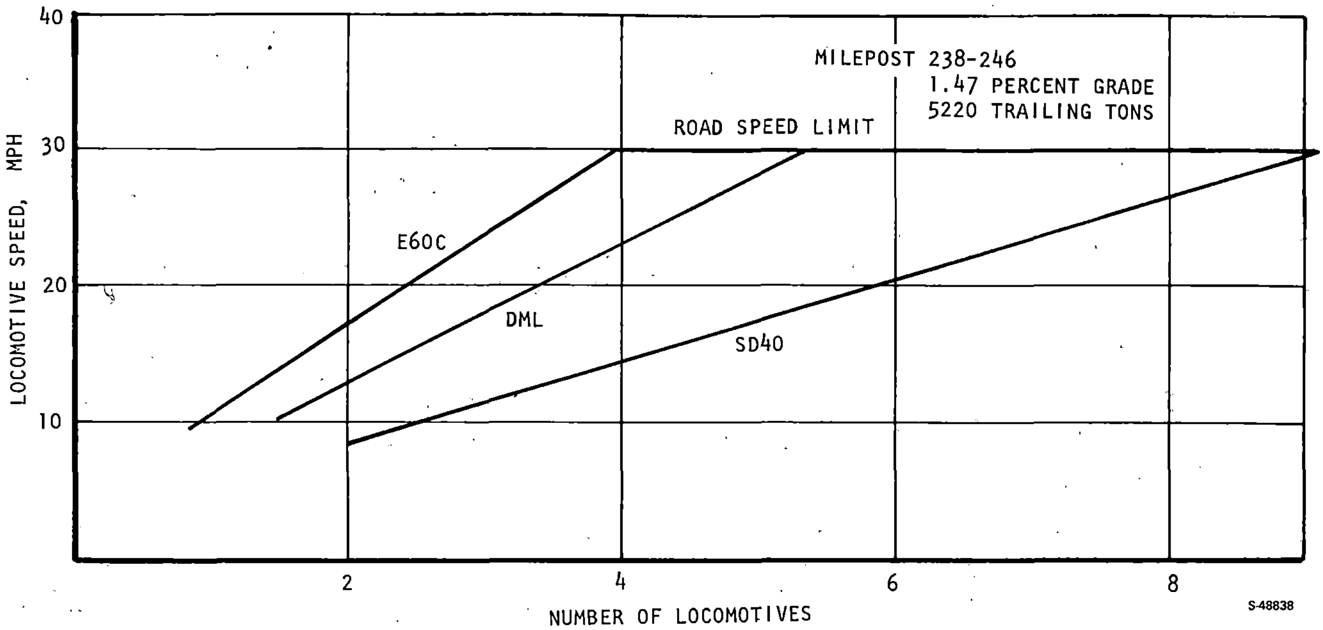


Figure 2-7. Speed on Ruling Grade for Harrisburg-Pittsburgh Route

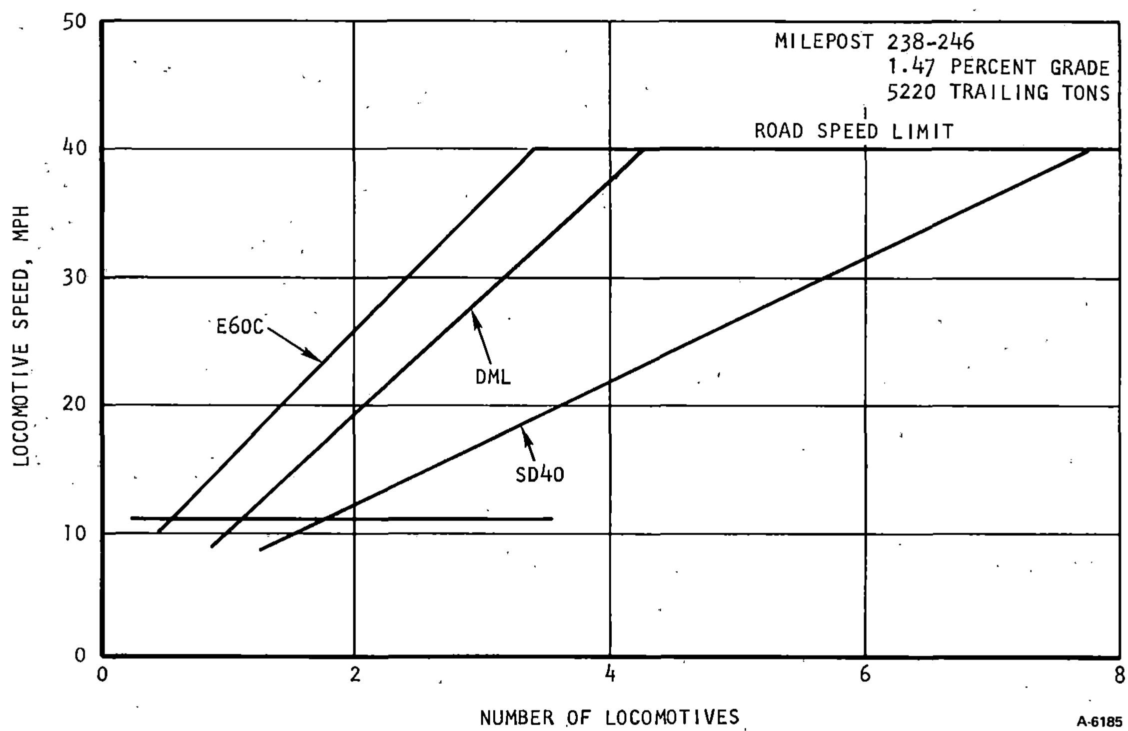


Figure 2-8. Speed on Ruling Grade for Pittsburgh-Harrisburg Route

sections are geographically identified in Figures 2-9 through 2-12. For each of the sections, the locomotives are operating power limited and therefore the increased power capability of the DML is an advantage that can be utilized. The TPC was used to estimate the journey time and fuel consumption for each section of electrification identified in Table 2-5. The results of this analysis are given in Tables 2-6 through 2-9, and are shown graphically in Figures 2-3 through 2-6. These results can be directly compared to the baseline diesel operation. The electrical energy consumption for the DML operation is shown in Figures 2-13 and 2-14.

Comprehensive electrification studies have been conducted on the Harrisburg-Pittsburgh route. For a comparison between these detailed electrification analyses and this study's output, the case of full electrification using GE E60C locomotives is reported in Table 2-10 and in Figures 2-15 and 2-16.

TABLE 2-5

SECTIONS OF NOTCH 8 OPERATION
HARRISBURG-PITTSBURGH

Number of Locomotives	WB		EB		Proposed Electrified Section	
	From	To	From	To	From	To
9	None		None		None	
7	238	248	259	250	238	259
5	222	248	271	250	222	271
3	167	248	337	248	167	337
2	106 280	248 346	351	248	106	351

TABLE 2-6

VARIATION OF JOURNEY TIME AND FUEL/ENERGY CONSUMPTION FOR
HARRISBURG-PITTSBURGH ELECTRIFICATION 237-259

Number of DML'S	Journey Time, min.			Fuel Consumed				Energy Consumed			
				Single Journey, gal		Annual, Mgal		Single Journey, Mwh		Annual, Gwh	
	WB	EB	Round Trip	WB	EB	WB	EB	WB	EB	WB	EB
9	335	391	726	2880	2683	30.9	28.8	5.25	4.51	56.5	48.4
7	337	395	732	2643	2434	28.3	26.1	5.16	4.03	55.5	43.2
5	342	404	746	2320	2151	24.9	23.1	5.05	3.57	54.0	38.3
3	370	446	816	1917	1727	20.5	18.5	4.95	3.39	53.0	36.3
2	447	483	930	1670	1579	17.9	16.9	4.90	3.37	52.5	36.1

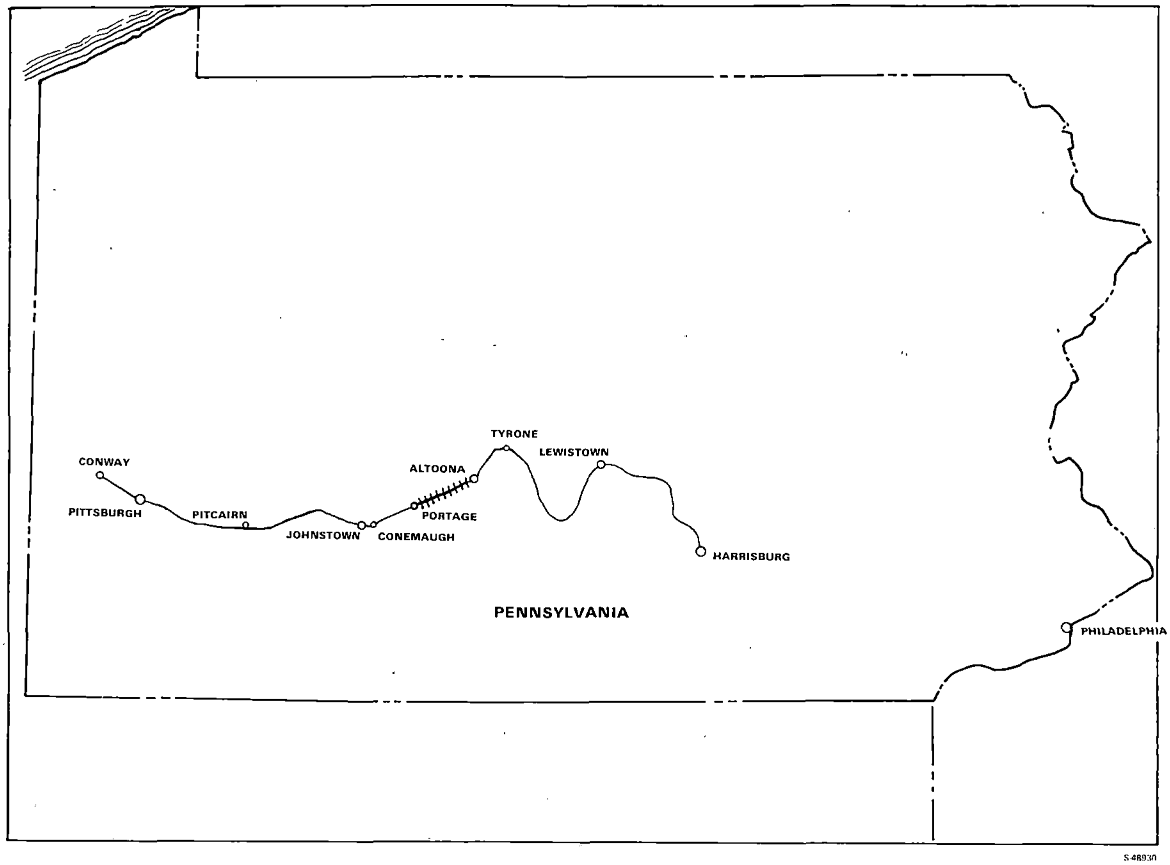


Figure 2-9. Altoona-Portage Route

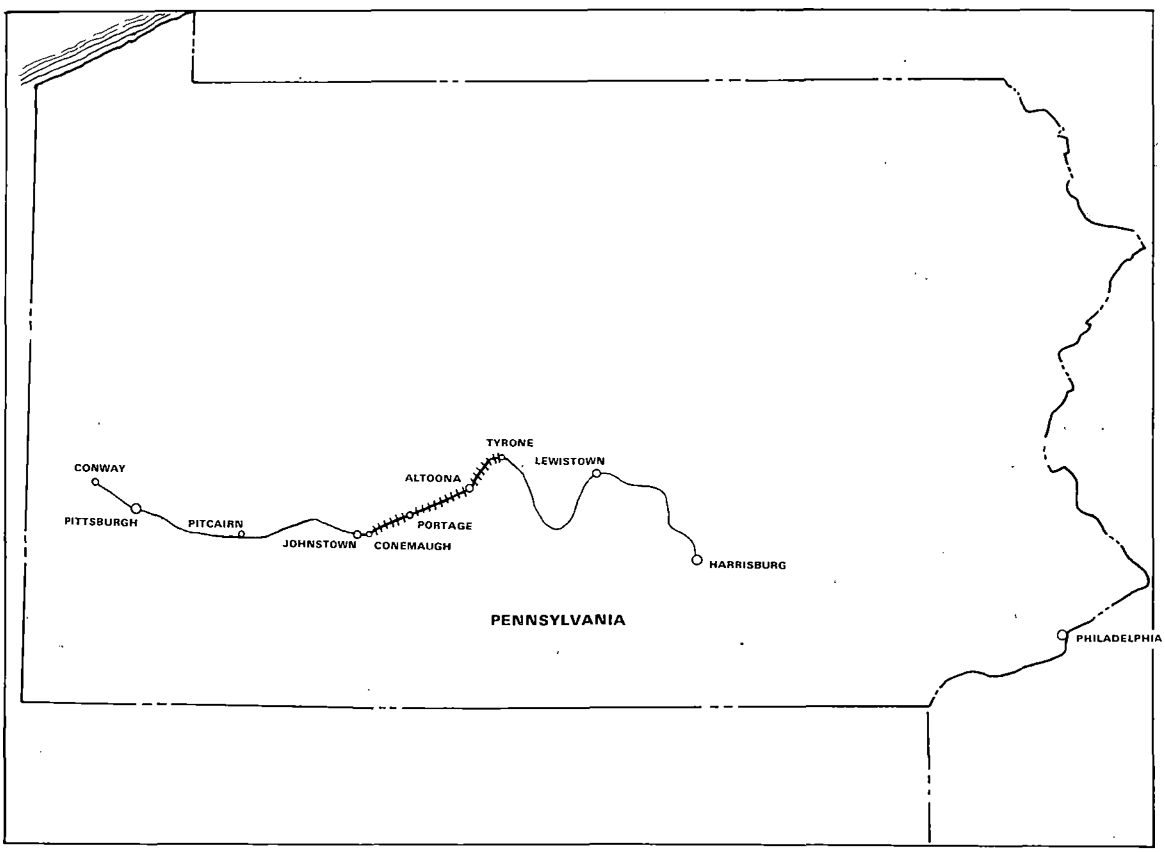


Figure 2-10. Tyrone-Conemaugh Route

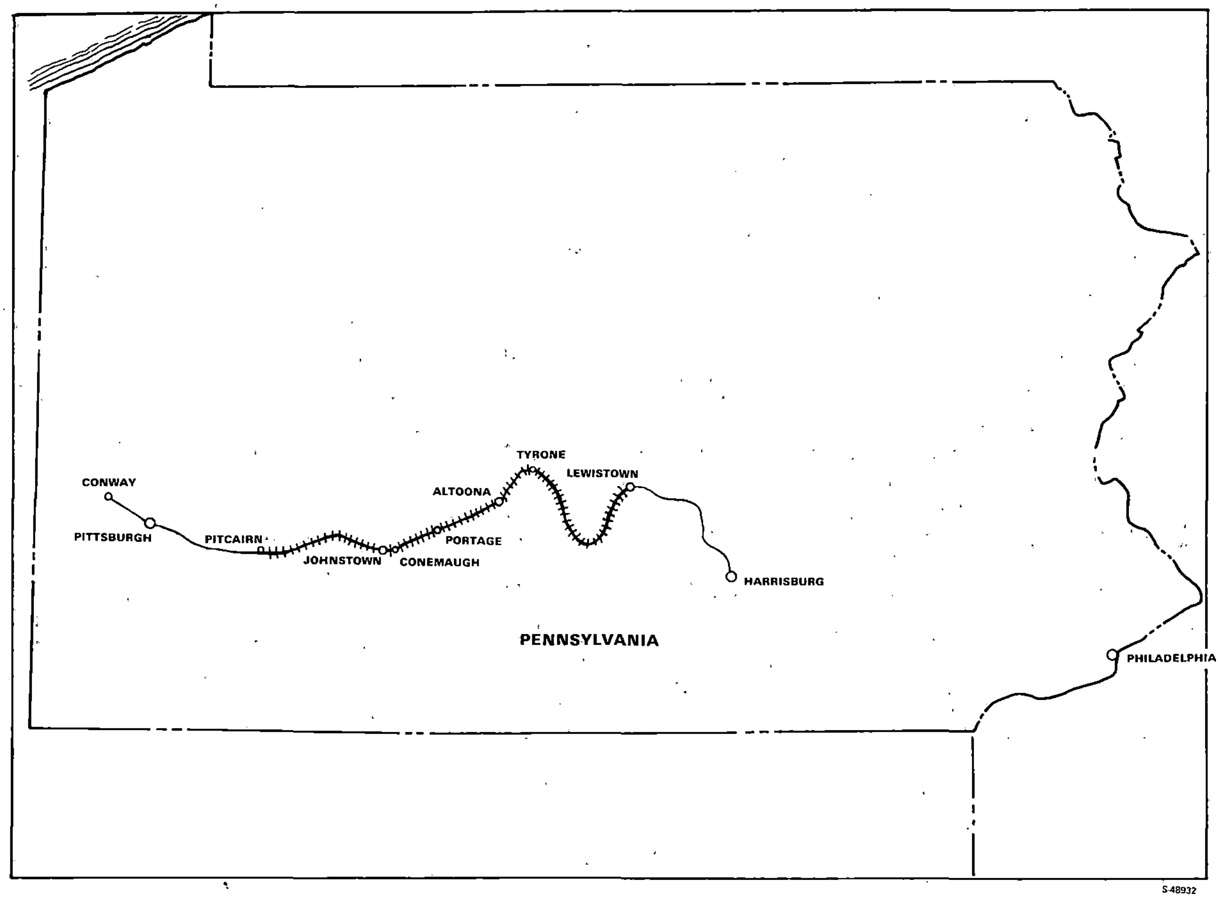


Figure 2-11. Lewistown-Pitcairn Route

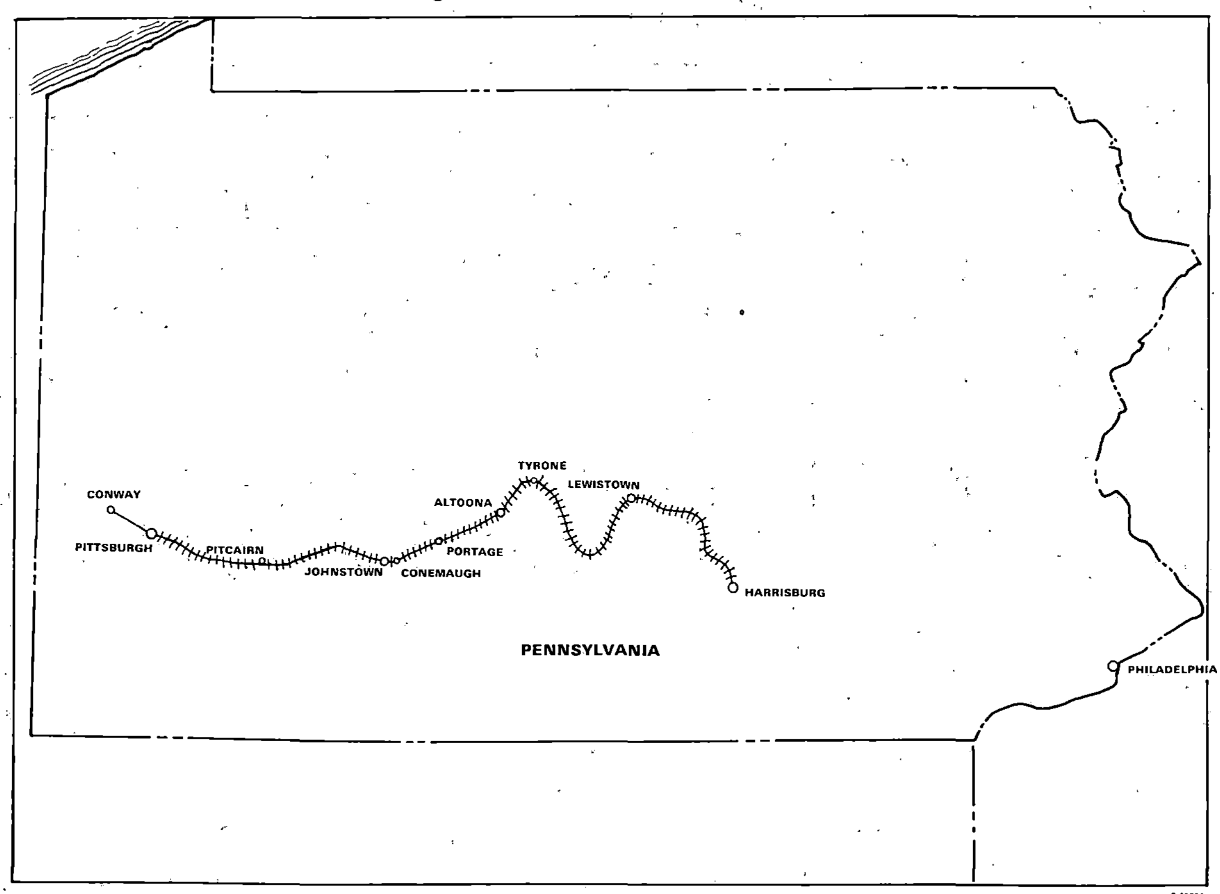


Figure 2-12. Harrisburg-Pittsburgh Route

TABLE 2-7

VARIATION OF JOURNEY TIME AND FUEL/ENERGY CONSUMPTION FOR HARRISBURG-PITTSBURGH ELECTRIFICATION 222-271

Number of DML'S	Journey Time, min.			Fuel Consumed				Energy Consumed			
				Single Journey, gal		Annual, Mgal		Single Journey, Mwh		Annual, Gwh	
	WB	EB	Round Trip	WB	EB	WB	EB	WB	EB	WB	EB
9	335	391	726	2770	2490	29.7	26.7	8.95	7.47	96.0	80.0
7	337	395	732	2338	2225	25.1	23.8	8.89	6.95	95.0	74.0
5	341	402	743	2024	1880	21.7	20.1	8.17	6.60	87.0	71.0
3	366	439	805	1669	1518	17.9	16.3	7.65	6.35	82.0	68.0
2	439	473	912	1486	1338	15.9	14.3	7.43	5.9	79.0	63.0

TABLE 2-8

VARIATION OF JOURNEY TIME AND FUEL/ENERGY CONSUMPTION FOR HARRISBURG-PITTSBURGH ELECTRIFICATION 167-337

Number of DML'S	Journey Time, min.			Fuel Consumed				Energy Consumed			
				Single Journey, gal		Annual, Mgal		Single Journey, Mwh		Annual, Gwh	
	WB	EB	Round Trip	WB	EB	WB	EB	WB	EB	WB	EB
9	334	390	724	1802	1728	19.3	18.5	23.32	21.16	250.0	227.0
7	336	394	730	1490	1435	16.0	15.9	21.23	19.70	228.0	211.0
5	340	401	741	1213	1075	13.0	11.5	20.54	19.09	220.0	205.0
3	359	435	794	862	756	9.2	8.1	18.7	17.15	200.0	184.0
2	409	453	862	708	586	7.6	6.3	16.69	15.87	179.0	170.0

TABLE 2-9

VARIATION OF JOURNEY TIME AND ENERGY CONSUMPTION FOR HARRISBURG-PITTSBURGH FULL ELECTRIFICATION (EXCEPT YARDS)

Number of DML'S	Journey Time, min.			Fuel Consumed				Energy Consumed,			
				Single Journey, gal		Annual, Mgal		Single Journey, Mwh		Annual, Gwh	
	WB	EB	Round Trip	WB	EB	WB	EB	WB	EB	WB	EB
9	333	390	720	56	62	1.2	1.33	30.9	26.7	331	286
7	336	394	730	43	55	0.92	1.18	30.3	26.4	325	283
5	339	400	739	37	47	0.79	1.00	28.1	24.1	301	258
3	358	431	789	29	40	0.62	0.86	24.4	22.6	262	242
2	395	450	845	26	31	0.56	0.67	23.1	20.1	248	215

TABLE 2-10

VARIATION OF JOURNEY TIME AND ENERGY CONSUMPTION FOR HARRISBURG-PITTSBURGH

Number of Electric Locomotives	Journey Time, min.			Energy Consumed			
				Single Journey, Mwh		Annual, Gwh	
	WB	EB	Round Trip	WB	EB	WB	EB
9	333	390	723	34.6	32.2	371	345
7	335	394	729	32.4	29.2	348	313
5	338	399	737	29.3	26.0	314	279
3	345	412	757	26.0	24.0	279	257
2	360	418	778	25.1	22.0	269	236

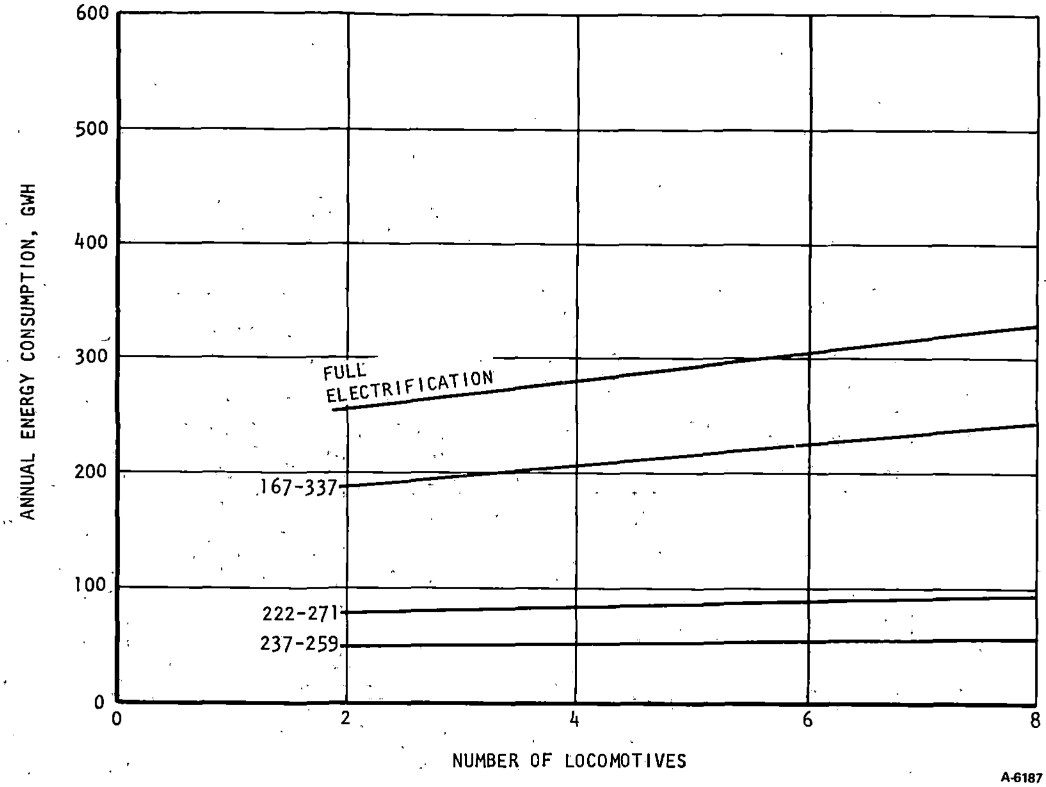


Figure 2-13. Harrisburg-Pittsburgh Energy Consumption

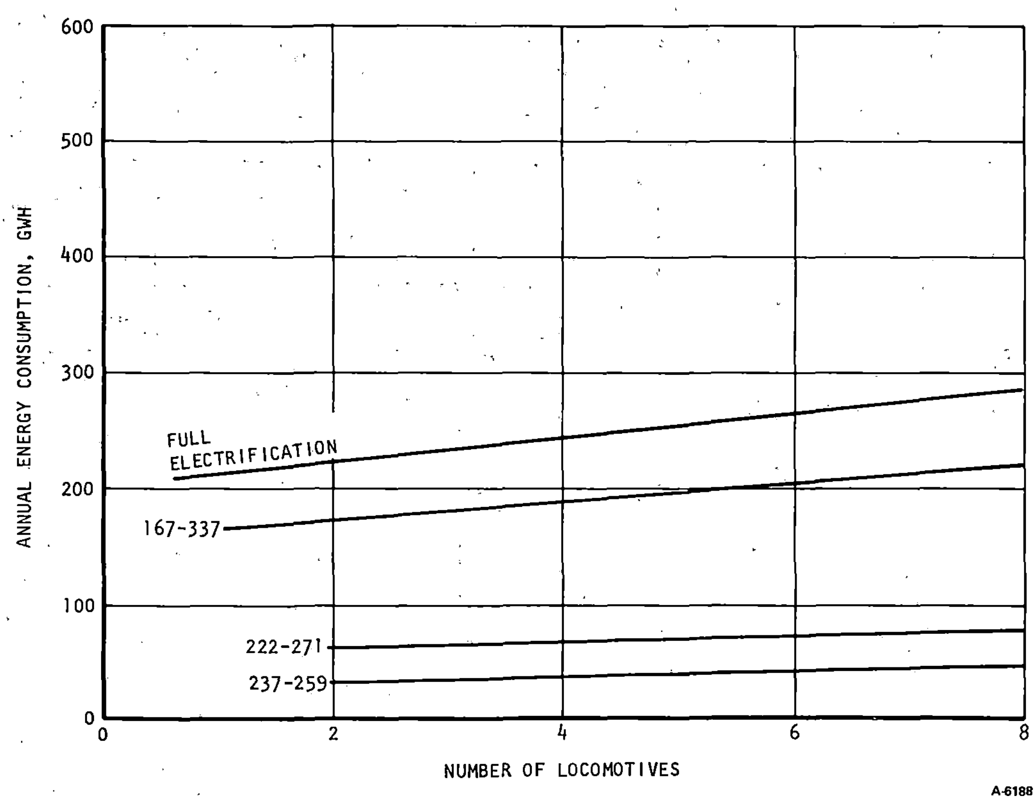


Figure 2-14. Pittsburgh-Harrisburg Energy Consumption

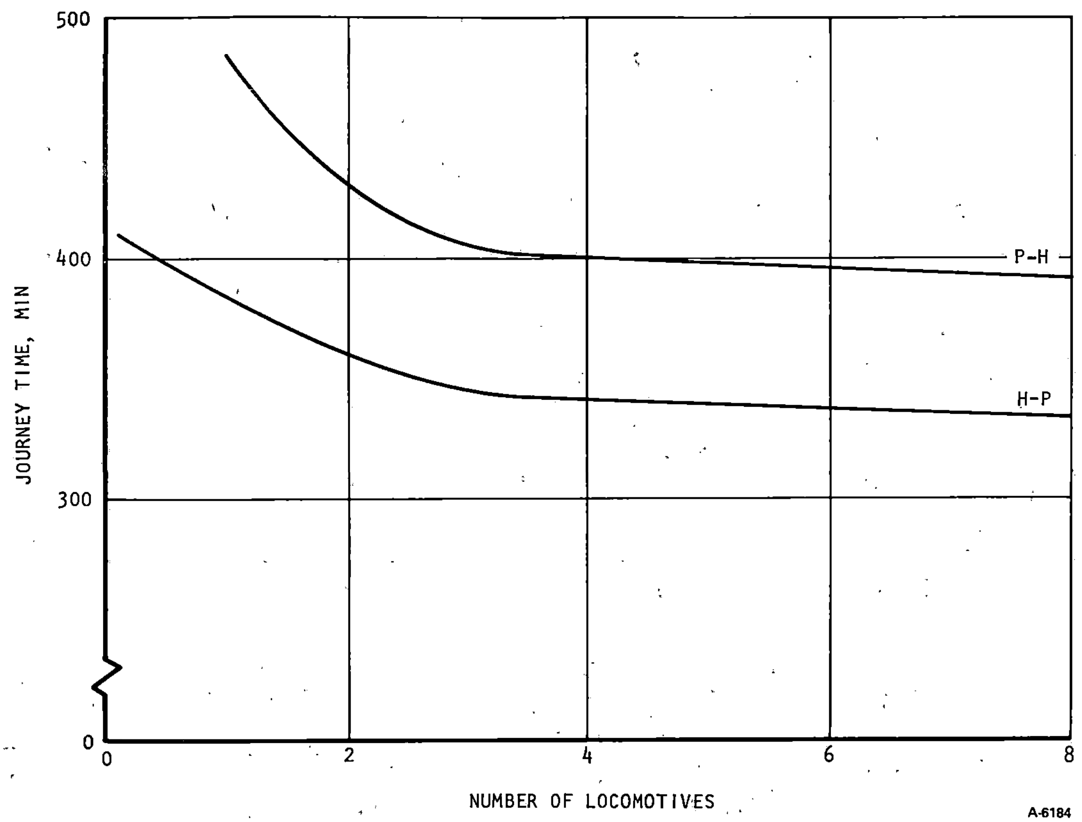


Figure 2-15. Journey Time with Conventional Electrification

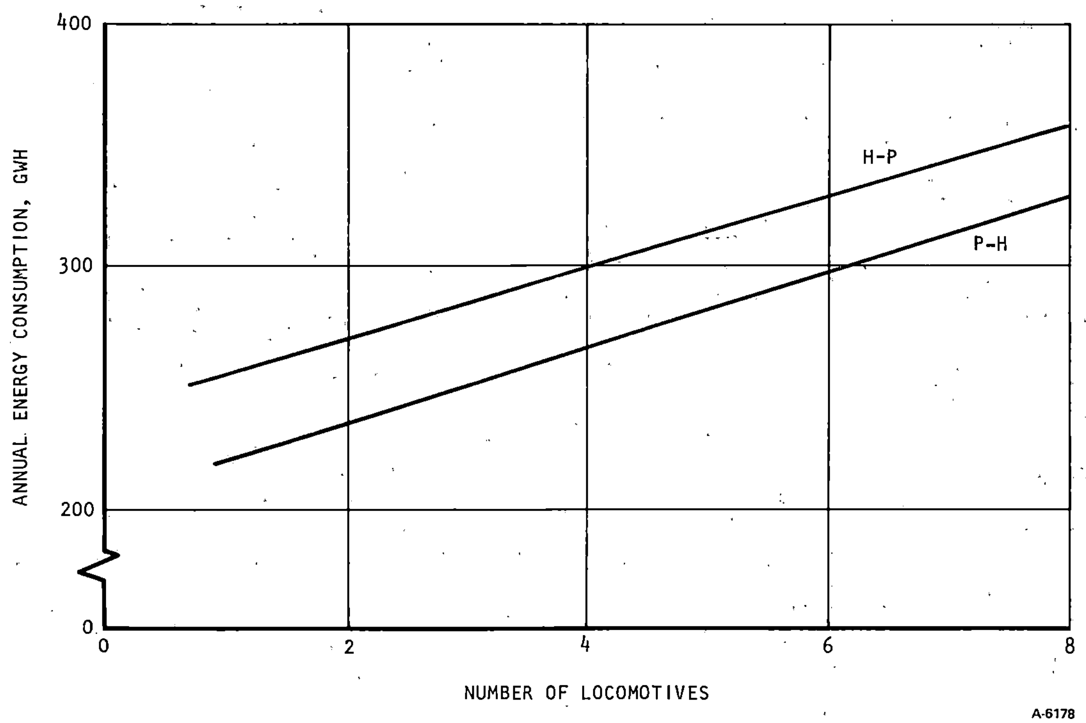


Figure 2-16. Energy Consumption for Conventional Electrification

b. Analysis of Results

Based on the average train and average power/weight ratio that has been identified, the operation of diesel and DML fleets on the Harrisburg-Pittsburgh route can be characterized as shown in Table 2-11. The number of DML's required to provide service equivalent to the existing diesel service has been estimated on the basis of achieving equal journey time over the route within the constraints of the minimum continuous speed of the locomotives, as illustrated in Figures 2-7 and 2-8. Diesel fuel consumption for the DML has been calculated on the basis of shutting down the diesel engine when in the electric mode, as discussed later in the report.

TABLE 2-11

CHARACTERISTICS OF HARRISBURG-PITTSBURGH
DIESEL AND DML OPERATION

	Diesel (SD40-2)		Dual-Mode Locomotive Location of Catenary (Milepost)								Normal Electrification (E60C)	
			237-259		222-271		167-337		Whole Route			
Characteristics	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
Trailing tons/train	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220
Number of locomotives	2.55	3.9	2.23	3.63	2.0	3.4	1.35	3.2	1.1	3.1	1.12	2.48
Journey time, min	475	352	475	352	475	352	475	352	475	352	475	352
Number of trains/yr	10728	10728	10728	10728	10728	10728	10728	10728	10728	10728	10728	10728
Annual fuel consumption, Mgal	21.0	25.4	17.3	21.5	14.3	18.5	5.3	9.5	0.5	0.7	--	--
Annual electrical energy, Gwh	--	--	36	51	63	82	168	195	213	268	222	278
Annual locomotive miles X 10^6	6.84	10.46	5.98	9.74	5.36	9.12	3.62	8.58	2.95	8.31	3.00	6.65
Locomotives per 1000 million ton miles	6.8										3.6	
Fleet size	190		173		159		134		124		100	
Surplus locomotives	--		17		31		56		66		190	
Catenary 4 track	--		22		49		64		77		85	
Catenary 3 track	--		--		--		102		160		160	
Catenary 2 track	--		--		--		--		5		5	

Locomotive utilization has been based on the following FRA data (Reference 4) for locomotive utilization:

	Min.	Max.	Average
Diesel locomotives per 10^9 GTTM*/yr	2.8	9.9	6.8
Electric locomotives per 10^9 GTTM/yr	1.94	4.22	3.6

The DML fleet size was then computed using the ratio of the average number of DML's to the number of diesel locomotives required for the same journey time, as determined above.

2. Los Angeles-Salt Lake City

This route, which is shown in Figure 2-17, is operated by Union Pacific and uses the Santa Fe tracks to negotiate the Cajon Pass in Southern California. Fifty percent of the traffic is operated at 15 mph (minimum) on the ruling grade, and fifty percent at 25 mph (minimum) on the ruling grade. As in many of the western routes, it is a relatively high-speed route with few significant curves, except when negotiating mountain passes. Passing sidings are located every 10 miles (approximately), and account for 100 of the 978 track miles over the 782 route miles. The route negotiates several mountain ranges in California, Nevada, and Utah. The ruling grade is the Cajon Pass, with maximum gradients of 2.03 and 2.2 percent on the normal ascending/descending tracks, respectively.

The average size train on this route is 4600 trailing tons, giving 7.0 or 3.7 SD40 locomotives for the high and low power trains, respectively, and 3478 trains per year in each direction.

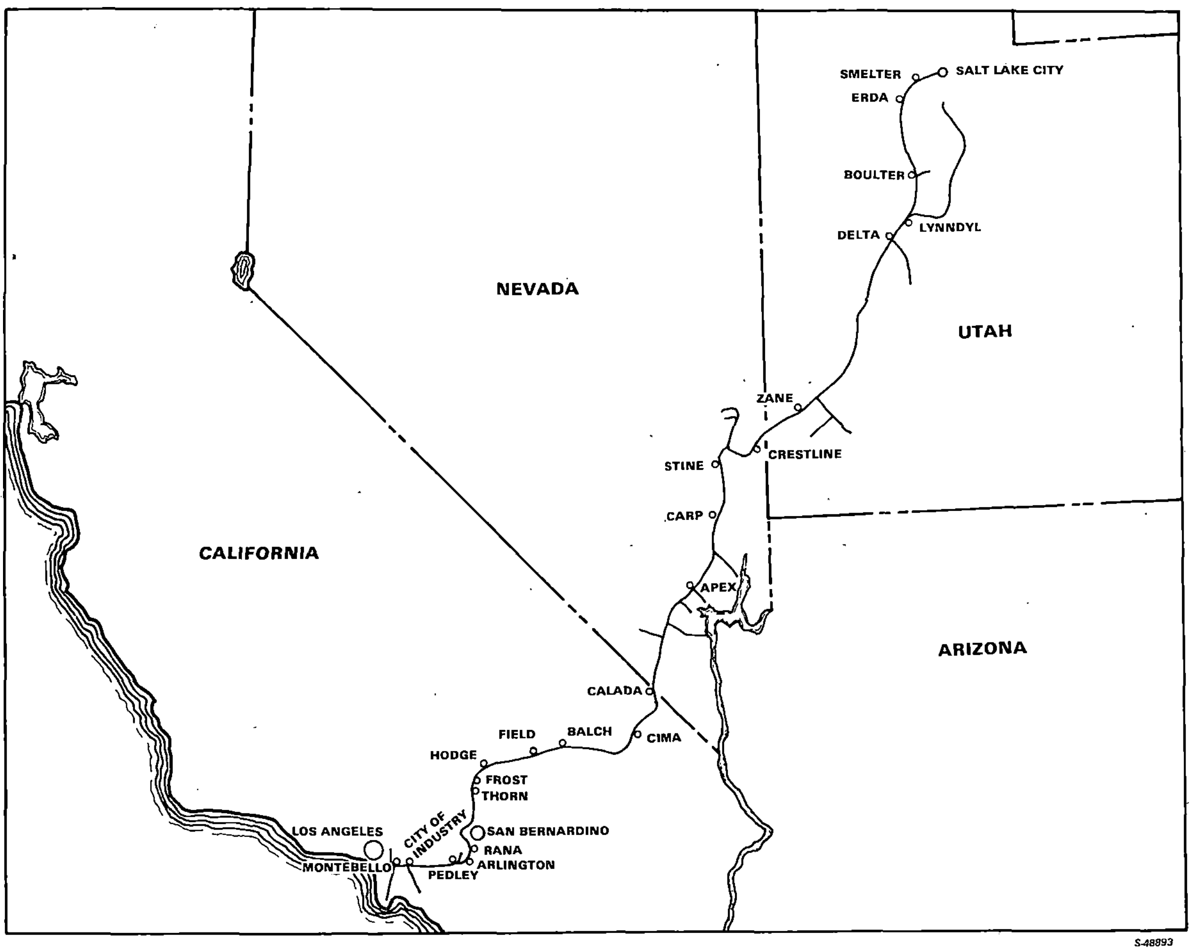


Figure 2-17. Los Angeles-Salt Lake City Route of Union Pacific

*GTMM = gross trailing ton miles.

a. TPC Output

The 4,600 trailing ton train was run over the route using the TPC, and the results for the existing diesel operation are shown in Tables 2-12 and 2-13, and in Figures 2-18 through 2-21.

The segments of notch 8 operation are shown in Table 2-14 and the resulting proposed electrified sections are shown in Figures 2-22 through 2-26.

TABLE 2-12

LOS ANGELES-SALT LAKE CITY JOURNEY TIME

Number of Locomotives	Journey Time, min	
	LA-SLC	SLC-LA
9	971	1236
7	1005	1257
5	1063	1292
3	1273	1427
2	1604	1656

TABLE 2-13

LOS ANGELES-SALT LAKE CITY FUEL CONSUMPTION

Number of Locomotives	Fuel Consumption, gal	
	LA-SLC	SLC-LA
9	11486	10255
7	10539	9286
5	9273	8107
3	7951	6641
2	7181	5845

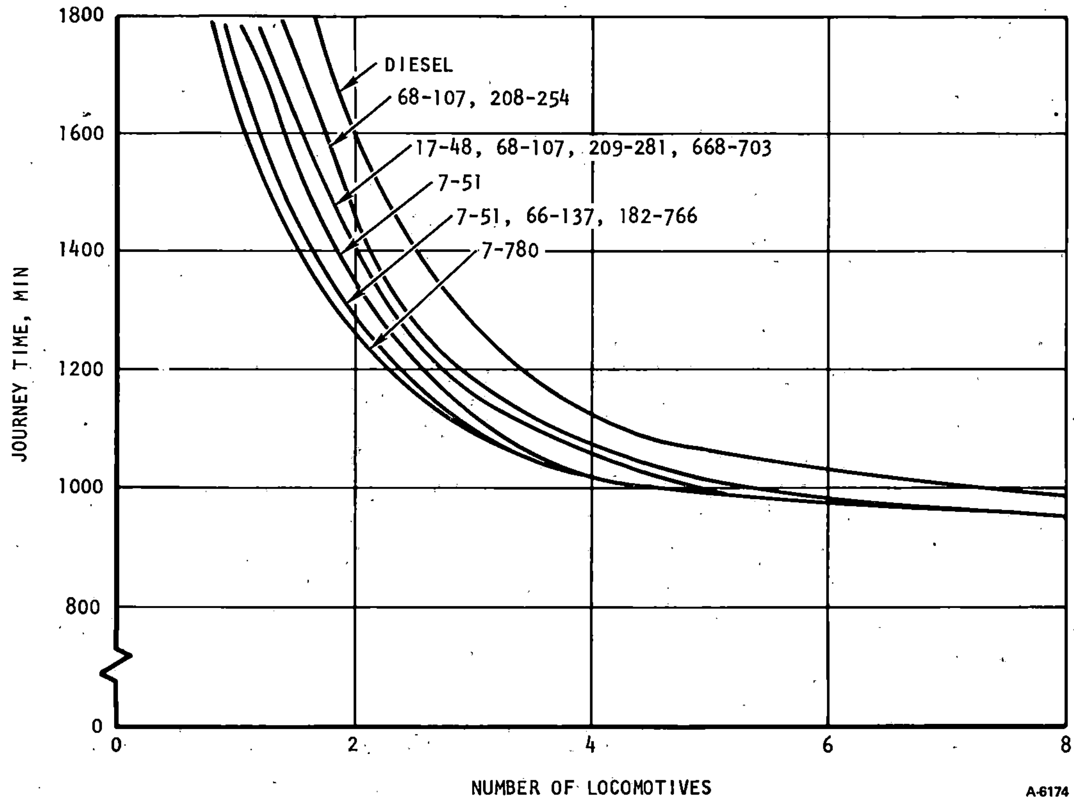


Figure 2-18. Los Angeles-Salt Lake City Journey Time

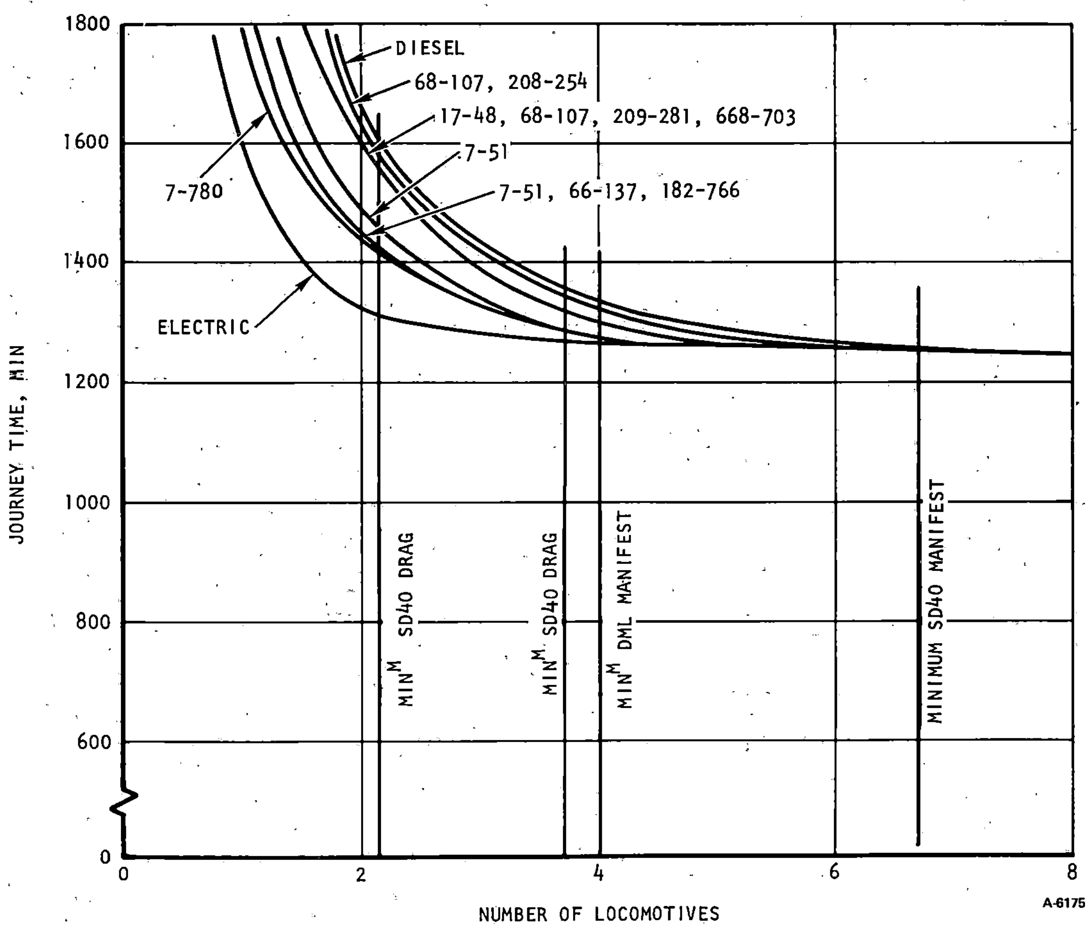


Figure 2-19. Salt Lake City-Los Angeles Journey Time

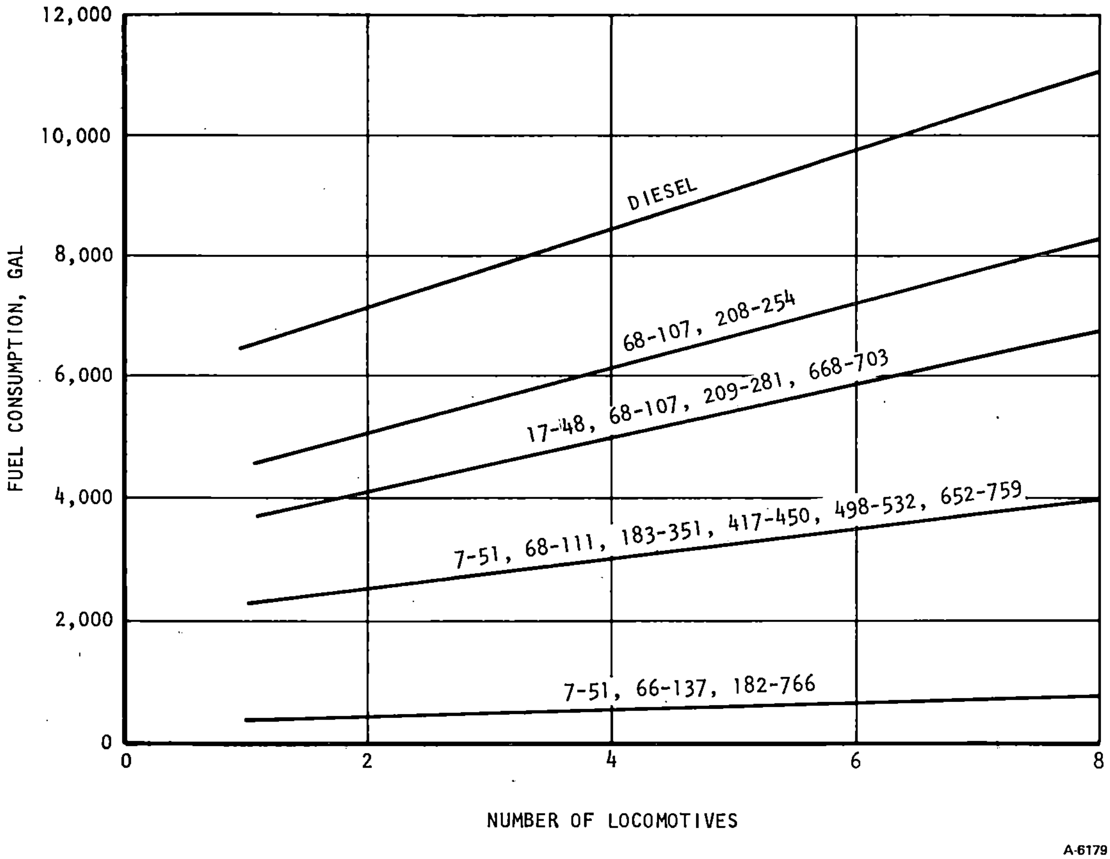


Figure 2-20. Los Angeles-Salt Lake City Fuel Consumption

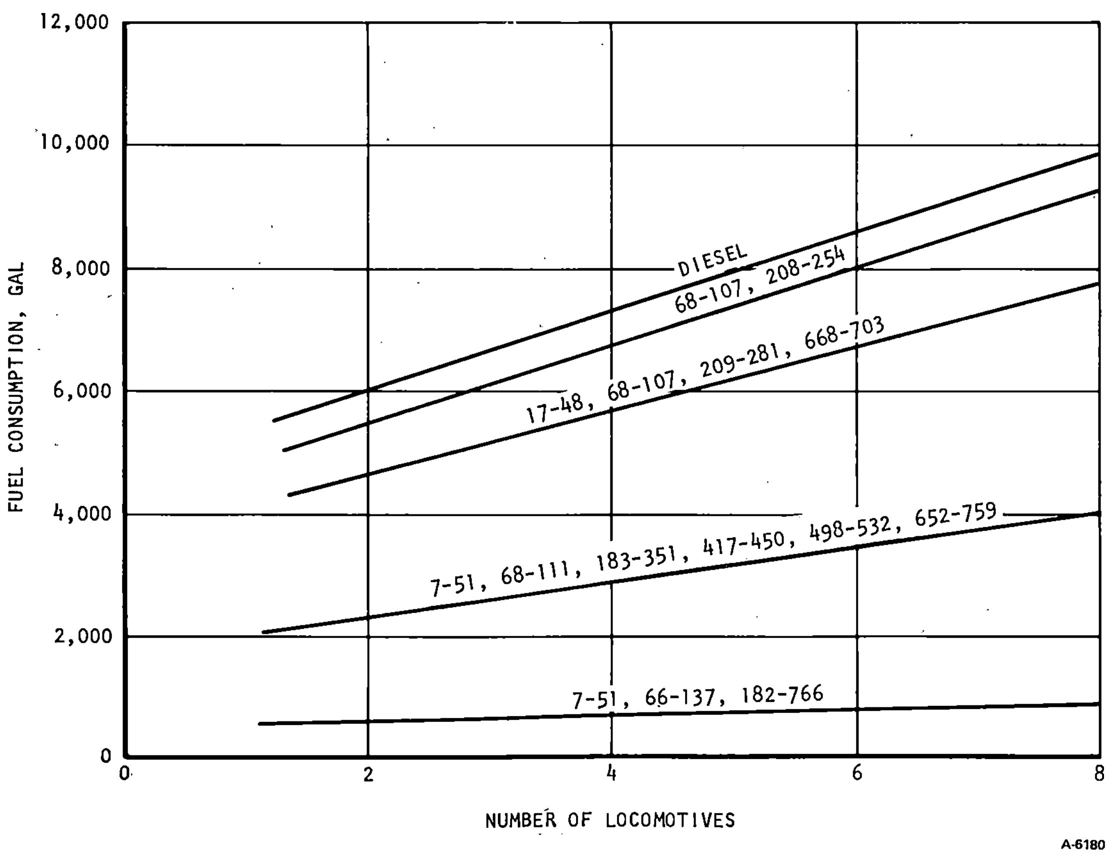


Figure 2-21. Salt Lake City-Los Angeles Fuel Consumption

TABLE 2-14

SECTIONS OF NOTCH 8 OPERATION LOS ANGELES - SALT LAKE CITY

Number of Locomotives	LA - SLC From	LA - SLC To	LA - SLC From	LA - SLC To	Proposed Electrified Section From	Proposed Electrified Section To
9	17	32	280	254	68	107
	68	95	107	95	211	254
	211	254				
	689	700				
7	17	35	758	703	17	48
	68	95	334	322	68	107
	209	254	281	254	209	281
	668	703	107	95	668	703
			48	38		
5	7	35	759	703	7	51
	68	95	532	498	68	111
	209	254	380	368	183	351
	297	309	334	309	417	450
	339	351	282	254	498	532
	417	450	202	183	652	759
	652	703	111	95		
			51	37		
3	7	37	766	703	7	51
	51	95	574	493	66	137
	209	254	391	253	182	766
	293	309	205	182		
	339	351	137	95		
	382	494	51	37		
	528	703				
2	7	38	780	703	7	780
	66	95	576	493		
	208	254	391	253		
	392	309	207	95		
	338	352	55	33		
	382	494				
	528	704				

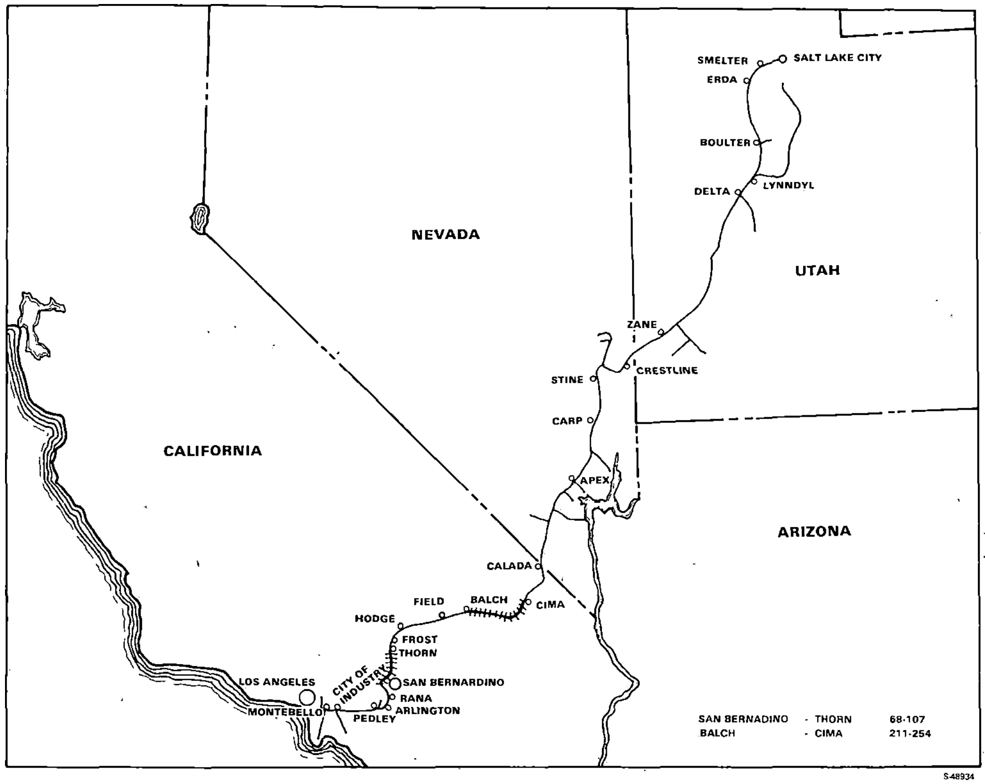


Figure 2-22. Los Angeles to Salt Lake City - First Stage Electrification

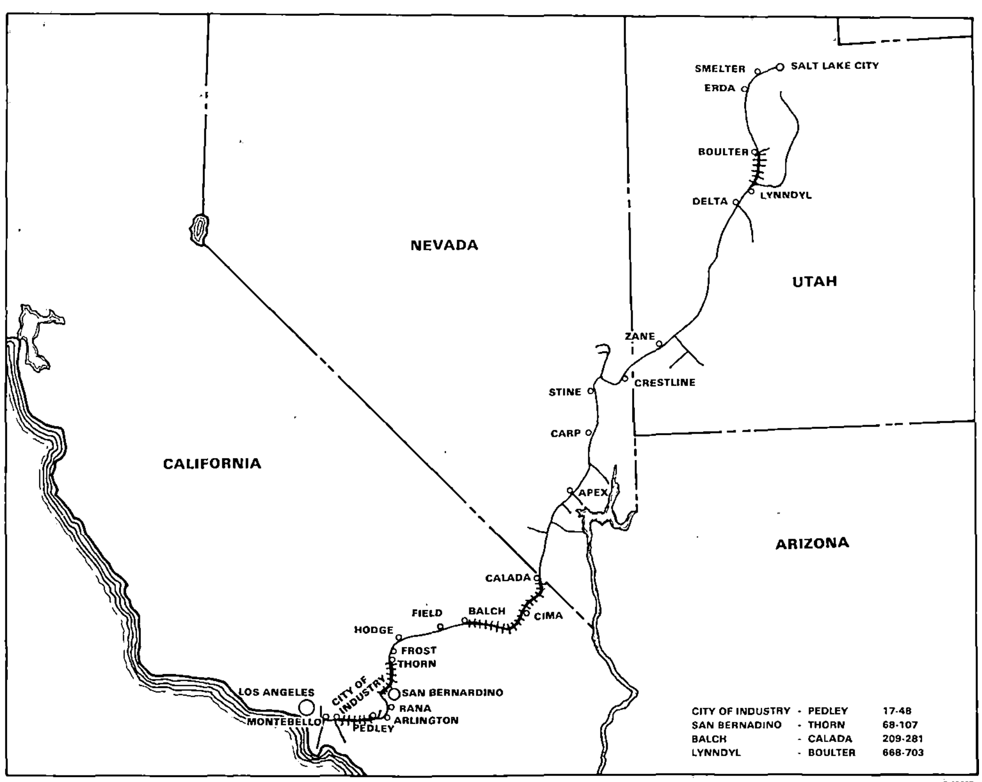


Figure 2-23. Los Angeles to Salt Lake City - Second Stage Electrification

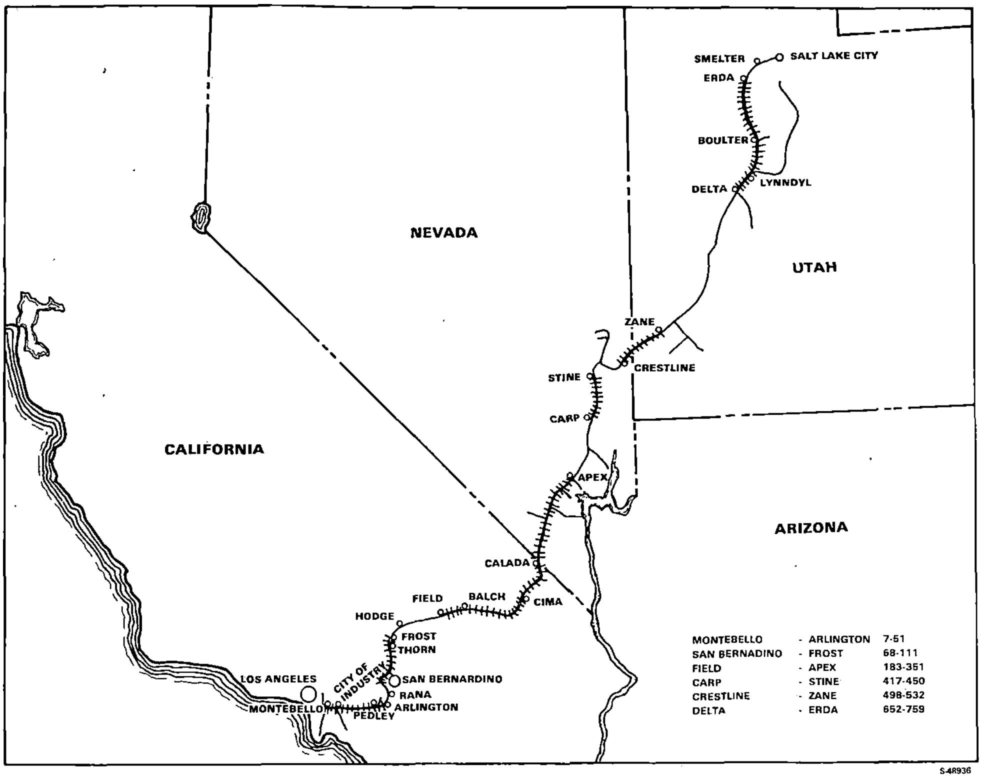


Figure 2-24. Los Angeles to Salt Lake City - Third Stage Electrification

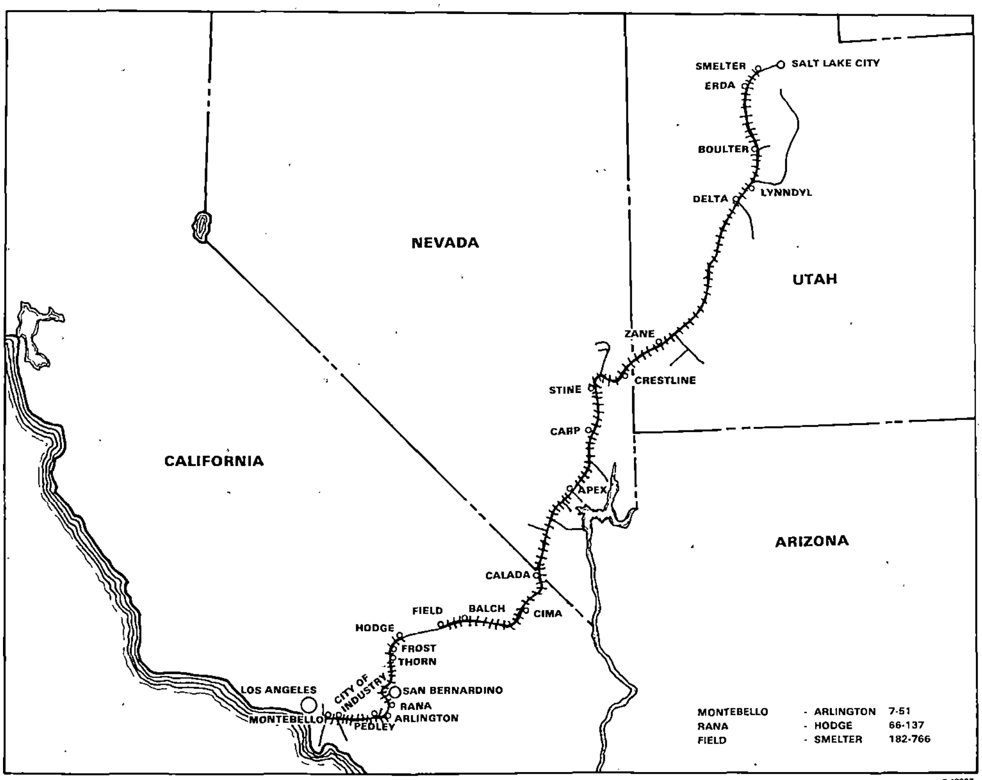


Figure 2-25. Los Angeles to Salt Lake City - Fourth Stage Electrification

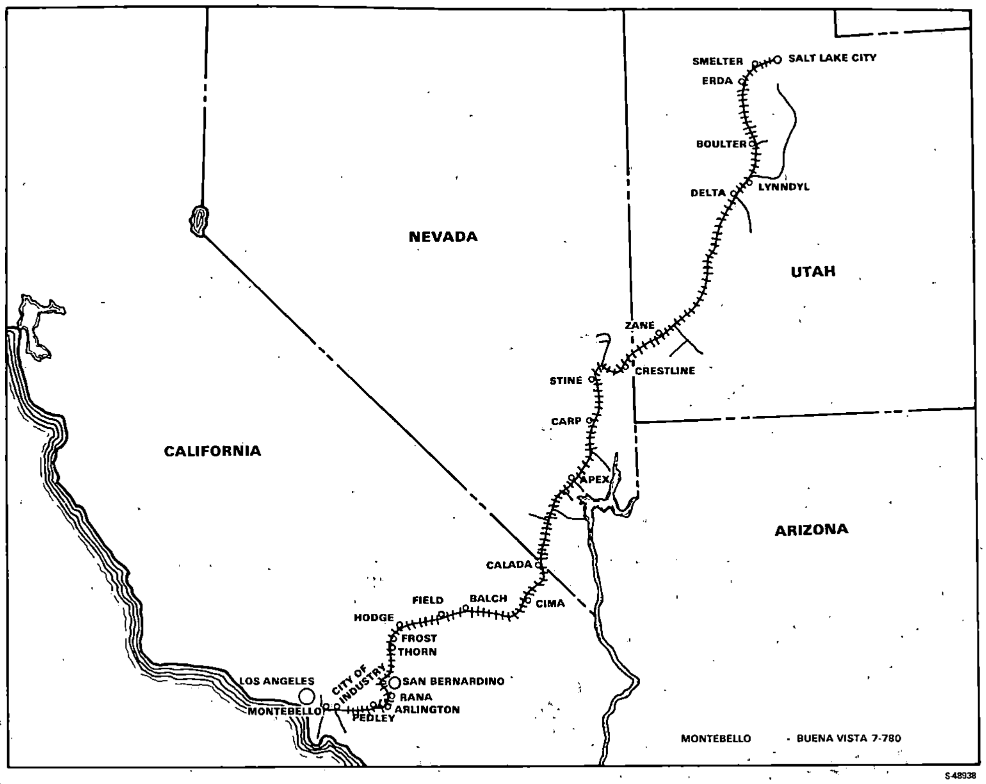


Figure 2-26. Los Angeles to Salt Lake City - Fifth Stage Electrification

The journey time and fuel and energy consumption calculations for each stage of electrification and for the whole route are shown in Tables 2-15 through 2-19 and in Figures 2-18 through 2-21, 2-27, and 2-28. Figures 2-29 and 2-30 define the limitation on number of locomotives imposed by the ruling grade. For comparison, a simulation of a full electric service using GE E60C locomotives is presented in Table 2-20 and Figures 2-18, 2-19, and 2-27 through 2-30.

TABLE 2-15

VARIATION OF JOURNEY TIME AND FUEL/ENERGY CONSUMPTION WITH NUMBER OF DML'S FOR LOS ANGELES-SALT LAKE CITY ELECTRIFICATION 68-107 AND 208-254

Number of Locomotives	Journey Time, min		Fuel Consumed Per Journey, gal		Electrical Energy Per Journey, Mwh	
	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA
9	953	1235	8480	9377	36.511	5.64
7	970	1251	7755	8502	34.578	4.98
5	1008	1280	6756	7558	29.278	5.07
3	1185	1417	5714	6149	29.88	3.779
2	1466	1644	4935	5448	29.34	3.938

TABLE 2-16

VARIATION OF JOURNEY TIME AND FUEL/ENERGY CONSUMPTION WITH NUMBER OF DML'S FOR LOS ANGELES-SALT LAKE CITY ELECTRIFICATION 17-48, 68-107, 209-281, AND 668-703

Number of Locomotives	Journey Time, min		Fuel Consumed Per Journey, gal		Electrical Energy Per Journey, Mwh	
	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA
9	947	1235	6923	8015	52.16	17.54
7	958	1242	6349	7221	47.29	16.12
5	995	1273	5534	6292	43.35	15.1
3	1147	1381	4643	5263	42.3	14.09
2	1426	1601	4095	4652	40.66	12.56

TABLE 2-17

VARIATION OF JOURNEY TIME AND FUEL/ENERGY CONSUMPTION
WITH NUMBER OF DML'S FOR LOS ANGELES-SALT LAKE CITY
ELECTRIFICATION 7-51, 68-111, 183-351, 417-450, 498-532, AND 652-759

Number of Locomotives	Journey Time, min		Fuel Consumed Per Journey, gal		Electrical Energy Per Journey, Mwh	
	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA
9	941	1235	4177	4232	75.91	56.15
7	966	1240	3720	3782	73.29	52.59
5	995	1267	3287	3268	65.89	48.40
3	1107	1321	2775	2649	61.09	42.9
2	1340	1486	2481	2306	58.45	40.7

TABLE 2-18

VARIATION OF JOURNEY TIME AND FUEL/ENERGY CONSUMPTION
WITH NUMBER OF DML'S FOR LOS ANGELES-SALT LAKE CITY
ELECTRIFICATION 7-51, 66-137, AND 182-766

Number of Locomotives	Journey Time, min		Fuel Consumed Per Journey, gal		Electrical Energy Per Journey, Mwh	
	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA
9	941	1235	812	922	109.71	82.83
7	966	1240	718	815	101.1	76.9
5	995	1267	578	739	94.42	71.9
3	1094	1317	456	622	76.07	66.0
2	1286	1447	420	558	84.8	61.5

TABLE 2-19

VARIATION OF JOURNEY TIME AND FUEL/ENERGY CONSUMPTION
WITH NUMBER OF DML'S FOR LOS ANGELES-SALT LAKE CITY
ELECTRIFICATION 7-780

Number of Locomotives	Journey Time, min		Fuel Consumed Per Journey, gal		Electrical Energy Per Journey, Mwh	
	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA
9	941	1235	47	40	114.02	93.00
7	966	1235	38	42	107.2	85.76
5	995	1267	45	30	98.99	78.94
3	1002	1313	22	21	91.57	72.00
2	1275	1441	48	17	88.37	68.3

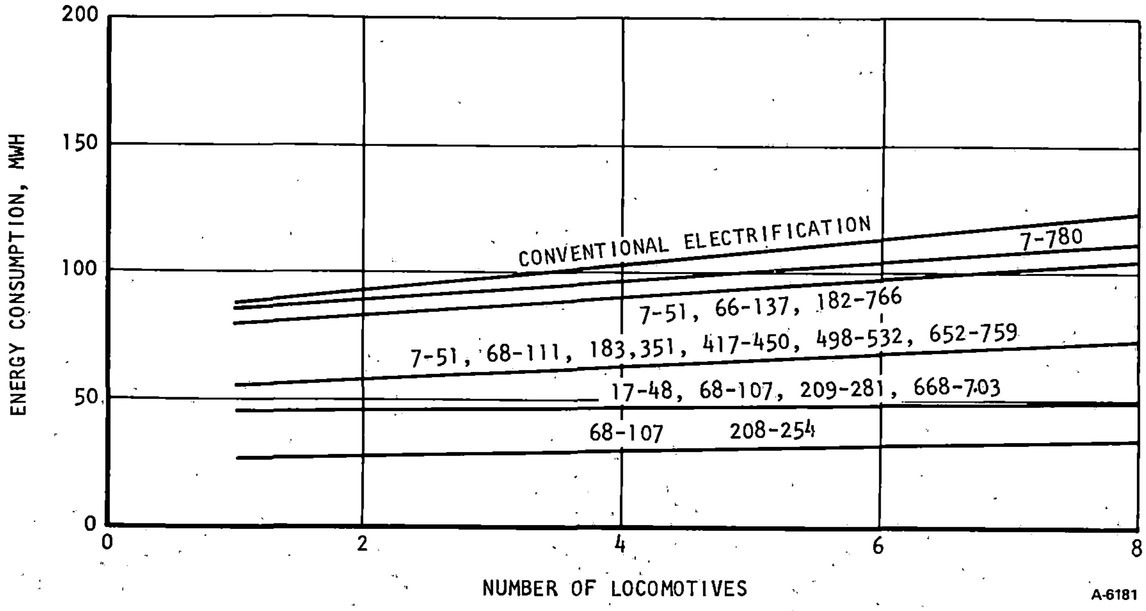


Figure 2-27. Los Angeles-Salt Lake City Route Energy Consumption

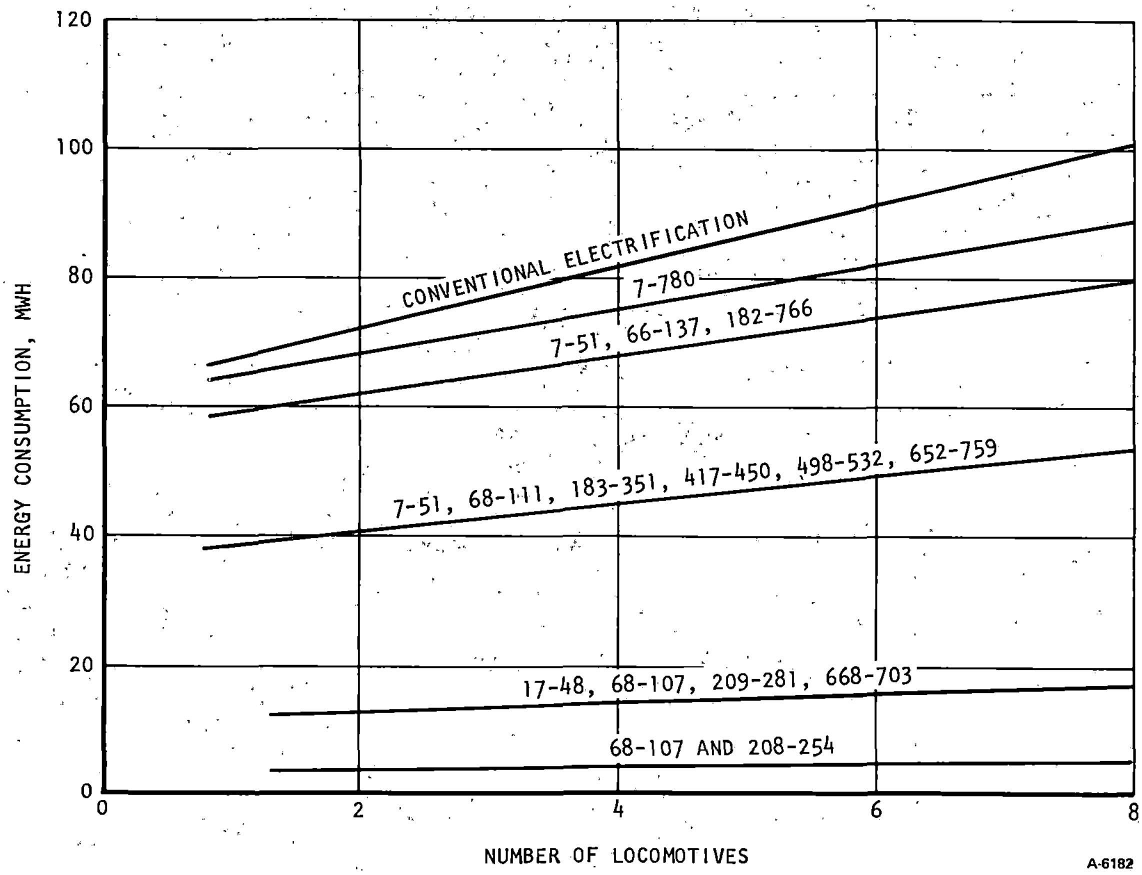


Figure 2-28. Salt Lake City-Los Angeles Route Energy Consumption

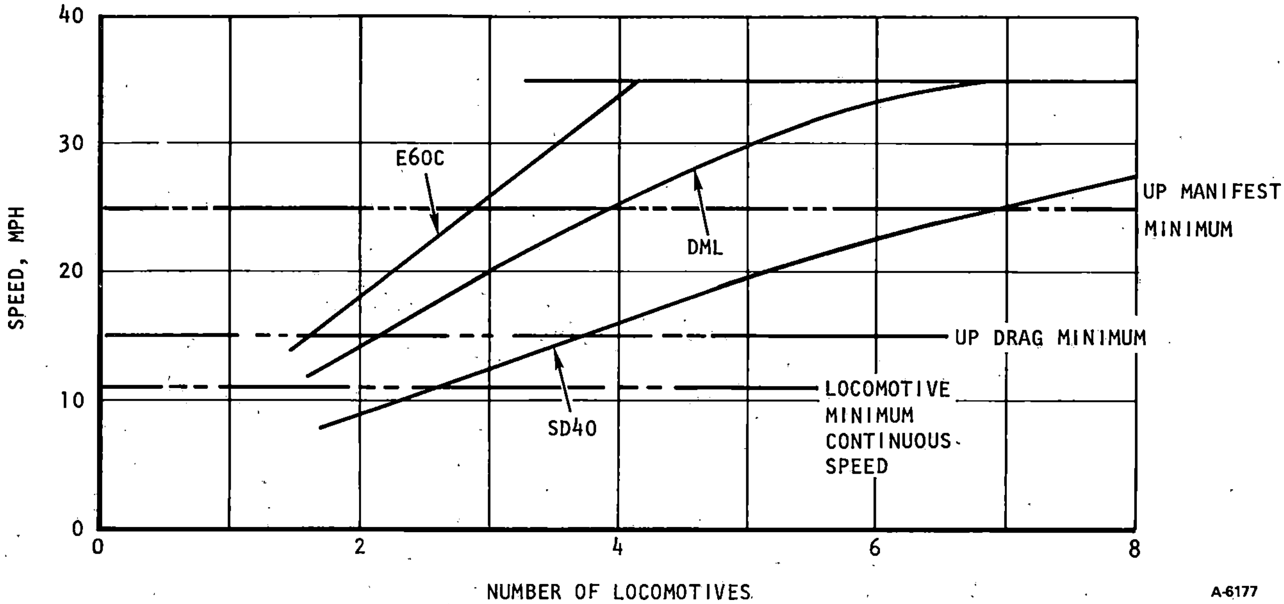


Figure 2-29. Los Angeles-Salt Lake City Route Speed on Ruling Grade

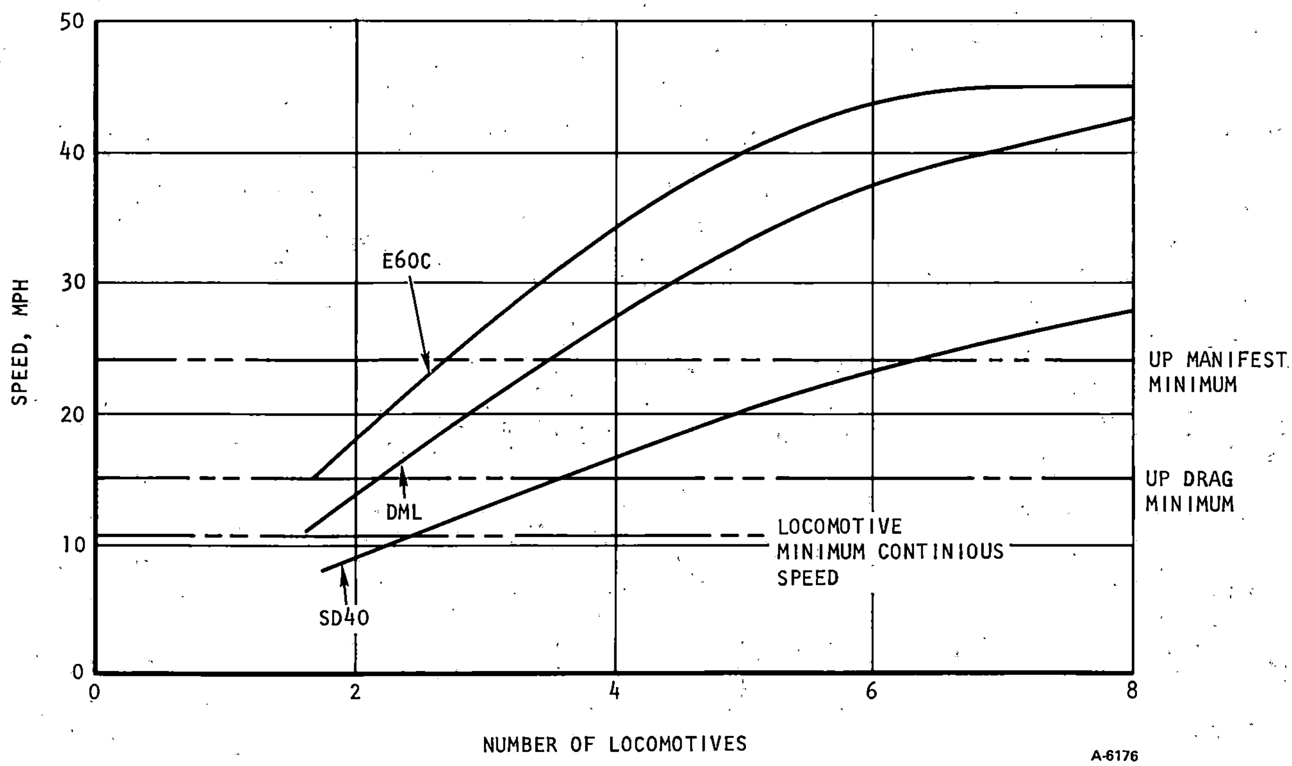


Figure 2-30. Salt Lake City-Los Angeles Route Speed on Ruling Route

TABLE 2-20

VARIATION OF JOURNEY TIME AND ENERGY CONSUMPTION
WITH NUMBER OF ELECTRIC LOCOMOTIVES

Number of E60C Locomotives	Journey Time, min		Energy Consumption, Mwh	
	LA-SLC	SLC-LA	LA-SLC	SLC-LA
9	931	1235	129	105
7	932	1240	117	97.4
5	937	1245	107	87.8
3	992	1280	94.5	77.7
2	1094	1321	91.0	72.0

b. Analysis of Results

Based on the average train and average power/weight ratios identified, the operation of the diesel and DML fleets on the Los Angeles-Salt Lake City route is characterized as shown in Tables 2-21 and 2-22, which in turn are used to determine the composite characteristics of Table 2-23.

ECONOMIC ANALYSIS

The decision to electrify the nation's major rail arteries will be made on economic considerations. Railroad electrification is generally accepted as being a desirable goal, but there are several reasons why electrification has not significantly progressed outside of the Northeast Corridor, including:

(a) Massive initial investment

(b) Low return on investment compared with other projects competing for available funds

(c) Inflexibility of the electric locomotive fleet

(d) Reluctance to rely too heavily on foreign experience

The successful development of a DML will address the points above and will allow a more gradual approach to electrification.

This economic analysis has been made in constant (1980) dollars and therefore no differential for inflation has been provided. Historical trends indicate that the cost of diesel fuel will inflate at a higher rate than electrical energy, and therefore the baseline economic analysis in this section is pessimistic in this respect.

Schedule of Cost Elements

A schedule of cost elements is given in Table 2-24. Where it was possible, previously published data that had been independently verified was used. The cost schedule for this program will be updated at the end of the study, and is described in Section 7 of this report.

1. Locomotives

The SD40-based DML cost estimate is based on the work recently completed for Transport Canada (Reference 5), and has been updated to reflect the change in power circuit and the impact of shutting down the engine in the electric mode. The breakdown of the cost estimate is given in Table 2-25. This estimate is used for the initial cost analysis and will be reviewed and refined during the course of the study and updated in Task 6 as indicated in the previous text.

TABLE 2-21

CHARACTERISTICS OF LOS ANGELES-SALT LAKE CITY
DIESEL, DML, AND ELECTRIC OPERATION
LOW PERFORMANCE OPERATION

	Diesel (SD40-2)		Dual-Mode Locomotive Location of Catenary (Milepost)										Normal Electrification (E60C)	
			68-107 211-254		17-48 68-107 209-281 668-703		7-51 68-111 183-351 417-450 498-532 652-759		7-51 66-137 182-766		7-780			
Characteristics	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SCL	SCL-LA
Trailing tons/train	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600
Number of locomotives	3.7	3.6	3.2	3.5	2.95	3.2	2.8	2.8	2.6	2.65	2.5	2.65	1.6	1.7
Journey time	1160	1375	1160	1375	1160	1375	1160	1375	1160	1375	1160	1375	1160	1375
Number of trains/yr	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739
Annual fuel consumption, Mgal	14.34	12.26	9.91	11.13	7.82	9.22	4.69	4.43	0.78	1.04	0.01	0.01	--	--
Annual electrical consumption, Gwh	--	--	41.74	6.9	80.0	24.3	104.3	73.9	147.8	111.3	158.0	121.7	158.3	122.6
Annual locomotive miles X 10^{-6}	5.00	4.86	4.32	4.73	3.99	4.32	3.78	3.78	3.51	3.58	3.38	3.58	2.16	2.0
Locomotives/10^9 ton-miles	6.8													
Fleet size	85		78		72		66		61		60		39	
Surplus locomotives	--		7		13		19		24		25		85	

TABLE 2-22

CHARACTERISTICS OF LOS ANGELES-SALT LAKE CITY
DIESEL, DML, AND ELECTRIC OPERATION
HIGH PERFORMANCE OPERATION

	Diesel (SD40-2)		Dual-Mode Locomotive Location of Catenary (Milepost)										Normal Electrification (E60C)	
			68-107 211-254		17-48 68-107 209-281 668-703		7-51 68-111 183-351 417-450 498-532 652-759		7-51 66-137 182-766		7-780			
Characteristic	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SCL	SCL-LA
Trailing tons/train	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600
Number of locomotives	7.0	6.7	5.3	4.0	4.9	4.0	4.6	4.0	4.6	4.0	4.6	4.0	2.9	3.0
Journey time	1000	1250	1000	1250	1000	1250	1000	1250	1000	1250	1000	1250	1000	1250
Number of trains/yr	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739	1739
Annual fuel consumption, Mgal	18.26	15.65	11.82	11.65	9.30	9.90	5.48	5.04	1.04	1.22	0.01	0.01	--	--
Annual electrical consumption, Gwh	--	--	55.65	6.96	81.73	25.2	113.0	78.2	160.0	118.2	173.9	130.4	168.7	133.9
Annual locomotive miles X 10^{-6}	9.46	9.05	7.16	5.4	6.6	5.4	5.7	5.4	5.7	5.4	5.7	5.4	3.6	3.5
Locomotives/10^9 ton-miles		6.8												3.6
Fleet size		85		58		55		54		54		54		37
Surplus locomotives		--		27		30		31		31		31		48

TABLE 2-23

CHARACTERISTICS OF LOS ANGELES-SALT LAKE CITY
DIESEL, DML, AND ELECTRIC OPERATION
COMBINED SERVICE

	Diesel (SD40-2)		Dual-Mode Locomotive Location of Catenary (Milepost) 68-107 211-254		17-48 68-107 209-281 668-703		7-51 68-111 183-351 417-450 498-532 652-759		7-51 66-137 182-766		7-780		Normal Electrification (E60C)	
Characteristics	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SCL	SCL-LA
Trailing tons/train	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600
Number of trains/yr	3478	3478	3478	3478	3478	3478	3478	3478	3478	3478	3478	3478	3478	3478
Annual fuel consumption, Mgal	32.60	27.91	21.73	22.78	17.12	19.12	10.17	9.47	1.82	2.26	0.02	0.02	--	--
Annual electrical consumption, Gwh	--	--	97.4	13.86	161.73	49.5	217.3	152.1	307.8	229.5	331.9	252.1	327.0	256.0
Annual locomotive miles X 10^{-6}	14.46	13.91	11.48	10.13	10.59	9.72	9.48	9.18	9.21	8.98	9.08	8.98	5.76	6.9
Locomotives/10^9 ton-miles	6.8												3.6	
Fleet size	170		136		127		120		115		114		76	
Surplus locomotives	--		34		43		50		55		56		170	
Catenary 2 track	--		39		39		43		71		101		101	
Catenary 1 track	--		43		138		386		628		672		676	
Passing siding	--		--		--		--		--		--		100	

TABLE 2-24

PRELIMINARY SCHEDULE OF COSTS*

Item	Cost, Dollars	Source
Locomotives		
Initial		
SD40 based DML	350,000	Reference 5
New SD40 locomotive	825,000	Conrail (updated)
New E60C locomotive	1,500,000	Conrail (updated)
Maintenance		
DML	+0.04/mile	Garrett Estimate
SD40	0.884/mile	Reference 6 (updated)
E60C	0.381/mile	Reference 6 (updated)
Electrification		
Initial, including substations		
Single track	305,000/mile	Reference 1 (updated)
Two track	513,000/mile	Reference 1 (updated)
Three track	577,000/mile	Reference 1 (updated)
Four track	641,000/mile	Reference 1 (updated)
Maintenance per year	1,876/mile	Reference 6 (updated)
Energy		
Diesel fuel	1.00/gal	This study
Electricity	0.018/kwh	This study

TABLE 2-25

BREAKDOWN OF DML COST

Component	Cost, 1980 dollars
Roof equipment	40,000
Main transformer	79,000
Power converter	146,000
Smoothing choke	5,000
Auxiliaries	20,000
Labor	60,000
Total	350,000

*NOTE: The revised economic data and analysis are contained in Section 7.

During meetings with Conrail in April 1979, the price of a standard SD40-2 was $750,000, which, assuming inflation at 10 percent is $825,000 in 1980 dollars. Similarly, an E60C was thought by Conrail to be priced at $1.35 million, which becomes $1.5 million in 1980.

For locomotive maintenance costs, two sources were used. During the Transport Canada study it was determined that relatively old diesel locomotives operating under adverse weather conditions often experienced in Northern Quebec had a total nonrotating electrical equipment maintenance cost of approximately $0.08/mile. The equipment under consideration comprises contactors, relays, printed wire assembly boards, and main and auxiliary rectifiers. It is estimated that the lack of moving parts and the anticipated dirt-free electrical compartment will result in a 50-percent maintenance reduction of the comparable electric mode equipment. In addition, the diesel engine maintenance will be significantly reduced since periods of full engine power will be reduced by the use of the electric mode. Therefore, the additional $0.04/mile assumed for electric mode maintenance is considered to be conservative. Maintenance costs for the conventional diesel and electric locomotives are based on a previous Department of Transportation report (Reference 6).

2. Electrification

The cost of electrification, including catenary, signaling, substations, and utility tie-ins was developed by Bechtel, Inc. under subcontract to Garrett during the performance of the Department of Transportation Wayside Energy Storage Study (Reference 1). The maintenance cost associated with electrification was based on Reference 6 data.

3. Energy

The price of diesel fuel is rising daily and is distorted by the large difference between contract and spot market prices. It is estimated that the average price of DF2 to the railroads, by the end of 1980, will be $1.00/gallon.

The cost of electrical energy varies widely across the country. To understand how a railroad's electricity bill is determined, an analysis was made using (1) a demand profile for the Richmond feeder station on the Northeast Corridor (NEC), and (2) Southern California Edison (SCE) electricity rates (the rate schedule is contained in Appendix B). An analysis of the integrated power demand is given in Table 2-26.

Using the SCE schedule of Appendix B, the cost of electricity becomes:

Customer charge		$ 1,075.00
Demand (15-min interval)		
On peak $5.05 X 26,000		131,300.00
Mid peak $0.65 X 37,800		24,570.00
Off peak		-
		$155,870.00
Energy		
On peak $0.0053 X 57,950		307.00
Mid-peak $0.0038 X 161,400		613.00
Off peak $0.0023 X 131,900		303.00
Daily	351,250	1,223.00
Per month (30 days)		$ 36,690.00
	Total	$193,635.00

$$\text{Average cost} = \frac{193,635}{351,250 \times 30} = \$0.0184/\text{kwh}$$

This average value, $0.0184/kwh, will be used in the initial economic analysis. Other data sources will be checked to determine the nationwide average electricity cost to be used in the final economic analysis. The variation in electricity cost is one of the parameters that lead to the conclusion that the application of DML's can only be considered on a site-specific basis. The results of the baseline economic analysis, as applied to the Conrail and UP routes, are contained in Tables 2-27 and 2-28, respectively.

TABLE 2-26

VARIATION OF PEAK INTEGRATED DEMAND WITH DEMAND INTERVAL FOR RICHMOND FEEDER STATION (NEC)

Integrated Demand, Mw

Demand Period Number	Demand Interval			Demand Period No.	Demand Interval		
	15 min	30 min	60 min		15 min	30 min	60 min
1	29.400	27.700	24.925	49	7.600		
2	26.000	22.150	18.375	50	8.200		
3	23.700	17.300	10.825	51	7.200		
4	20.600	19.450	11.200	52	7.600		
5	17.400	11.850	9.700	53	10.800		
6	17.200	9.800	11.500	54	11.200		
7	18.800	8.400	18.825	55	9.600		
8	20.100	14.000	26.500	56	9.400		
9	13.200	10.800	13.800	57	8.800		
10	10.500	8.600	11.750	58	12.000		
11	11.100	9.900	11.350	59	8.200		
12	8.500	13.100	8.250	60	6.600		
13	8.400	15.200	7.650	61	8.000		
14	8.400	22.450	10.250	62	9.200		
15	10.200	31.300	8.900	63	9.000		
16	17.800	21.700	10.700	64	16.600		
17	11.400	16.900	12.200	65	13.400		
18	10.200	10.700	22.950	66	11.200		
19	7.200	13.700	31.900	67	10.800		
20	10.000	9.800	26.500	68	13.400		
21	11.600	12.300	8.650	69	18.400		
22	8.200	10.400	8.000	70	23.400		
23	9.400	9.300	11.950	71	24.000		
24	16.800	7.200	14.600	72	26.000		
25	11.600	7.900		73	28.600		
26	18.800	7.400		74	37.800		
27	18.300	11.000		75	31.600		
28	26.600	9.500		76	29.600		
29	28.000	10.400		77	26.000		
30	34.600	7.400		78	26.600		
31	22.400	8.600		79	28.800		
32	21.000	12.800		80	21.600		
33	17.800	12.300		81	11.800		
34	16.000	12.100		82	7.400		
35	13.600	20.900		83	5.000		
36	7.800	25.000		84	10.400		
37	11.800	33.200		85	11.800		
38	15.600	30.600		86	10.000		
39	8.000	27.800		87	3.000		
40	11.600	25.200		88	7.200		
41	10.200	9.600		89	9.400		
42	14.400	7.700		90	11.000		
43	11.400	10.900		91	15.200		
44	9.400	5.100		92	12.200		
45	9.200	10.200		93	13.200		
46	9.400	13.700		94	13.200		
47	6.600	13.200		95	16.400		
48	7.800	16.000		96	15.600		

TABLE 2-27

ECONOMIC ANALYSIS OF APPLICATION OF DML'S HARRISBURG-PITTSBURGH BASELINE CASE (IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts)				Normal Electrification
	237-259	222-271	167-337	Whole Route	
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	60.55	55.65	46.90	43.4	150.00
Locomotives transferred	(7.01)	(12.79)	(23.10)	(27.23)	(78.37)
Net total	67.64	74.27	123.68	160.41	221.00
Annual					
Diesel fuel saving	(7.6)	(13.6)	(31.6)	(45.2)	(46.4)
Electrical energy	1.56	2.61	6.53	8.66	9.0
Locomotive maintenance	(0.76)	(1.91)	(4.02)	(4.89)	(11.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(0.96)	(1.7)	(3.08)	(3.63)	(10.45)
Net saving	7.71	14.52	31.85	44.59	58.98
ROI	11.4	19.6	25.8	27.8	26.7

TABLE 2-28

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY BASELINE (IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts)					Normal Electrification
	211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	
Initial						
Catenary	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	47.6	44.45	42.0	40.25	39.9	114.000
Locomotives transferred	(14.025)	(17.74)	(20.625)	(22.69)	(23.1)	(38.775)
Net total	66.697	88.807	161.164	245.523	273.573	354.018
Annual						
Diesel fuel saving	(16.00)	(24.27)	(40.87)	(56.43)	(60.11)	(60.51)
Electrical energy	2.00	3.80	6.65	9.67	10.512	10.503
Locomotive maintenance	(5.18)	(6.31)	(6.42)	(8.27)	(8.393)	(20.58)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(1.87)	(2.365)	(2.75)	(3.02)	(3.08)	(5.17)
Net saving	20.896	28.813	42.585	56.739	59.621	74.267
ROI	31.2	32.4	26.4	23.1	21.8	21.0

Structure of Economic Analysis

The deployment of DML's results in the following initial costs and credits:

Electrification--Assumed to be a constant cost/mile and includes signaling, catenary, substations, etc.

Locomotives Modified--A certain number of locomotives will have to be modified to the DML configuration.

Locomotives Transferred--A surplus of locomotives will result from the deployment of DML's; these locomotives will be transferred to other duties, and a credit will be taken for the DML scheme.

The following annual costs and credits will result from the DML deployment:

Diesel Fuel--The use of electric mode will reduce the consumption of diesel fuel. Furthermore, the reduction in locomotive fleet size will reduce the amount of fuel that is wasted by unnecessary idling of engines.

Electrical Energy--The diesel fuel saving is offset by electrical energy consumption, which varies as the extent of electrification varies.

Locomotive Maintenance--Although the maintenance cost will increase slightly, the reduction in locomotive fleet size should result in a net reduction of locomotive fleet maintenance.

Catenary Maintenance--All catenary maintenance must be charged to the deployment of the DML's.

Locomotive replacement--The reduction in fleet size results in a reduction in annual locomotive replacement costs.

To calculate the return on investment, the average annual savings over the 30-hr life of the project were used. There are many methods of calculating and comparing the economic benefits of a project. The data presented in this report may be used by a railroad to calculate economic benefits according to their derived methodology. The Garrett methodology avoids the need to consider site specific factors, such as cost of capital, taxation, discount rates, etc. that vary from railroad to railroad.

Sensitivity Analysis

To derive sufficient data to perform an economic analysis, it has been necessary to make certain assumptions, which if not valid, could completely alter the result of the economic analysis. To identify cost items to which the study results are particularly sensitive, a sensitivity analysis was carried out on a number of items, as described below.

1. Electrification Costs

In a conventional electrification scheme, the cost of the wayside electrification equipment is the single highest factor. There is little experience in the U.S. with large electrification schemes, and therefore it is difficult to derive an accurate cost per mile figure until more experience has been gained.

To account for this uncertainty, the sensitivity of the economic analysis to the catenary cost was tested by assuming that these costs increased by 50 percent over the previous best estimate and the results are shown in Tables 2-29 and 2-30.

2. Locomotive Costs

Neither the DML nor the GE E60C (used as the conventional electric locomotive alternative to the DML) have been produced in the quantities required for the schemes analyzed in this study. Therefore, a certain doubt exists concerning the accuracy of the locomotive cost estimates; therefore, the sensitivity of the result to a 50 percent increase in locomotive costs has been tested and is reported in Tables 2-31 and 2-32.

3. Diesel Fuel

The cost of diesel fuel is rising daily, and it is extremely difficult to predict the future price trend due to the political pressures outside the U.S. It should be noted that during 1979, the price

TABLE 2-29

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
50 PERCENT INCREASE IN CATENARY COST
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts) 237-259	222-271	167-337	Whole Route	Normal Electrification
Initial					
Catenary	21.153	47.113	149.817	216.363	224.005
Locomotives	60.55	55.65	46.90	43.4	150.00
Locomotives transferred	(7.01)	(12.79)	(23.10)	(27.23)	(78.37)
Net total	74.693	89.973	173.617	232.533	295.685
Annual					
Diesel fuel saving	(7.6)	(13.6)	(31.6)	(45.2)	(46.4)
Electrical energy	1.56	2.61	6.53	8.66	9.0
Locomotive maintenance	(0.76)	(1.91)	(4.02)	(4.89)	(11.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(0.96)	(1.7)	(3.08)	(3.63)	(10.45)
Net saving	7.71	14.52	31.85	44.59	58.98
ROI	10.3	16.1	18.3	19.2	19.9

TABLE 2-30

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
50 PERCENT INCREASE IN CATENARY COST
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts) 68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	Normal Electrification
Initial						
Catenary	49.683	93.145	209.68	341.944	385.160	418.189
Locomotives	47.6	44.45	42.0	40.25	39.9	114.00
Locomotives transferred	(14.025)	(17.74)	(20.625)	(22.69)	(23.1)	(38.775)
Net total	83.258	119.855	231.055	359.154	401.96	493.414
Annual						
Diesel fuel saving	(16.00)	(24.27)	(40.87)	(56.43)	(40.11)	(60.51)
Electrical energy	2.00	3.80	6.65	9.67	10.512	10.503
Locomotive maintenance	(5.18)	(6.31)	(6.42)	(8.27)	(8.393)	(20.58)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(1.87)	(2.365)	(2.75)	(3.02)	(3.08)	(5.17)
Net saving	20.896	28.813	42.585	56.739	59.621	74.267
ROI	25.1	24.0	18.4	15.8	14.8	15.05

TABLE 2-31

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
50 PERCENT INCREASE IN LOCOMOTIVE COSTS
(IN 1980 $M)

Cost Element	Extent of Electrification (Milepost)				Normal Electrification
	237-259	222-271	167-337	Whole Route	
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	90.825	83.47	70.35	65.10	225.0
Locomotives transferred	(7.01)	(12.79)	(23.10)	(27.23)	(78.37)
Net total	97.92	102.9	147.13	182.11	296.0
Annual					
Diesel fuel saving	(7.6)	(13.6)	(31.6)	(45.2)	(46.4)
Electrical energy	1.56	2.61	6.53	8.66	9.0
Locomotive maintenance	(0.76)	(1.91)	(4.02)	(4.89)	(11.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(0.96)	(1.7)	(3.08)	(3.63)	(10.45)
Net saving	7.71	14.52	31.85	44.59	58.98
ROI	7.9	14.1	21.6	24.5	19.9

TABLE 2-32

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
50 PERCENT INCREASE IN LOCOMOTIVE COSTS
(IN 1980 $M)

Cost Element	Extent of Electrification (Milepost)					Normal Electrification
	68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	
Initial						
Electrification	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	71.4	66.675	63.0	60.375	59.85	172.5
Locomotives transferred	(21.03)	(26.61)	(30.94)	(34.03)	(34.65)	(58.16)
Net total	83.492	102.162	171.849	254.308	281.973	393.133
Annual						
Diesel fuel saving	(16.00)	(24.27)	(40.87)	(56.43)	(40.11)	(60.51)
Electrical energy	2.00	3.80	6.65	9.67	10.512	10.503
Locomotive maintenance	(5.18)	(6.31)	(6.42)	(8.27)	(8.393)	(20.58)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(2.805)	(3.55)	(4.125)	(4.53)	(4.62)	(7.755)
Net saving	21.831	29.998	43.96	58.249	61.161	76.852
ROI	26.1	29.4	25.6	22.9	21.7	19.5

of diesel fuel almost doubled. While it is unlikely that the price will double each year, it is unrealistic to assume that the price of diesel fuel will only rise to keep pace with the general price level (GPL), which was the assumption made in the baseline economic analysis.

A sensitivity analysis was conducted assuming that the price of diesel fuel increased at the rate of 4 percent per year above the GPL (assumed to be zero) for the 30-yr life of the project. The resulting ROI's are shown in Tables 2-33 and 2-34.

4. Electrical Energy

Because of the diverse nature of the base energy sources (oil, coal, natural gas, hydro, and nuclear) used to produce electricity, the cost of electrical energy is much less sensitive to increases in any one raw material cost than is diesel fuel. The increase in electrical energy costs will vary from utility to utility, depending on the need to renew, renovate, or extend capital plant. However, at least one utility has raised rates to large consumers by less than the GPL for the mid-1979 to mid-1980 period. This is expected to be the exception rather than the rule. To account for a possible increase in electrical energy costs, the economic analysis has been repeated assuming an inflation rate for electrical energy of 4 percent above GPL. The results are presented in Tables 2-35 and 2-36.

5. Traffic Growth

The baseline analysis assumes that the traffic levels on the two routes under consideration remain constant over the next thirty years. However, the traffic density is subject to many forces, such as competition from alternate forms of transportation, state of the economy, political pressures, etc. To test for these variables, the economic analysis has been repeated assuming traffic levels changes of ±2 percent per year over the thirty-year life of the project, normalized to the mid-year level. This analysis required the redefinition of the route characteristics for the two routes under consideration, and this is identified in Tables 2-37 through 2-40. The results of the economic analysis are contained in Tables 2-41 through 2-44.

6. Locomotive Utilization

To determine the size of the locomotive fleet required to haul the assumed level of traffic, average data have been used. This is clearly a potential source of error, and therefore the sensitivity of the result was tested. The results are reported in Tables 2-45 through 2-48 for ±20 percent variation in locomotive utilization from the baseline value.

7. Locomotive Life

The economic life of a diesel locomotive is assumed to be 15 years. To test the sensitivity of the result to the assumed life of the locomotive, the economic analysis was repeated assuming a locomotive life of 20 years. These results are shown in Tables 2-49 and 2-50.

Results of Economic Analysis

A summary of the economic analysis of the application of DML's and conventional electric locomotives to the two selected routes is given in Table 2-51; this table shows that the end result is most sensitive to a variation in the price of diesel fuel, and as the extent of electrification increases, the DML result is also sensitive to the cost of electrification.

The significant result of this economic analysis is that it shows that the application of DML's to two routes with differing characteristics, which results in an ROI comparable to that of conventional electrification for an initial outlay reduced by up to 30 percent for a fully electrified railroad. This is reflected in Figure 2-31.

A summary of the sensitivity analysis is given in Table 2-52, which shows that the DML economics are particularly sensitive to diesel fuel prices. All other variations produce only a limited variation in ROI.

This economic analysis will be updated at the conclusion of this study if it is determined through further work that the assumptions made to complete the economic analysis were significantly erroneous. The updated analysis will include testing the sensitivity of the result to diesel fuel costs.

TABLE 2-33

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
DIESEL FUEL INFLATION 4 PERCENT PER YEAR ABOVE GPL
(IN 1980 $M)

Cost Element	Extent of Electrification 237-259	222-271	167-337	Whole Route	Normal Electrification
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	60.55	55.65	46.90	43.4	150.00
Locomotives transferred	(7.01)	(12.79)	(23.10)	(27.23)	(78.37)
Net total	67.64	74.27	123.68	160.41	221.00
Annual					
Diesel fuel saving	(13.68)	(24.5)	(56.9)	(81.4)	(83.56)
Electrical energy	1.56	2.61	6.53	8.66	9.0
Locomotive maintenance	(0.76)	(1.91)	(4.02)	(4.89)	(11.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(0.96)	(1.7)	(3.08)	(3.63)	(10.45)
Net saving	13.79	25.41	57.15	80.79	96.12
ROI	20.4	34.2	46.2	50.4	43.5

TABLE 2-34

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
DIESEL FUEL INFLATION 4 PERCENT PER YEAR ABOVE GPL
(IN 1980 $M)

Cost Element	Extent of Electrification 68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	Normal Electrification
Initial						
Electrification	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	47.6	44.45	42.0	40.25	39.9	114.00
Locomotives transferred	(14.025)	(17.74)	(20.625)	(22.69)	(23.1)	(38.775)
Net total	66.697	88.807	161.164	245.523	273.573	354.018
Annual						
Diesel fuel saving	(28.8)	(43.71)	(73.60)	(101.60)	(108.3)	(108.97)
Electrical energy	2.00	3.80	6.65	9.67	10.512	10.503
Locomotive maintenance	(5.18)	(6.31)	(6.42)	(8.27)	(8.393)	(20.58)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(1.87)	(2.365)	(2.75)	(3.02)	(3.08)	(5.17)
Net saving	33.696	48.253	75.315	101.909	107.811	122.727
ROI	50.5	54.3	46.7	41.5	39.4	34.7

TABLE 2-35

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
ELECTRICAL ENERGY INFLATION 4 PERCENT PER YEAR ABOVE GPL
(IN 1980 $M)

Cost Element	Extent of Electrification 237-259	222-271	167-337	Full Electrification	Conventional Electrification
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	60.55	55.65	46.90	43.4	150.00
Locomotives transferred	(7.01)	(12.79)	(23.10)	(27.23)	(78.37)
Net total	67.64	74.27	123.68	160.41	221.00
Annual					
Diesel fuel saving	(7.6)	(13.6)	(31.6)	(45.2)	(46.4)
Electrical energy	2.81	4.7	11.76	15.60	16.21
Locomotive maintenance	(0.76)	(1.91)	(4.02)	(4.89)	(11.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(0.96)	(1.7)	(3.08)	(3.63)	(10.45)
Net saving	6.46	12.42	26.62	37.65	51.75
ROI	9.5	16.7	21.5	23.5	23.4

TABLE 2-36

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
ELECTRICAL ENERGY INFLATION 4 PERCENT PER ANNUM ABOVE GPL
(IN 1980 $M)

Cost Element	Extent of Electrification 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	Conventional Electrification
Initial						
Electrification	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	47.6	44.45	42.0	40.25	39.9	114.00
Locomotives transferred	(14.025)	(17.74)	(20.625)	(22.69)	(23.1)	(38.775)
Net total	66.697	88.807	161.164	245.523	273.573	354.018
Annual						
Diesel fuel saving	(16.00)	(24.27)	(40.87)	(56.43)	(60.11)	(60.51)
Electrical energy	3.60	6.84	11.98	17.41	18.93	18.92
Locomotive maintenance	(5.18)	(6.31)	(6.42)	(8.27)	(8.393)	(20.58)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(1.87)	(2.365)	(2.75)	(3.02)	(3.08)	(5.17)
Net saving	19.296	25.773	38.87	48.999	51.503	65.85
ROI	28.9	29.0	24.1	20.0	18.8	18.6

TABLE 2-37
CHARACTERISTICS OF HARRISBURG-PITTSBURGH
DIESEL, DML, AND ELECTRIC OPERATION
2 PERCENT PER YEAR DECREASE IN TRAFFIC

Characteristics	Diesel		Dual-Mode Locomotive Location of Catenary 237-259		222-271		167-337		Full Electrification		Conventional Electrification	
	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
Trailing tons	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220
Number of lomotives	2.55	3.9	2.23	3.63	2.0	3.4	1.35	3.2	1.1	3.1	1.12	2.48
Journey time, min	475	352	475	352	475	352	475	352	475	352	475	352
Number of trains/yr	7971	7971	7971	7971	7971	7971	7971	7971	7971	7971	7971	7971
Annual fuel consumption, mgal	15.6	18.87	12.85	15.97	10.63	13.75	3.94	7.06	0.37	0.52	--	--
Annual electrical energy consumption, gwh	--	--	26.75	37.89	46.81	60.93	124.83	145.0	158.3	199.0	164.9	206.5
Annual locomotive miles	5.08	7.77	4.44	7.24	3.98	6.78	2.69	6.37	2.19	8.31	2.22	4.94
Locomotives per 1000 million ton-miles	6.8										3.6	
Fleet size	142		129		118		100		93		75	
Surplus locomotives	--		13		24		42		49		142	
Catenary 4 track	--		22		49		64		77		85	
Catenary 3 track	--		--		--		102		160		160	
Catenary 2 track	--		--		--		--		5		5	

TABLE 2-38

CHARACTERISTICS OF HARRISBURG - PITTSBURGH
DIESEL, DML, AND ELECTRIC OPERATION
2 PERCENT INCREASE IN TRAFFIC PER YEAR

Characteristics	Diesel		Dual-Mode Locomotive Location of Catenary: 237-259		222-271		167-337		Full Electrification		Conventional Electrification	
	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
Trailing tons	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220	5220
Number of locomotives	2.55	3.9	2.23	3.63	2.0	3.4	1.35	3.2	1.1	3.1	1.12	2.48
Journey time, min	475	352	475	352	475	352	475	352	475	352	475	352
Number of trains/yr	14438	14438	14438	14438	14438	14438	14438	14438	14438	14438	14438	14438
Annual fuel consumption, mgal	28.3	34.2	23.3	28.9	19.2	24.9	7.1	12.8	0.7	0.9	--	--
Annual electrical energy consumption, gwh	-	-	48.5	68.6	84.8	110.0	226.0	262.0	287.0	361.0	299.0	374.0
Annual locomotive miles	9.2	14.1	8.05	13.1	7.2	12.3	4.87	11.5	3.9	11.2	4.0	8.9
Locomotives per 1000 million ton-miles	6.8										3.6	
Fleet size	256		233		214		180		167		135	
Surplus locomotives	--		23		42		76		89		256	
Catenary 4 track	--		22		49		64		77		85	
Catenary 3 track	--		--		--		102		160		160	
Catenary 2 track	--		--		--		--		5		5	

TABLE 2-39

CHARACTERISTICS OF LOS ANGELES-SALT LAKE CITY
DIESEL, DML, AND ELECTRIC OPERATION COMBINED OPERATION
2 PERCENT DECREASE IN TRAFFIC PER YEAR

Characteristics	Diesel		Dual-Mode Locomotive Location of Catenary										Conventional Electrification	
			68-107 211-254		17-48 68-107 209-281 668-703		7-51 68-111 183-351 417-450 498-532 652-759		7-51 66-137 182-766		7-780			
	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SCL	SCL-LA
Trailing tons	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600
Number of trains/yr	2548	2548	2548	2548	2548	2548	2548	2548	2548	2548	2548	2548	2548	2548
Annual fuel consumption, mgal	25.0	20.6	16.1	16.8	12.7	14.1	7.5	7.0	1.3	1.7	0.15	0.15	--	--
Annual electrical consumption, gwh	--	--	72.1	10.3	119.7	36.6	160.8	112.6	227.8	169.8	245.6	186.6	242.0	189.8
Annual locomotive miles X 10^{-6}	10.7	10.3	8.5	7.5	7.8	7.19	7.0	6.8	6.8	6.6	6.72	6.6	4.26	4.08
Locomotives/10^9 ton miles	6.8												3.6	
Fleet size	126		101		94		89		85		85		57	
Surplus locomotives	--		25		32		37		39		39		126	
Catenary 2 track	--		39		39		43		71		101		101	
Catenary 1 track	--		43		138		386		628		672		676	
Passing siding	--		--		--		--		--		--		100	

TABLE 2-40

CHARACTERISTICS OF LOS ANGELES-SALT LAKE CITY
DIESEL, DML, AND ELECTRIC OPERATION COMBINED OPERATION
2 PERCENT INCREASE IN TRAFFIC PER YEAR

Characteristics	Diesel		Dual-Mode Locomotive, Location of Catenary: 68-107, 211-254		17-48, 68-107, 209-281, 668-703		7-51, 68-111, 183-351, 417-450, 498-532, 652-759		7-51, 66-137, 182-766		7-780		Conventional Electrification	
	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SLC	SLC-LA	LA-SCL	SCL-LA
Trailing tons	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600
Number of trains/yr	4660	4660	4660	4660	4660	4660	4660	4660	4660	4660	4660	4660	4660	4660
Annual fuel consumption, mgal	43.7	37.4	29.1	30.5	22.9	25.6	13.6	12.7	2.4	3.0	.03	.03	--	--
Annual electrical consumption, gwh	--	--	130.5	18.6	217.	66.3	291.1	203.8	412.5	307.5	444.7	337.8	438.2	343.7
Annual locomotive miles X 10^{-6}	194.	18.6	15.4	13.6	14.19	12.6	12.7	12.3	12.3	12.0	12.2	12.0	7.7	8.1
Locomotives/10^9 ton-miles	6.8												3.6	
Fleet size	228		183		171		161		154		153		102	
Surplus locomotives	--		45		57		67		74		75		228	
Catenary 2 track	--		39		39		43		71		101		101	
Catenary 1 track	--		43		138		386		628		672		676	
Passing siding	--		--		--		--		--		--		100	

TABLE 2-41

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
DECREASE IN TRAFFIC LEVEL
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts) 237-259	222-271	167-337	Whole Route	Normal Electrification
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	44.8	41.181	34.71	32.12	111.00
Locomotives transferred	(5.18)	(9.465)	(17.09)	(20.15)	(57.99)
Net total	53.722	63.125	117.498	156.212	202.38
Annual					
Diesel fuel saving	(5.6)	(10.1)	(23.4)	(33.4)	(34.3)
Electrical energy	1.15	1.93	4.83	6.41	6.66
Locomotive maintenance	(0.56)	(1.41)	(2.97)	(3.62)	(8.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(0.71)	(1.26)	(2.28)	(2.68)	(7.73)
Net saving	6.73	10.75	23.5	32.82	43.48
ROI	12.5	17.0	20.0	21.0	21.5

TABLE 2-42

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
INCREASE IN TRAFFIC LEVEL
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts) 237-259	222-271	167-337	Whole Route	Normal Electrification
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	81.37	74.571	62.846	58.156	201.00
Locomotives transferred	(9.39)	(17.139)	(30.95)	(36.488)	(105.016)
Net total	86.082	88.841	131.774	165.91	245.354
Annual					
Diesel fuel saving	(10.2)	(18.22)	(42.34)	(60.57)	(62.18)
Electrical energy	2.09	3.49	8.75	11.6	12.06
Locomotive maintenance	(1.02)	(2.56)	(5.39)	(6.55)	(15.54)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(1.29)	(2.27)	(4.13)	(4.86)	(14.00)
Net saving	10.37	19.47	42.79	59.91	79.611
ROI	12.04	21.9	32.47	36.10	32.45

TABLE 2-43

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
DECREASE IN TRAFFIC
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts)					Normal Electrification
	68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	
Initial						
Electrification	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	34.87	32.564	30.76	29.487	29.23	83.516
Locomotives transferred	(10.27)	(12.996)	(15.11)	(16.62)	(16.92)	(28.407)
Net total	57.722	81.665	155.44	240.83	269.083	333.902
Annual						
Diesel fuel saving	(11.72)	(17.78)	(29.9)	(41.3)	(44.04)	(44.33)
Electrical energy	1.46	2.78	4.87	7.08	7.701	7.69
Locomotive maintenance	(3.79)	(4.62)	(4.7)	(6.06)	(6.149)	(15.07)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(1.387)	(1.73)	(2.01)	(2.21)	(2.26)	(3.787)
Net saving	15.266	21.018	30.935	41.178	43.298	54.0
ROI	26.4	25.7	19.9	17.1	16.1	16.2

TABLE 2-44

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
INCREASE IN TRAFFIC
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts)					Normal Electrification
	68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	
Initial						
Electrification	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	63.77	59.55	56.27	53.93	53.46	152.74
Locomotives transferred	(18.79)	(23.76)	(27.63)	(30.4)	(30.9)	(51.95)
Net total	78.102	97.887	168.429	251.493	279.333	379.583
Annual						
Diesel fuel saving	(21.44)	(32.52)	(54.766)	(75.62)	(80.55)	(81.08)
Electrical energy	2.68	5.092	8.911	12.96	14.086	14.074
Locomotive maintenance	(6.94)	(8.45)	(8.6)	(11.08)	(11.25)	(27.577)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(2.506)	(3.169)	(3.685)	(4.046)	(4.13)	(6.928)
Net saving	28.052	38.715	57.335	76.745	80.394	98.021
ROI	35.9	39.6	34.0	30.5	28.8	25.8

TABLE 2-45

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
DECREASE IN LOCOMOTIVE UTILIZATION
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts) 237-259	222-271	167-337	Whole Route	Normal Electrification
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	72.66	66.78	56.28	52.08	180.00
Locomotives transferred	(8.41)	(15.348)	(27.72)	(32.676)	(94.044)
Net total	78.352	82.841	128.438	163.646	235.326
Annual					
Diesel fuel saving	(7.6)	(13.6)	(31.6)	(45.2)	(46.4)
Electrical energy	1.56	2.61	6.53	8.66	9.0
Locomotive maintenance	(0.76)	(1.91)	(4.02)	(4.89)	(11.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(1.152)	(2.04)	(3.696)	(4.356)	(12.54)
Net saving	7.902	14.85	32.466	45.316	61.05
ROI	10.1	17.9	25.3	27.7	25.9

TABLE 2-46

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
INCREASE IN LOCOMOTIVE UTILIZATION
(IN 1980 $M)

Cost of Element	Extent of Electrification (Mileposts) 237-259	222-271	167-337	Whole Route	Normal Electrification
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	48.44	44.52	37.52	34.72	120.00
Locomotives transferred	(5.61)	(10.232)	(18.48)	(21.784)	(62.696)
Net total	56.932	65.697	118.918	157.178	206.674
Annual					
Diesel fuel saving	(7.6)	(13.6)	(31.6)	(45.2)	(46.4)
Electrical energy	1.56	2.61	6.53	8.66	9.0
Locomotive maintenance	(0.76)	(1.91)	(4.02)	(4.89)	(11.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(0.768)	(1.36)	(2.46)	(2.90)	(8.36)
Net saving	7.518	14.17	31.23	43.86	56.87
ROI	13.2	21.6	26.3	27.9	27.5

TABLE 2-47

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
DECREASE IN LOCOMOTIVE UTILIZATION
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts)					Normal Electrification
	68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	
Initial						
Electrification	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	57.12	53.34	50.4	48.3	47.88	136.8
Locomotives transferred	(16.83)	(21.288)	(24.75)	(27.228)	(27.72)	(46.53)
Net total	73.412	94.149	165.439	249.035	276.933	369.063
Annual						
Diesel fuel saving	(16.00)	(24.27)	(40.87)	(56.43)	(60.11)	(60.51)
Electrical energy	2.00	3.80	6.65	9.67	10.512	10.503
Locomotive maintenance	(5.18)	(6.31)	(6.42)	(8.27)	(8.393)	(20.58)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(2.244)	(2.838)	(3.30)	(3.624)	(3.696)	(6.204)
Net saving	21.27	29.286	43.135	57.343	60.237	75.301
ROI	29.0	31.1	26.1	23.0	21.8	20.4

TABLE 2-48

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
INCREASE IN LOCOMOTIVE UTILIZATION
(IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts)					Normal Electrification
	68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	
Initial						
Electrification	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	38.08	35.56	33.60	32.20	31.92	91.2
Locomotives transferred	(11.22)	(14.192)	(16.5)	(18.125)	(18.48)	(31.02)
Net total	59.982	83.465	156.889	242.011	270.213	338.973
Annual						
Diesel fuel saving	(16.00)	(24.27)	(40.87)	(56.43)	(60.11)	(60.51)
Electrical energy	2.00	3.80	6.65	9.67	10.512	10.503
Locomotive maintenance	(5.18)	(6.31)	(6.42)	(8.27)	(8.393)	(20.58)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(1.496)	(1.892)	(2.20)	(2.416)	(2.464)	(4.136)
Net saving	20.522	28.34	42.035	56.135	59.005	73.233
ROI	34.2	34.0	26.8	23.2	21.8	21.6

TABLE 2-49

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO HARRISBURG-PITTSBURGH
INCREASE IN LOCOMOTIVE LIFE (IN 1980 $M)

Cost Element	Extent of Electrification (Mileposts) 237-259	222-271	167-337	Whole Route	Normal Electrification
Initial					
Catenary	14.102	31.409	99.878	144.242	149.37
Locomotives	60.55	55.65	46.90	43.40	150.00
Locomotives transferred	(7.01)	(12.79)	(23.10)	(27.23)	(78.37)
Net total	67.64	74.27	123.68	160.41	221.00
Annual					
Diesel fuel saving	(7.6)	(13.6)	(31.6)	(45.2)	(46.4)
Electrical energy	1.56	2.61	6.53	8.66	9.0
Locomotive maintenance	(0.76)	(1.91)	(4.02)	(4.89)	(11.6)
Catenary maintenance	0.05	0.09	0.32	0.47	0.49
Saving in locomotive replacement	(0.72)	(1.275)	(2.31)	(2.72)	(7.84)
Net saving	7.47	14.095	31.08	43.68	56.37
ROI	11.0	19.0	25.1	27.2	25.5

TABLE 2-50

ECONOMIC ANALYSIS OF APPLICATION OF DML'S TO LOS ANGELES-SALT LAKE CITY
INCREASE IN LOCOMOTIVE LIFE (IN 1980 $M)

Cost of Element	Extent of Electrification (Mileposts) 68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole Route	Normal Electrification
Initial						
Electrification	33.122	62.097	139.789	227.963	256.773	278.793
Locomotives	47.6	44.45	42.0	40.25	39.9	114.00
Locomotives transferred	(14.025)	(17.74)	(20.625)	(22.69)	(23.1)	(38.775)
Net total	66.697	88.807	161.164	245.523	273.573	354.018
Annual						
Diesel fuel saving	(16.00)	(24.27)	(40.87)	(56.43)	(60.11)	(60.51)
Electrical energy	2.00	3.80	6.65	9.67	10.512	10.503
Locomotive maintenance	(5.18)	(6.31)	(6.42)	(8.27)	(8.393)	(20.58)
Catenary maintenance	0.154	0.332	0.805	1.311	1.45	1.49
Saving in locomotive replacement	(1.4025)	(1.774)	(2.062)	(2.265)	(2.31)	(3.877)
Net saving	20.429	28.22	41.90	55.984	58.851	72.974
ROI	30.6	31.8	26.0	22.8	21.5	20.6

TABLE 2-51

SUMMARY OF PRELIMINARY ECONOMIC ANALYSIS*

	Return on Investment (percent)										
	Harrisburg-Pittsburgh					Los Angeles-Salt Lake City					
	Dual-Mode Locomotive Location of Catenary (Mileposts)					Dual-Mode Locomotive Location of Catenary (Mileposts)					
Sensitivity	237-259	222-271	167-337	Whole Route	Normal Electrification	68-107 211-254	17-48 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	7-780	Normal Electrification
Baseline	11.4	19.6	25.8	27.8	26.7	31.2	32.4	26.4	23.1	21.8	21.0
Electrification + 50 percent	10.3	16.1	18.3	19.2	19.9	25.1	24.0	18.4	15.8	14.8	15.5
Locomotive costs + 50 percent	7.9	14.1	21.6	24.5	19.9	26.1	29.4	25.6	22.9	21.7	19.5
Diesel fuel + 4 percent per annum	20.4	34.2	46.2	50.4	43.5	50.5	54.3	46.7	41.5	39.4	34.7
Electrical energy + 4 percent per annum	9.5	16.7	21.5	23.5	23.4	28.9	29.0	24.1	20.0	18.8	18.6
Traffic growth - 2 percent per annum	12.5	17.0	20.0	21.0	21.5	26.4	25.7	19.9	17.1	16.1	16.2
Traffic growth + 2 percent per annum	12.04	21.9	32.5	36.1	32.45	35.9	39.6	34.0	30.5	28.8	25.8
Locomotive utilization - 20 percent per annum	10.1	17.9	25.3	27.7	25.9	29.0	31.1	26.1	23.0	21.8	20.4
Locomotive utilization + 20 percent per annum	13.2	21.6	26.3	27.9	27.5	34.2	34.0	26.8	23.2	21.8	21.6
Locomotive life, 20 yr	11.0	19.0	25.1	27.2	25.5	30.6	31.8	26.0	22.8	21.5	20.6

*The final ecomonic analysis is contained in Section 7 of this report.

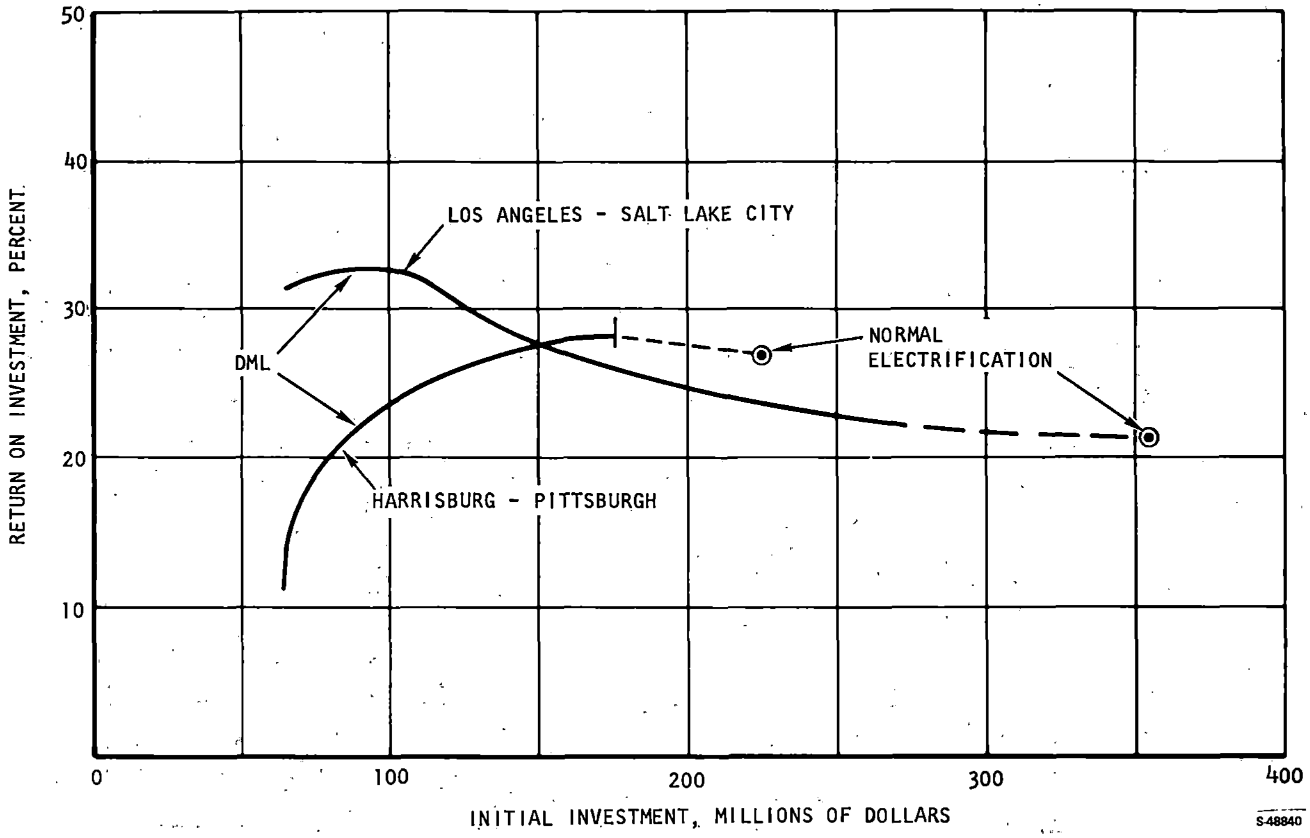


Figure 2-31. Variation of ROI with Initial Investment (Baseline)

TABLE 2-52

SENSITIVITY ANALYSIS SUMMARY

Sensitivity		Typical Variation in ROI	
		Whole Route DML, percent	Conventional Electrification, percent
Electrification	+50 percent	-30.0	-26.0
Locomotive costs	+50 percent	-11.8	-26.0
Diesel fuel	+4 percent per yr	+81.3	+62.9
Electrical energy	+4 percent per yr	-15.5	-12.4
Traffic growth	-2 percent per yr	-24.5	-19.5
Traffic growth	+2 percent per yr	+26.3	+21.7
Locomotive utilization	-20 percent	- 0.3	- 3.0
Locomotive utilization	+20 percent	+ 0.4	+ 3.0
Locomotive life	20 yr	- 2.2	- 4.5

LOCOMOTIVE POPULATION

The most likely method of DML deployment is by retrofitting the existing diesel locomotives. Therefore, it is necessary to determine the distribution of locomotive types and ages for those railroads which may, in the future, consider electrification. Information on their locomotive fleet broken down by model and age was requested from the following railroads.

(a) Atchison Topeka and Santa Fe (AT&SF)

(b) Burlington Northern (BN)

(c) Chessie

(d) Chicago and North Western (C&NW)

(e) Chicago Milwaukee St. Paul and Pacific (CMSP&P)

(f) Consolidated Rail Corporation (Conrail)

(g) Duluth Missabe and Iron Range (DMIR)

(h) Louisville and Nashville (L&N)

(i) Missouri Pacific (Mopac)

(j) Norfolk and Western (N&W)

(k) Seaboard Coast Line (SCL)

(l) Southern (SOU)

(m) Southern Pacific (SP)

(n) Union Pacific (UP)

The data that were received are described in Appendix A, and are summarized in Tables 2-53 and 2-54 for the EMD and GE locomotives, respectively. It was judged that since the ALCO locomotives were a small and diminishing population, it was not necessary to report on their numbers. Further analysis of the data provided a more specific summary as given in Table 2-55.

PROTOTYPE SELECTION

The economic analysis previously reported confirmed the desirability of developing the concept of a DML further, in fact to the stage where a prototype could be evaluated in railroad service. The survey of locomotive population among selected railroads shows that the leading contenders for a long-term retrofit program are:

- SD40-2
- SD45
- GP38-2

The prototype DML should be based on one of these models, and it is the recommendation of this study that the prototype be based on the EMD SD40-2. This recommendation was made to FRA early in the study and was accepted.

TABLE 2-54

SUMMARY OF GE LOCOMOTIVE POPULATION

	U23B		B23-7		U25B		U28B		U30B		B30-7		U33B		U36B		U23C		U25C		U28C		U30C		C30-7		U33C		U36C		TOTAL	
	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age
AT&SF	49	9.5	40	1.35	-	-	-	-	-	-	-	-	-	-	-	-	20	11.0	-	-	10	14.0	6	11.0	89	1.9	25	11.0	154	6.5	393	6.08
BN	-	-	-	-	30	15.5	16	13.8	15	13.3	-	-	-	-	-	-	11	11.0	69	14.8	-	-	177	5.4	147	1.8	34	10.7	-	-	499	10.8
CHESSIE	30	11.0	-	-	27	17.0	-	-	35	7.0	20	2.0	-	-	-	-	-	-	-	-	-	-	13	13.0	-	-	-	-	-	-	125	9.9
C & NW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CMSP & P	5	6.7	-	-	11	14.7	12	13.9	6	13.0	-	-	-	-	-	-	-	-	-	-	-	-	8	5.4	-	-	3	12.0	4	7.8	49	11.2
Conrail	99	6.2	141	1.1	161	5.3	2	13.6	56	12.3	-	-	79	10.8	4	3.3	19	9.1	20	14.3	15	13.2	10	12.7	10	2.1	39	11.4	13	7.3	668	6.8
DMIR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L&N	97	12.8	15	3.0	27	16.4	3	14.0	6	13.3	-	-	-	-	-	-	-	-	28	15.1	-	-	77	8.8	36	1.0	-	-	-	-	289	10.3
Mopac	38	5.0	70	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	35	8.9	-	-	-	-	-	-	143	4.04
N&W	-	-	-	-	-	-	-	-	4	10.0	-	-	-	-	-	-	-	-	-	-	-	-	3	6.0	80	1.4	-	-	-	-	87	1.95
SCL	-	-	40	1.75	-	-	-	-	19	13.0	-	-	28	12.0	106	9.0	-	-	17	16.0	3	15.0	4	14.0	16	1.0	-	-	7	9.0	240	8.6
SOU	53	6.7	20	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	13.0	-	-	10	9.0	-	-	327	6.1
SP	-	-	-	-	2	4.5	-	-	-	-	83	1.3	-	-	-	-	-	-	-	-	-	-	37	11.8	-	-	205	8.8	-	-	327	7.2
UP	-	-	-	-	-	-	20	14.0	-	-	-	-	-	-	-	-	-	-	-	-	6	14.0	149	5.9	100	1.1	-	-	-	-	275	8.75
Total	371	8.7	326	5.6	258	9.3	53	13.8	141	11.2	103	1.4	107	11.1	110	8.8	50	10.3	134	14.9	34	13.7	524	7.3	478	1.5	316	9.5	178	6.7	3183	7.5

TABLE 2-53

SUMMARY OF EMD LOCOMOTIVE POPULATION

	GP30		GP35		GP38		GP38-2		GP38AC		GP39		GP39X		GP39-2	
	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age
AT&SF	80	17.5	156	14.0	59	10.0	-	-	-	-	-	-	-	-	96	4.3
BN	54	17.4	40	15.4	6	10.0	32	6.6	-	-	-	-	-	-	-	-
CHESSIE	112	17.6	85	15.0	130	12.3	-	-	-	-	20	11.0	-	-	-	-
C & NW	22	N/A	39	N/A	-	-	-	-	-	-	-	-	-	-	-	-
CMSP & P	16	16.7	11	14.9	-	-	16	5.8	-	-	-	-	-	-	-	-
Conrail	82	17.0	197	15.1	281	9.8	339	5.1	-	-	-	-	-	-	-	-
DMIR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L&N	68	17.4	19	16.0	50	9.4	108	6.9	-	-	-	-	-	-	-	-
Mopac	-	-	48	15.5	42	15.3	219	4.5	-	-	-	-	-	-	-	-
N&W	53	18.0	77	15.9	-	-	-	-	-	-	-	-	-	-	-	-
SCL	34	17.0	15	16.0	-	-	77	5.9	-	-	-	-	-	-	-	-
SOU	115	17.5	72	16.1	114	10.8	257	5.5	56	9.0	-	-	6	0.0	-	-
SP	16	17.0	160	11.3	-	-	-	-	-	-	-	-	-	-	-	-
UP	148	17.5	24	16.0	-	-	60	5.7	-	-	-	-	-	-	-	-
Total	800	17.5	943	14.4	682	10.8	1108	5.4	56	9.0	20	11.0	6	0.0	96	4.3

	GP40		GP40-2		GP40X		GP50		SD24		SD26		SD35		SD38		SD38-2	
	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age
AT&SF	-	-	-	-	10	2.0	-	-	-	-	79	5.5	-	-	-	-	-	-
BN	40	12.7	-	-	-	-	-	-	15	21.0	-	-	-	-	-	-	-	-
CHESSIE	216	10.6	272	5.2	-	-	-	-	-	-	-	-	41	16.0	-	-	-	-
C & NW	-	-	-	-	-	-	50	0.0	-	-	-	-	-	-	-	-	10	N/A
CMSP & P	72	12.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Conrail	265	11.8	110	1.8	-	-	-	-	-	-	-	-	46	14.7	35	9.6	-	-
DMIR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	N/A	5	N/A
L&N	29	13.3	-	-	-	-	-	-	-	-	-	-	32	15.1	-	-	5	5.0
Mopac	-	-	-	-	-	-	10	0.0	-	-	-	-	-	-	-	-	-	-
N&W	60	13.5	-	-	-	-	-	-	-	-	-	-	78	15.0	-	-	-	-
SCL	133	12.0	25	6.0	-	-	-	-	-	-	-	-	17	15.5	-	-	-	-
SOU	-	-	-	-	3	2.0	70	0.0	-	-	-	-	108	14.8	-	-	-	-
SP	8	14.0	49	1.4	4	2.0	-	-	-	-	-	-	27	9.2	-	-	-	-
UP	51	12.4	-	-	6	2.0	-	-	-	-	-	-	-	-	-	-	-	-
Total	874	11.8	456	4.0	23	2.0	130	0.0	15	21.0	79	5.5	349	14.6	43	9.6	20	5.0

	SD39		SD40		SD40-2		SD45		SD45-2		DD35		DD40X		TOTAL	
	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age	No.	Age
AT&SF	20	11.0	-	-	104	1.7	119	12.0	88	7.8	-	-	-	-	811	8.6
BN	-	-	31	10.0	481	3.1	173	10.7	-	-	-	-	-	-	872	11.9
CHESSIE	-	-	83	12.2	20	3.0	-	-	-	-	-	-	-	-	979	11.4
C & NW	-	-	38	N/A	135	N/A	61	N/A	-	-	-	-	-	-	355	N/A
CMSP & P	-	-	-	-	89	6.6	10	11.6	-	-	-	-	-	-	214	11.4
Conrail	-	-	115	11.8	166	1.5	173	12.4	13	7.1	-	-	-	-	1822	9.8
DMIR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	N/A
L&N	-	-	34	10.6	139	3.2	-	-	-	-	-	-	-	-	484	10.8
Mopac	-	-	90	9.7	306	3.1	-	-	-	-	-	-	-	-	715	8.0
N&W	-	-	45	11.7	144	4.2	115	11.7	-	-	-	-	-	-	572	11.6
SCL	-	-	-	-	36	0.75	38	11.5	15	6.0	-	-	-	-	572	12.9
SOU	-	-	29	9.55	119	5.3	68	12.3	-	-	-	-	-	-	1017	8.6
SP	26	11.4	88	13.8	169	1.9	348	11.9	243	6.8	-	-	-	-	1138	9.2
UP	-	-	244	12.3	621	3.1	50	12.0	-	-	18	15.3	45	10.0	1267	8.06
Total	46	11.2	797	11.7	2529	4.8	1155	11.8	359	7.0	18	15.3	45	10.0	10649	9.3

TABLE 2-55

LOCOMOTIVE POPULATION SUMMARY

Model	Number	Average Age, yr	Percent of Total
SD35	349	14.0	2.9
SD40	797	11.7	6.6
SD40-2	2,529	4.8	21.0
SD45	1,155	11.8	9.6
SD45-2	359	7.0	3.0
GP30	800	17.5	6.6
GP35	943	14.4	7.8
GP38	682	10.8	5.7
GP38-2	1,108	5.4	9.2
GP40	874	11.8	7.2
GP40-2	456	4.0	3.8
U30C	524	7.3	4.3
U30-7	478	1.5	4.0
U33C	316	9.5	2.6
U23B	371	8.7	3.1
B23-7	326	1.3	2.7
TOTAL	12,067	8.9	100.1

NOTES: 1. Based on survey of 14 railroads
2. Only models with more than 300 in sample included in this table

SECTION 3

BASELINE CONCEPT

CATENARY VOLTAGE

Following the modern-day precedents in Europe, Africa, Asia, and Australia, main line railroad electrification in the United States will be at industrial frequency, resulting in 60-Hz ac supply to the locomotive. The variable still to be defined in the baseline concept, however, is the voltage at which the catenary will be electrified. This is almost exclusively a question of economics since the two standard voltages of 25 and 50 kv are equally acceptable from both the technical and safety viewpoints. Although the catenary system for a 50-kv scheme has been estimated to be 7 percent more expensive than for a 25 kv-scheme (see Reference 6), a substantial savings can be achieved in the number of substations required over a given route. Experience with 50-kv operation has been as follows:

Black Mesa & Lake Powell (BM & LP)--This railroad was opened in 1974, and is located in Northern Arizona. It was the first railroad to be electrified at 50 kv, and currently operates using six General Electric E60C locomotives. The design analysis that led to the selection of the 50-kv version shows that the system would require either three 25-kv substations or one 50-kv substation.

South African Railways (SAR)--Originally built and electrified for exclusive use by the South African Iron and Steel Industrial Corporation (ISCOR), this is the first major 50-kv railroad electrification with a total route length of 530 miles and train loadings and performance similar to operations in the U.S. In addition to the iron ore duty, SAR plans to make extensive use of the line for general freight traffic. The original design study showed that the line would require six 50-kv substations or up to twenty-four 25-kv substations.

Both of these railroads were purpose-built and are located in barren, desolate country, where the achievement of 50-kv standard clearances, as shown in Table 3-1, does not impose any undue technical or financial penalties. This is similar to many of the railroads operating in the western U.S., although highway bridges may present an occasional problem. In the eastern U.S., however, the more closely spaced centers of population means significant penalties to the railroad attempting to electrify at 50 kv rather than 25 kv. This has led to the general opinion that railroads west of Chicago will electrify at 50 kv, while those to the east will electrify at 25 kv.

TABLE 3-1

STANDARD CLEARANCES FOR RAILROAD ELECTRIFICATION

	Clearance, in.	
	25 kv	50 kv
Static	8.0	16.0
Passing	6.5	13.0

The catenary voltage level impacts the locomotive design in two basic areas--roof equipment and main tranformer. These items will be specifically addressed during the later stages of the study.

OPERATIONAL CHARACTERISTICS

In general, the operating characteristics of the DML are constrained to be similar to the base locomotive to which the retrofit has been applied. There are, however, significant areas of improvement and compromise that are the results of the retrofit. In most cases, the result is a locomotive that combines the best characteristics of the diesel and the electric locomotives.

POWER SOURCES

The DML is capable of operating with either the onboard diesel engine or a high-voltage ac catenary as the power source. The power rating of the diesel engine will be between 2000 and 3000 traction hp, depending on the base locomotive; for all six-axle locomotives, it is the output from this engine that determines the power rating of the locomotive in the diesel mode.

During electric operation, the locomotive takes power from the catenary and therefore the power rating of the locomotive can be reconsidered. It is proposed that the existing traction motors (D77's) from the base locomotive be utilized. These traction motors have a rating of 536 kw (input) when operated from the main alternator, with a ripple level of 3 percent. In the electric mode with a ripple level of 10 percent (maintained at this level by the smoothing inductor), the traction motor rating will remain at 536-kw input, thereby giving a locomotive power rating of 3880 rail hp. The traction motor power rating is discussed in more detail later in the report.

METHODS OF DEPLOYMENT

There are two methods of deployment available to railroads whether the railroad is already electrified or not: (1) the alternative to conventional electric locomotives, and (2) the complementary to electric locomotives.

Alternative to Conventional Electric Locomotives

The basic differences between the DML and an electric locomotive are the lower power rating of the DML, which results in an increased fleet size and higher maintenance costs of the DML. These DML disadvantages have been compensated for in the economic analysis to the extent that the ROI for DML deployment can be higher than that for conventional electrification. The major operational characteristic that could not be factored into the economic analysis was the superior flexibility of the DML when compared to the electric locomotive. One of the few disadvantages of railroad electrification is the resulting relatively inflexible operating system that is wholly dependent not only on the integrity of the electric locomotive design (which due to the lower number of moving parts is inherently superior to the diesel locomotive), but also on the integrity of the catenary system (which can be subjected to failures caused by highway vehicles at grade crossing; animals - particularly birds; climatic extremes - particularly temperature, snow, and wind; and maintenance requirements that may restrict normal train movement), and on the utility distribution system (almost completely out of the control of the railroad and dependent of the strength and ability of the utility to supply the railroad and other users with some capacity to spare). The DML, by retaining the diesel engine, enables this disadvantage to be overcome and results in the improvement of flexible railroad operations because diesel fuel dependency is reduced, and because the diesel engine rather than the catenary can be used in the event of a wayside system problem (albeit at a reduced speed in some cases).

Following an initial deployment such as this, the railroad could gradually electrify the remaining portions of the railroad, as described in Section 2 of this report. Having achieved full electrification, the DML's can gradually be retired in favor of the conventional electric locomotive, at which time the DML would become complementary to the electric locomotive.

Complementary to Electric Locomotives

There are many examples on an electrified railroad of trains starting or finishing their journeys off the electrified main line. The major traffic that remains on the electrified route could be handled using conventional electric locomotives, and the other traffic could make use of DML's. In this way, maximum use is made of the catenary, and dependence on diesel fuel is greatly reduced.

A comprehensive economic analysis of this method of deployment has not been made, but it is clear that the initial cost of the modification would be offset by the reduced energy costs and reduced maintenance (since the diesel engine would be shut down when the locomotive was on standby and would only use a small percentage of the duty cycle to supply power).

LOCOMOTIVE WEIGHT

The existing SD40-2 locomotive has a base weight of 368,000 lb, which may be increased by ballasting or using a heavy underframe at the railroads option to 416,000 lbs, although most railroads have a maximum locomotive weight limitation of 395,000 lb. This lower locomotive weight is dictated typically by considerations of bridge strength and is particularly prevalent in the eastern states. The ultimate objective of the DML design is to achieve the overall locomotive weight of 395,000 lb, with an attendant maximum axle load of 68,000 lb and a maximum imbalance between bolster loads of 5,000 lb.

LOCOMOTIVE HEIGHT

To retain the same degree of flexibility for the DML as the basic locomotive, it is necessary to achieve the same overall height in the diesel mode, i.e, with the pantograph down, as in the base locomotive. This requires recessing the roof equipment (pantograph, vacuum circuit breaker, etc.) so that the new equipment, with the pantograph down, is no higher than the highest part of the basic locomotive; in the case of the SD40-2, it is nominally 15 ft, 7-1/4 in. from top of rail to the cooling fan guard. This design objective is easier to achieve on the 25-kv version than the 50-kv version and is described in detail later in Section 4.

The impact of increasing the overall locomotive height will present the most problems at maintenance and terminal facilities. This area of concern must be examined by each railroad to determine the acceptability of the increased height.

LOCOMOTIVE OPERATING RANGE

During the investigation of the effect of power to weight ratio on train performance, calculations were made of the fuel consumption required for both the standard diesel and the dual-mode locomotives. These data are summarized in Tables 3-2 and 3-3. In both cases, it is probable that the most likely minimum deployment of DML's would be the second case considered (based on ROI) for which the fuel consumption is reduced by 25 to 32 percent for the hp/ton values applicable to those routes. The permissible reduction in fuel tank capacity that could be permitted while still maintaining the overall range of the locomotive is application dependent and must be evaluated for each case separately. However, for the purposes of this study, it has been assumed that, if necessary, the fuel tank capacity may be reduced by 30 percent (i.e., a 30-percent reduction in length) to locate electric mode equipment and/or achieve weight balance.

TABLE 3-2

COMPARISON OF ROUND-TRIP FUEL CONSUMPTION FOR HARRISBURG-PITTSBURGH ROUTE USING DIESEL AND DUAL-MODE LOCOMOTIVES

Number of Locomotives	Diesel Locomotive, gal	Location of Catenary for Dual-Mode Locomotive, Milepost							
		237-259		222-271		167-337		Whole Route	
		gal	Percent reduction	gal	Percent reduction	gal	Percent reduction	gal	Percent reduction
9	6357	5563	12.5	5260	17.3	3530	44.5	118	98.1
7	5863	5077	13.4	4563	22.2	2925	49.9	98	98.3
5	5014	4471	11.0	3844	23.3	2288	54.4	84	98.3
3	4238	3644	14.0	3187	24.8	1618	61.8	69	98.4
2	3869	3249	16.0	2824	27.0	1294	66.6	57	98.5

TABLE 3-3

COMPARISON OF ROUND-TRIP FUEL CONSUMPTION FOR LOS ANGELES-SALT LAKE CITY ROUTE USING DIESEL AND DUAL-MODE LOCOMOTIVES

Number of Locomotives	Diesel Locomotive, gal	Location of Catenary for Dual-Mode Locomotive, milepost									
		68 to 107 211 to 254		17 to 48 68 to 107 209 to 281 688 to 703		7 to 51 68 to 111 183 to 351 417 to 450 498 to 532 652 to 759		7 to 51 66 to 137 182 to 766		Whole Route	
		gal	Percent reduction	gal	Percent reduction	gal	Percent reduction	gal	Percent reduction	gal	Percent reduction
9	21741	17857	17.9	14938	31.3	8409	61.3	1734	92.0	87	99.6
7	19825	16257	18.0	13570	31.6	7502	62.2	1533	92.3	80	99.6
5	17380	14314	17.6	11826	32.0	6555	62.3	1317	92.4	75	99.6
3	14592	11863	18.7	9906	32.1	5424	62.3	1078	92.6	43	99.7
2	13026	10383	20.3	8747	32.8	4787	63.3	978	92.5	65	99.5

ENGINEER INTERFACE

A design objective during the development of the DML will be to avoid changing the interface with the engineer, thus avoiding costly retraining. Converter control during electric mode operation will be achieved using train line signals currently available in the locomotive. Dynamic braking will be controlled in the same manner.

Changeover from electric mode to diesel mode and vice-versa may be accomplished either manually or automatically using track magnets, whichever is preferred by the railroad. The automatic system requires additional equipment that will require maintenance and will have a finite failure rate, whereas the manual system imposes yet another duty on the engineer. However, unless the automatic system is used, it will not be possible to M-U DML's with standard locomotives.

A fault annunciation panel will be required in the cab to inform the engineer of the status of the electric mode equipment on that locomotive. Certain fault indications will be trainlined to enable the general status of other locomotives to be determined.

Access between locomotives will be unaffected inasmuch as the running board along the engineer's side of the locomotive will be kept clear. However, it may be necessary to locate equipment on the nonengineer's side running board, thereby preventing access to that side of the locomotive while the locomotive is in motion. If this is unacceptable to the railroads, it is possible to provide a third door from the cab, which gives access to the non-engineer's side running board.

BRAKING

The existing locomotive braking systems (air and resistive) will be supplemented as an option by a regenerative braking capability when operating in the electric mode. The effectiveness of the regenerative brake in terms of energy savings is very much site specific and must be carefully evaluated against the increased cost of the electrical equipment.

POWER CIRCUIT

Diesel Locomotive Power Circuit

The power circuit of the DML is heavily constrained by the power circuit of the base locomotive. Before developing a power circuit suitable for both diesel and electric mode operation, it is necessary to understand the characteristics and limitations of the existing equipment. The SD40-2 power circuit, typical of a 6-axle EMD locomotive, is shown in Figure 3-1 in a simplified form. The following discussion is specifically aimed at that locomotive, but the principles could be applied to most U.S. locomotives.

Electrical power is derived from an engine-driven alternator running under power at speeds ranging from 490 to 900 rpm, depending on the notch selected by the engineer. At 900 rpm, the alternator output frequency is 120 Hz into the rectifier; from the rectifier, dc is supplied to the traction motor circuits. Alternator output voltage is controlled by varying the alternator excitation, thereby giving smooth, rapid, and efficient control of the current supplied to the traction motor circuits.

The required size of the alternator is minimized by the use of series-parallel transition (not used in the EMD 50 series locomotives), where at low road speed when the current requirement is high, the motors are connected in three parallel groups of two motors each in series. As the speed rises, the current requirement drops, and the voltage requirement increases until the maximum output voltage of the alternator is approached. At this stage, a transition occurs to reconnect all six traction motors in parallel across the alternator by dropping out the S-contactors (see Figure 3-1) and energizing the P-contactors. This forward transition has the effect of halving the alternator output voltage requirement, but doubling the current requirement. The variation of output current and voltage with speed is shown in Figure 3-2.

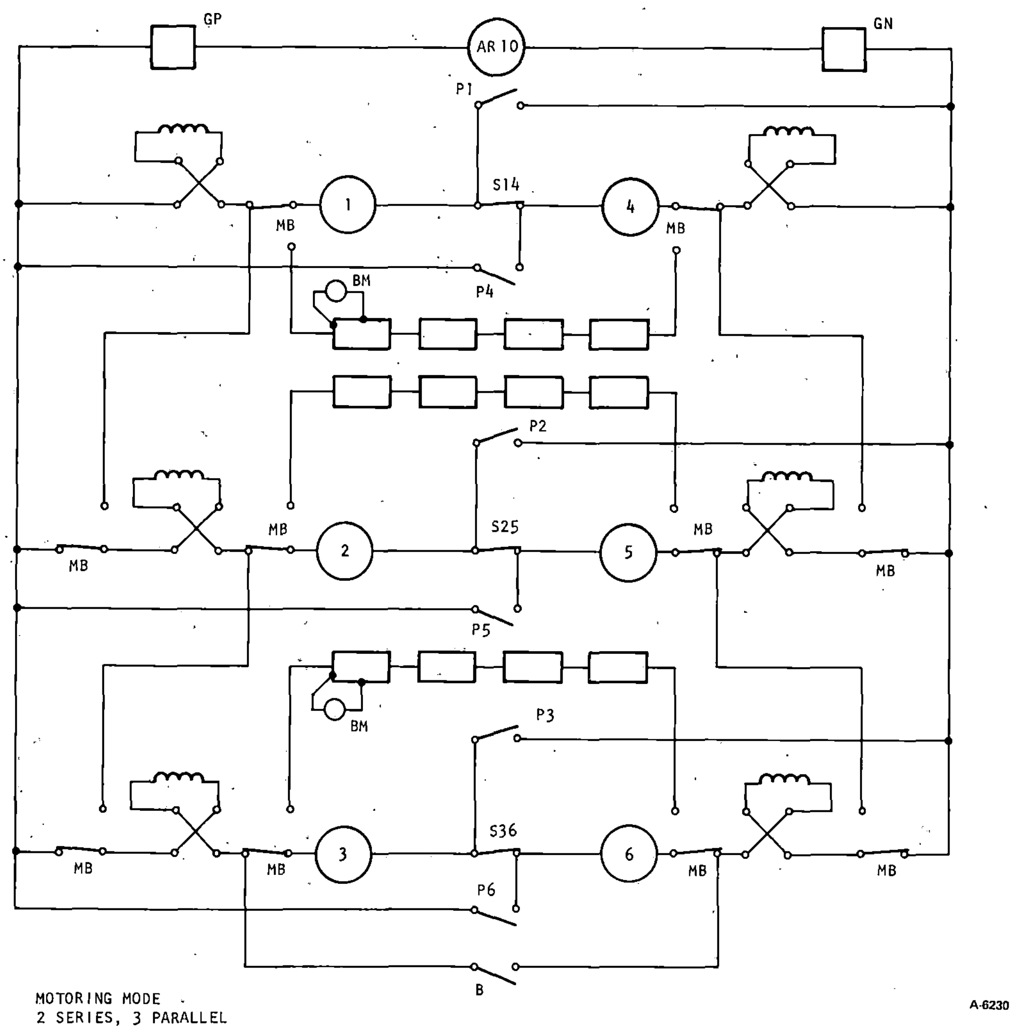


Figure 3-1. Simplified Diesel Locomotive Power Circuit

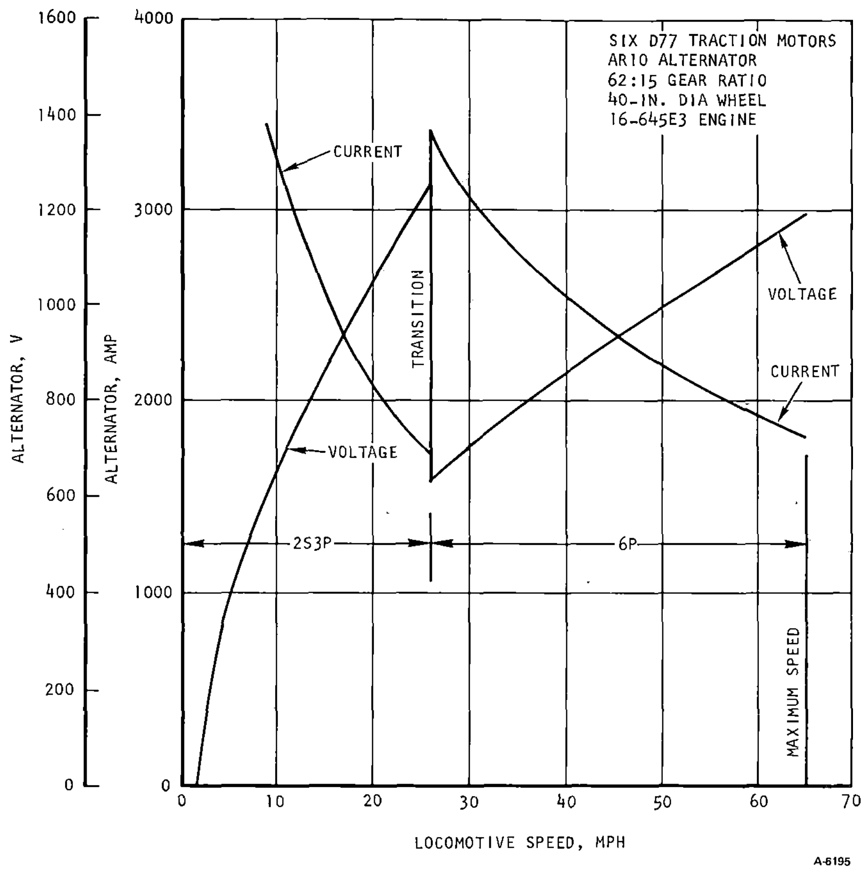


Figure 3-2. AR10 Output Characteristics (SD40-2)

The unusual feature of this circuit is the absence of field weakening of the traction motors at higher locomotive speeds to approximate constant power operation, which is achieved in this locomotive by continuously raising the applied voltage. The power circuit of the original SD40 did employ field weakening by external shunting, but this was found to cause flashovers. The problem became so acute that field weakening was completely eliminated and the system described above was introduced. The performance of this motor in the weak field mode is of major importance in the formulation of the concept of the DML, because in an electric mode operation, the upper voltage of the traction motors is fixed by the catenary voltage and transformer ratio. If it is necessary to hold that voltage at or near maximum speed, it is necessary to operate the converter at partial conduction over a wide speed range, resulting in possible difficulties associated with poor power factor and electromagnetic interference.

DML Power Circuit

Until the development of the thyristor as a device suitable for traction applications, voltage control of traction motors on a high voltage ac locomotive had been accomplished using a tap changer on the main locomotive transformer, operating on either the primary or secondary winding. This form of control resulted in notching peaks that could, under adverse circumstances, initiate a wheel spin. The advent of the thyristor has made smooth, notchless, and high response control of tractive effort possible. The thyristor converter, however, has two major drawbacks compared with tap changer control--lower power factor and higher levels of electromagnetic interference. Both of these problems can be addressed by the careful design of the converter to minimize external effects on the electrical system. On the positive side, the thyristor converter has many advantages over the tap changer. These include:

(a) Smooth tractive effort control
(b) Fast response
(c) Smaller and lighter transformer
(d) Lower maintenance
(e) Lower first cost

A considerable advantage is gained in the reduction of interference with the power supply system if a number of series bridges are used to control power, since this results in only a fraction of the current being chopped compared with the single bridge arrangement. Experience to date has shown that the optimum arrangement is the use of two controlled series bridges, representing the best compromise between the complexity of the locomotive control equipment and the necessary filtering equipment.

A conventional electric locomotive usually controls each motor, or at least each pair of motors, individually to maximize use of the available adhesion, particularly at starting. In the case of the DML, however, such a level of control is restricted due to the constraints of weight and volume imposed upon the converter. It is proposed, therefore, to retain the level of control existing on the base locomotive, i.e., all-axle control, where to reduce the tractive effort exerted by one traction motor, it is necessary to reduce the tractive effort applied by all motors. Furthermore, to minimize the size of the transformer, the series/parallel transition will be retained.

The final decision regarding the basic DML circuit is the high-speed operation of the traction motors. As previously discussed, the gradual field-weakening of the motor would permit constant power operation above base speed. The D77 is a noncompensated (no pole-face winding), solid iron (unlaminated) design. The influence of armature reaction on the shape of the main pole flux is not reduced as it is with a compensated machine, and the permissible amount of field weakening is determined mainly by the ratio of the armature winding turns per pole to the field winding turns and the shape of the main-pole air gap. Traction motors specifically designed for weak-field operation usually have a relatively large air gap arranged so that the gap length at the pole tips is approximately twice the gap length at the pole center. This is a compromise, however, since the features would increase both the machine frame size and the losses.

1. Nonregenerative DML

Using the considerations described above, the recommmended power scheme is shown in Figure 3-3. A high-voltage current is taken from the catenary via the pantograph to the vacuum circuit breaker, which affords both local fault protection and maintenance isolation. A lightning arrestor and primary overload current transformer are also provided. The main transformer has a single primary winding and two secondary windings, with each secondary winding connected to a half-controlled converter bridge, which are in turn connected in series with each other. A smoothing inductor is connected in series with the positive side of the converter output. The positive and negative sides of the transformed, rectified, and smoothed catenary supply are then connected in parallel with the output from the AR10 alternator by making connections at GP and GN. The remainder of the power circuit is identical to the existing diesel mode circuit.

Dynamic brake operation is shown in Figures 3-4 and 3-5. The armature circuit is identical to the existing diesel mode circuit, and the only modification to the field circuit is the paralleling of the alternator and transformer supplies to provide for operation in either mode.

2. Regenerative DML

The selected power scheme for a regenerative DML is shown in Figure 3-6. There are two areas of major impact compared to the nonregenerative version:

(a) A provision for a method of controlling field strength independent of the main transformer windings during brake

(b) A provision for an energy efficient method of compensating for differing wheel diameters and traction motor tolerances

Other differences compared with the nonregenerative option are the need for separate feed for dynamic brake blower motor, fully controlled bridges, and additional contactors.

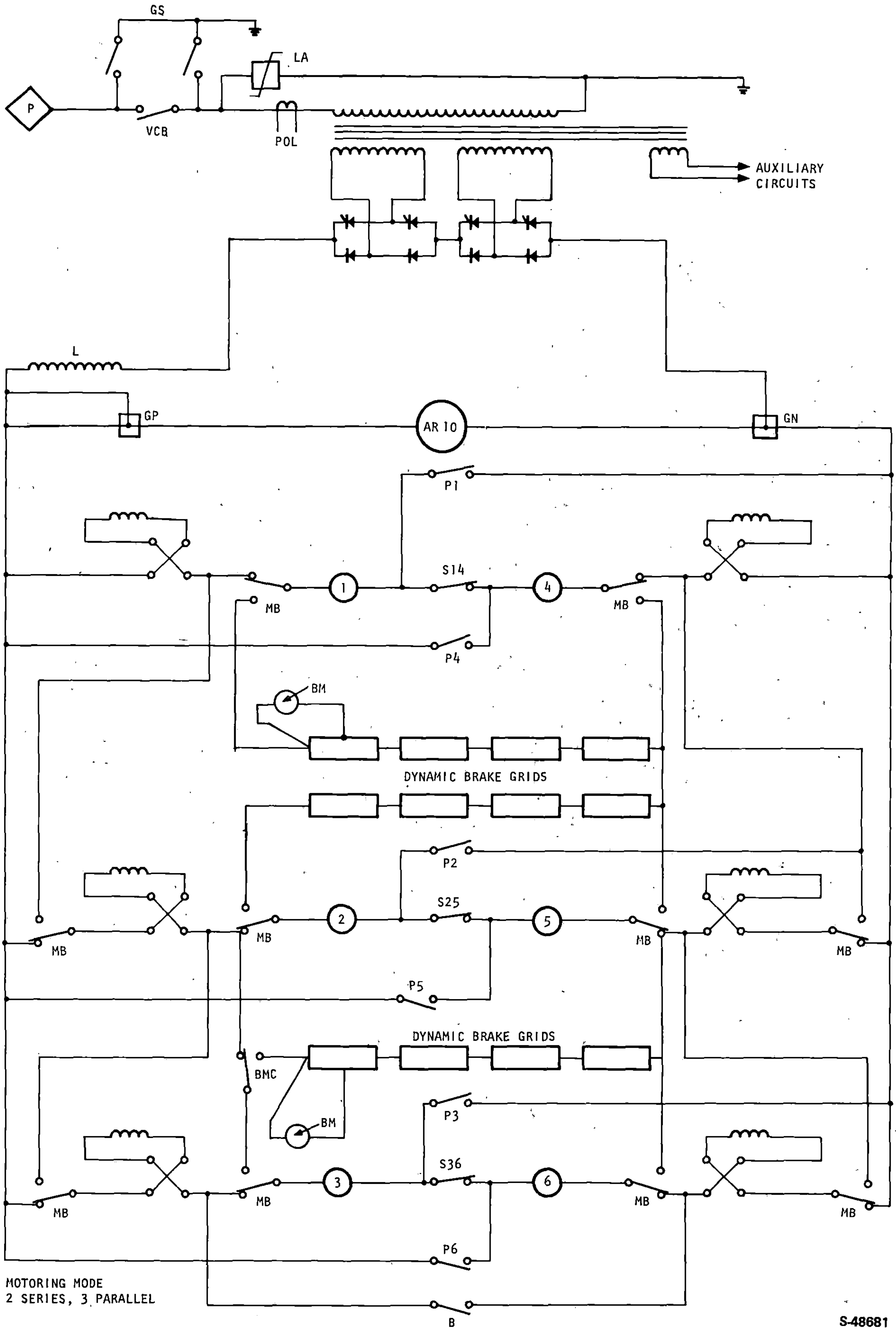


Figure 3-3. Simplified DML Power Schematic (Nonregenerative Option)

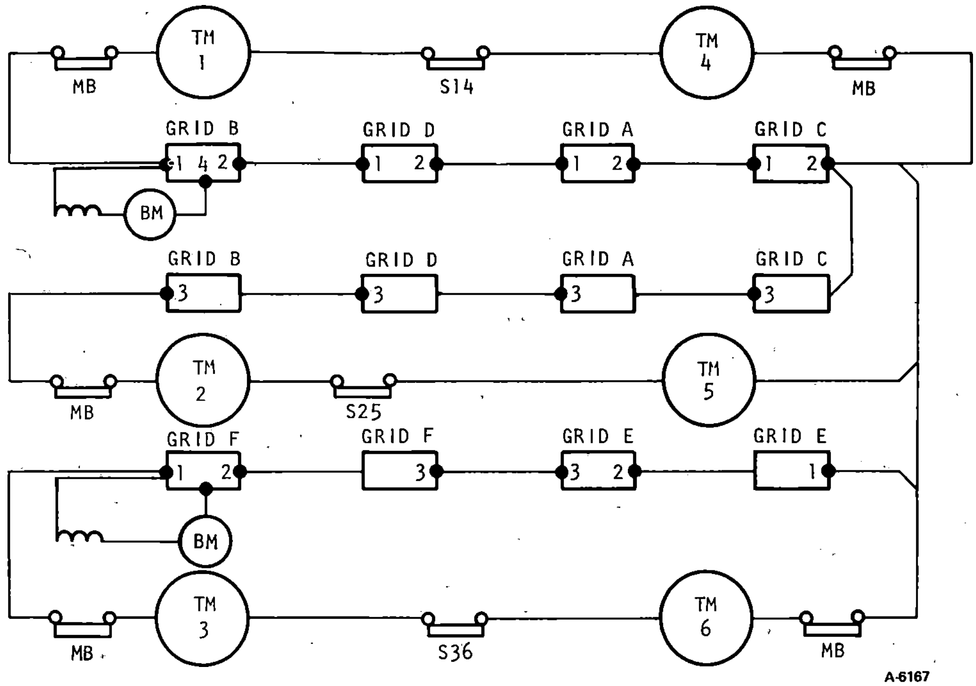


Figure 3-4. Armature Circuit Arrangement for Dynamic Braking Nonregenerative)

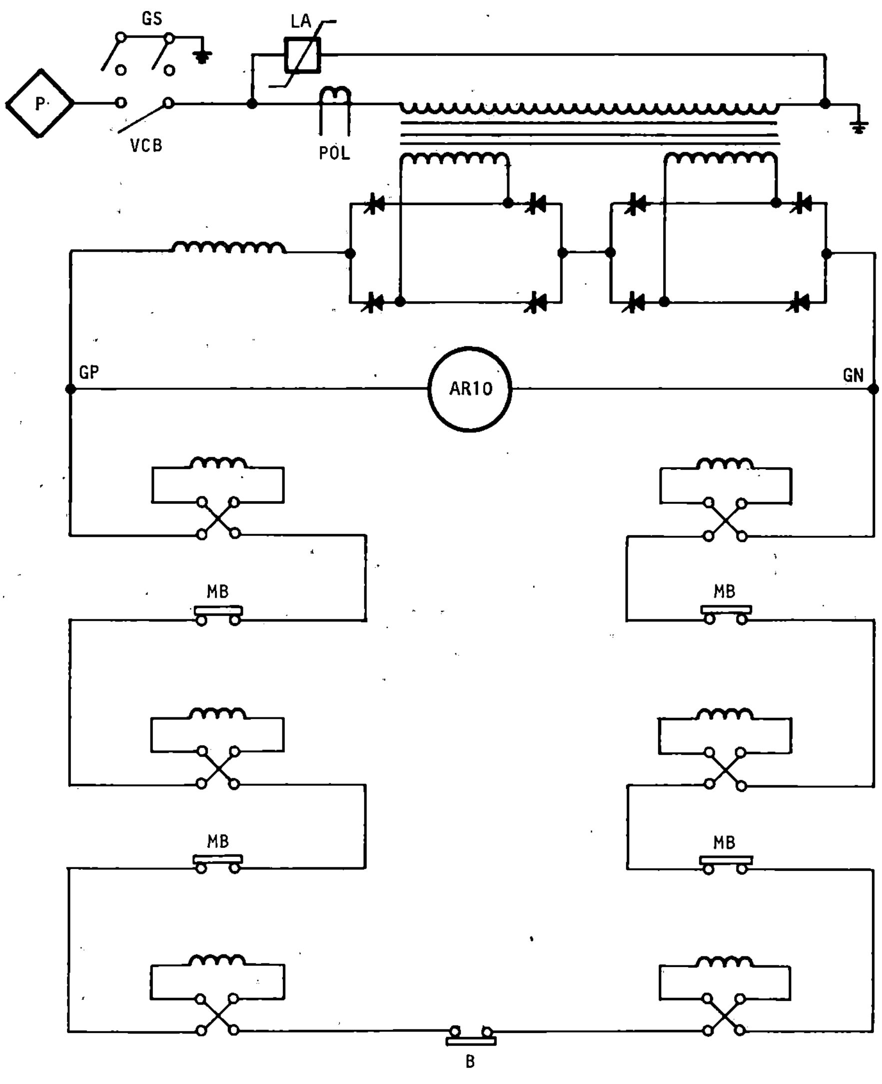


Figure 3-5. Traction Motor Field Connections for Dynamic Brake (Nonregenerative)

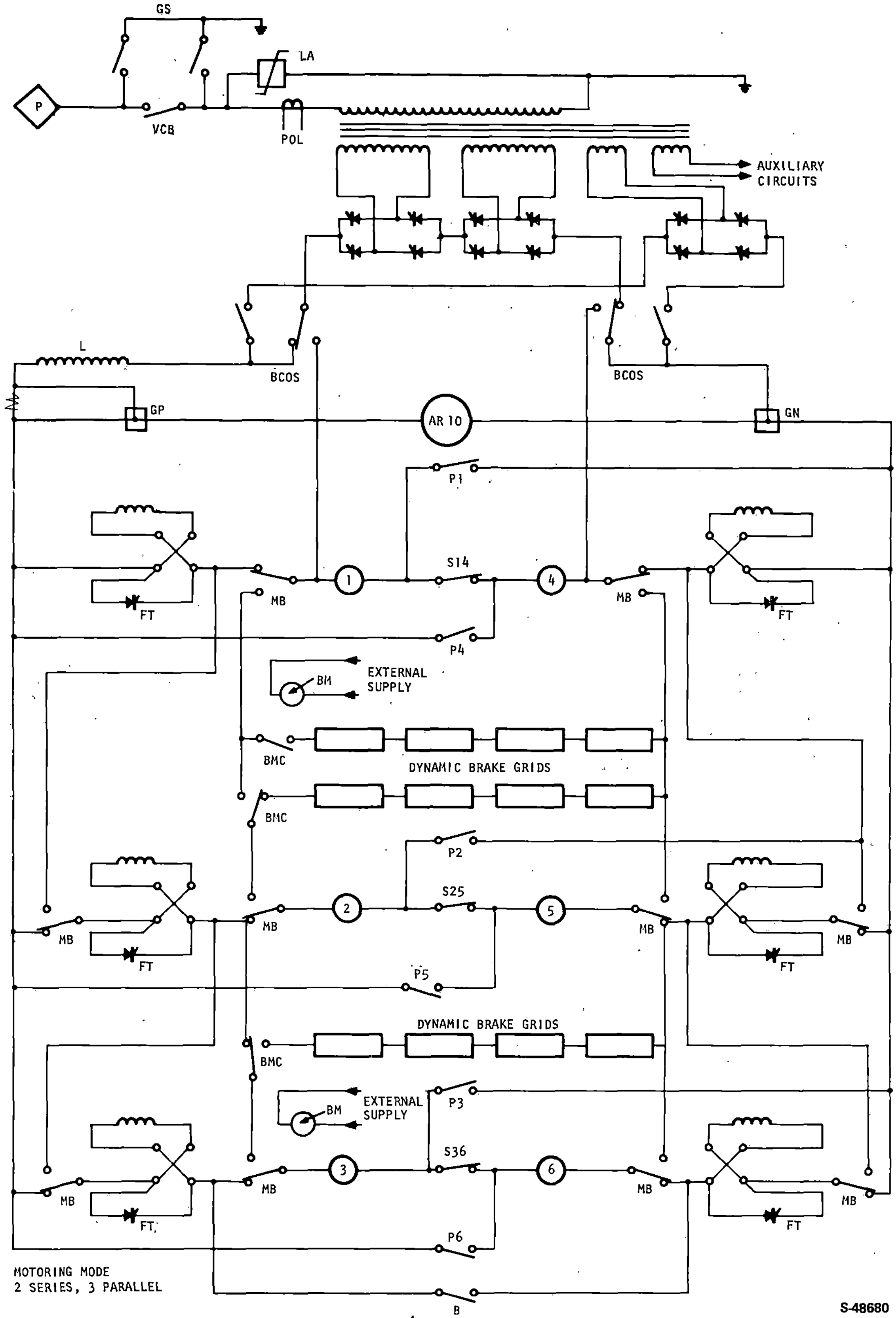


Figure 3-6. Simplified DML Power Schematic (Regenerative Option)

a. Field Supply

To provide a field power supply controlled independently from the armature circuits during regenerative brake, it is necessary to provide a separate transformer winding, auxiliary converter, and a brake changeover switch to separate the field and armature circuits as shown in Figures 3-7 and 3-8.

b. Tolerance Compensation

In any situation where machines are connected in parallel, it is necessary to provide some method of compensating for the permissible variation in machine characteristics and wheel diameters. In the existing resistive brake circuit, it is necessary to provide this compensation when the extended brake feature is employed, as shown in Figure 3-9. In this situation, grids B and F behave as stabilizing resistors compensating for imbalance between machines and for ensuring that the machines are always in the generator mode during brake. This solution would not be energy efficient during regenerative brake because of the energy to be dissipated in the stabilizing resistor (estimated to be approximately 25 percent of the output of the traction motors), and therefore an alternate method of stabilization would be desirable. Two options have been identified: (1) separately excite the traction motors, and (2) provide a method of controlled field shunting. The separate excitation of the traction motors involves the following:

(a) External power supply (an additional auxiliary load in both modes of approximately 40 kw (without forcing), which would involve the increase in rating at the transformer auxiliary winding, engine driven auxiliary alternator, and motor alternator set

(b) Field power conditioning equipment

(c) Additional auxiliary transformer on three-phase side of auxiliary

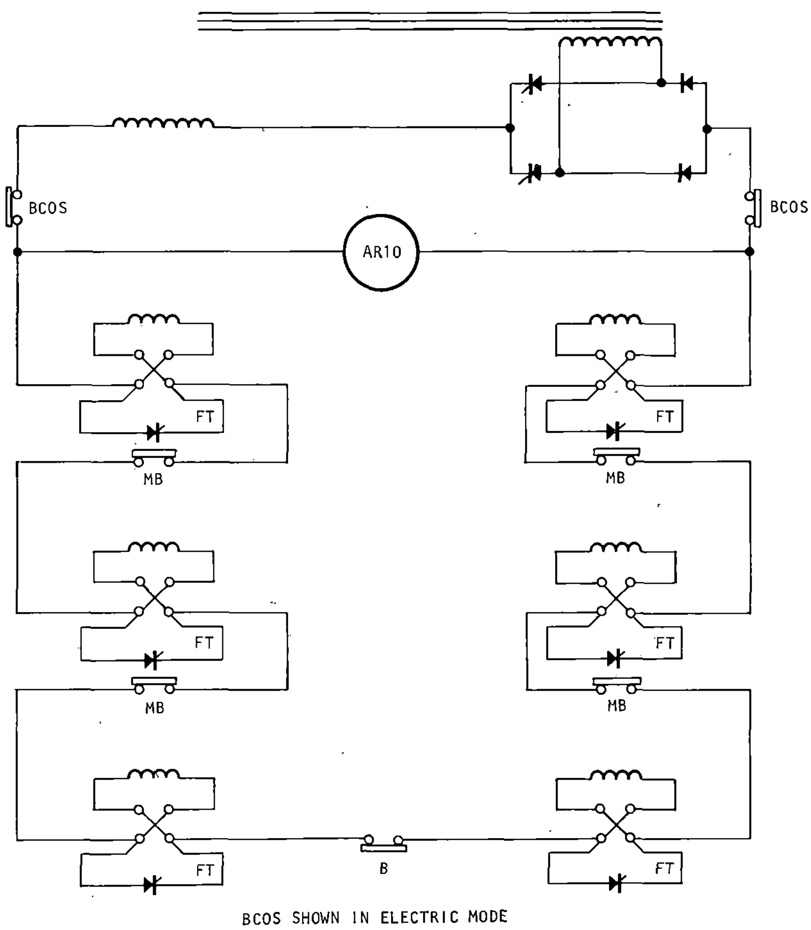


Figure 3-7. Traction Motor Field Connections During Dynamic Braking (Regenerative Option)

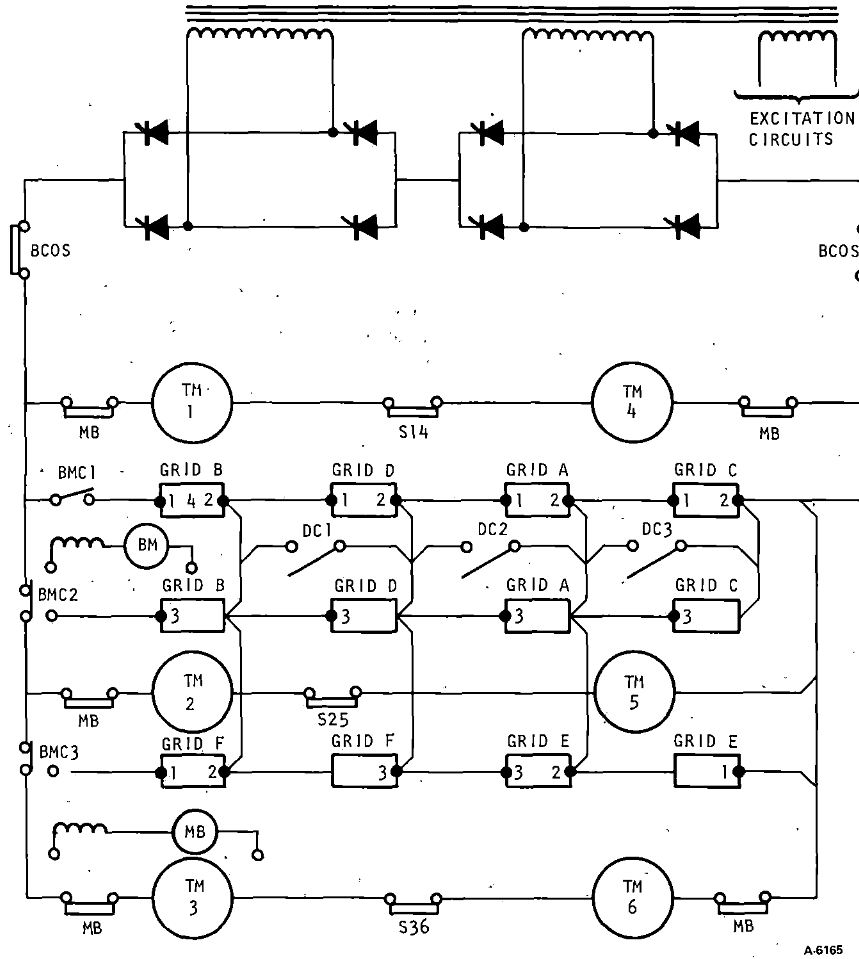


Figure 3-8. Armature Circuit Arrangement for Dynamic Braking (Regenerative)

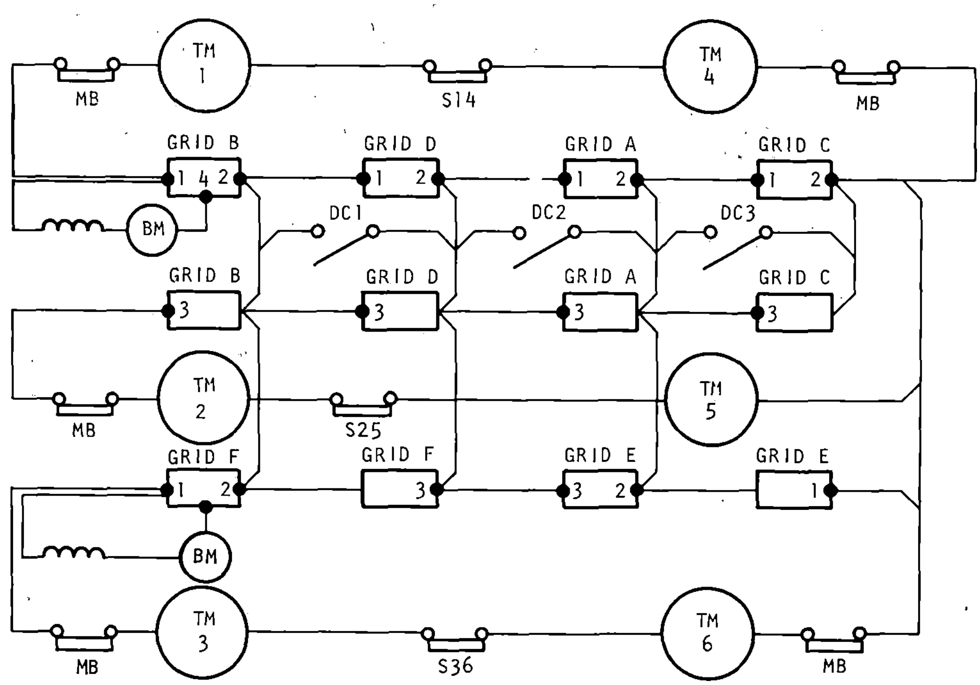


Figure 3-9. Typical Diesel Locomotive Extended Range Dynamic Brake Circuit

The alternate method of tolerance compensation is to provide a method of controlled field shunting that would effectively be a chopper connected across the terminals of the existing reverser switch. This system does not require an external power source, and it has fewer components than the separate excitation system. However, it does require force-commutated thyristors. The system schematic is shown in Figure 3-7; the field chopper effectively shorts the traction motor field in a controlled mark-space ratio determined by the current being taken by each motor.

Each method of tolerance compensation has the same technical result, and therefore the choice is simply one based on cost. The field shunting option is recommended on this basis.

ENERGY MANAGEMENT

The investigation of the variation in power/weight ratio allowed the data in Table 3-4 to be derived. This data show the significant cost advantage of electrically derived energy compared to diesel fuel derived energy, and simply reflect the rising cost of diesel fuel compared with electrical energy.

TABLE 3-4

COMPARISON OF FUEL AND ELECTRICAL ENERGY CONSUMPTION
FOR EQUAL JOURNEY TIME (AVERAGE)

Route	Diesel Fuel, Gal	Diesel Fuel, Dollars	Diesel Fuel, Dollars	Electrical Energy, Mwh	Electrical Energy, Dollars	Electrical Energy, Dollars
LA - SLC	9373	9373	17,398	94.02	1692	3,020
SLC - LA	8025	8025		73.75	1328	
H - P	2368	2368	4,325	25.91	466	838
P - H	1957	1957		20.69	372	

The DML design should be so that diesel fuel consumption, where possible, is minimized and particularly it would appear desirable to at least set the diesel engine to slow idle and possibly to shut down the engine altogether if the period of electric mode operation is to be significant. To shut down the diesel engine enroute raises its own particular problems, such as protection of the engine from hydraulic lock in the event of seal leakage during shutdown, and the condition of the battery and its ability to restart the diesel engine. Consideration of these problems must be compared to the penalty of consuming 3 to 5 gal/h of diesel fuel. The solution depends on the duty cycle. If the DML is used almost exclusively in the electric mode, then the diesel engine should be shut down during electric mode operation. However, if the locomotive is to be operated only for short periods (less than 60 min) in the electric mode, it would probably be advisable to allow the engine to idle. It is clear from comparing the cost of diesel fuel with that of electrical energy that it is not desirable to supply any of the auxiliary loads from the diesel engine, and therefore the impact of shutting down the diesel engine or allowing it to idle is independent of the question of auxiliary loads, which are discussed later.

POWER ENHANCEMENT

One of the advantages of the dual-mode locomotive is its ability to operate at a power level not restricted by the output of the diesel engine over those sections of the route, where this is desirable. The limitation on the locomotive power is the rating of the traction motors when operating in the electric mode and being supplied with current having a relatively high level of ripple. The GE 752 traction motors are currently used in the E44 and E50 locomotives, the latter having a rating of 550 kw, which supports the 536-kw rating assumed for the D77 in electric mode operation.

ADHESION UTILIZATION

The term adhesion, as used in railroading, is not synonymous with the coefficient of friction. The adhesion value assumed in calculations related to tractive effort has built into it a confidence level that is a measure of the confidence a dispatcher may have that a certain minimum value of the coefficient of friction will exist over the route in question. Because the adhesion level assumed is a subjective question, many railroads assume different values that represent experience, climate, terrain, speed, rail condition, etc. A selection of various railroads adhesion values is shown in Table 3-5.

TABLE 3-5

ADHESION LEVELS ASSUMED BY RAILROADS

Railroad	Adhesion Assumed Percent
AT & SF	20
Conrail	18
SCL	25
Southern	18
UP	20

The relationship between the tractive effort capability, adhesive weight, and speed of an SD40-2 using Air Brake Association data (Reference 3) is shown in Figure 3-10. At certain speeds, the unballasted SD40-2 is adhesion limited, whereas the fully ballasted version is not. For the adhesion values assumed, it would appear that the optimum weight of an SD40-2 would be approximately 396,000 lb. The critical speed range is during start-up. As soon as a train is underway and base speed (defined as the limit of constant current operation occasioned by the power limit) is reached, tractive effort drops very quickly and adhesion ceases to be a limitation at approximately 13 mph. Therefore, once a train is underway, it is almost always power limited in its operation since speed below 15 mph is uncommon except in cases of equipment failure.

Similarly, the DML suffers a theoretical adhesion limitation either side of base speed in both its minimum weight (395,000 lb) and fully ballasted (416,000 lb) conditions. However, as with the basic diesel locomotive, the adhesion restriction only applies at starting and has minimal impact on train performance. The adhesion limit assumes a certain variation in weight due to consumable supplies. The DML variation in weight will be less than a conventional diesel locomotive (referred to later in this report), and therefore a higher adhesion could be assumed for the same confidence level.

AUXILIARIES

The configuration of the auxiliary equipment must be so that it is compatible with operation in both the diesel and electric modes. This effectively eliminates consideration of engine driven auxiliaries such as air compressor and equipment blower since the engine, at best, will be at idle speed during electric mode operation brake and may be shut down altogether. Therefore, it is necessary to review the configuration and performance of the existing diesel locomotive and then establish an acceptable, compatible system for the DML.

Diesel Locomotive Auxiliaries

Since the diesel engine is the only energy source on the locomotive, all auxiliaries must be either directly or indirectly driven by that engine. Certain auxiliary loads are exclusive to the diesel mode such as radiator fans and main generator excitation, and need not be considered since they are supplied by the engine-driven D14 alternator. Auxiliaries that require consideration are:

- (a) Main compressor
- (b) Equipment blower
- (c) Battery charging, lighting, and control

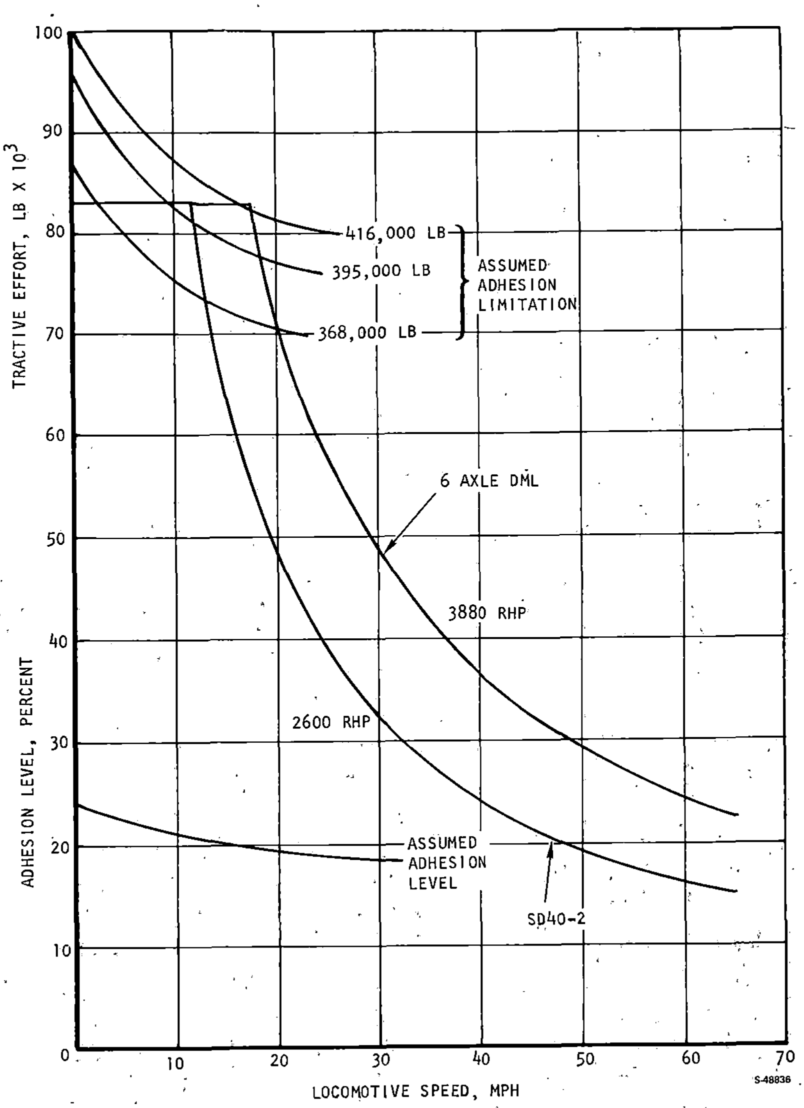


Figure 3-10. Relationship Between Tractive Effort Capability, Adhesion Weight, and Speed of an SD40-2 and 6-Axle DML

Currently, these loads are provided by the diesel engine. A revised auxiliary scheme must maintain at least an equivalent performance in both modes.

The standard main compressor fitted to the SD40-2 is a two-stage, three-cylinder, water-cooled machine having a displacement of 254 cfm at 900 rpm, and is directly coupled to the engine. The main reservoir is maintained by an electrically operated governor within the pressure range of 130 to 140 lb/sq in. When the main air reservoir pressure is within this range, the compressor runs unloaded. Considering the variation in speed of the diesel engine over a typical duty cycle, it is estimated that the effective displacement of the compressor is less than 150 cfm. An optional six-cylinder compressor is available having a displacement at 900 rpm of 400 cfm.

The equipment blower fitted to the SD40-2 takes air from the clean air compartment and delivers it into the traction motor air ducts. Bleeds for electrical cabinet cooling/pressurization, generator pit aspirator, and dynamic brake blower motor bearing cooling are taken from this duct. Each traction motor requires 2850 cfm of cooling air for the 356-kw operation in the SD40-2.

Battery charging, lighting, and control loads are supplied by a 10-kw alternator with an 18 kw-version available as an option.

DML Auxiliaries

The proposed auxiliary scheme is shown in Figure 3-11, where the common interface between the diesel and electric mode power supplies is a dc input to a motor-alternator set. The engine-driven alternator is driven at twice crankshaft speed via a belt-drive from the auxiliary drive shaft. In the electric mode, the rectified output from the transformer auxiliary winding is supplied to the motor-alternator (M-A) set. The constant voltage available from the dc link from either power source enables the M-A set to operate at constant speed. By maintaining the performance of the auxiliaries, the locomotive will be able to operate satisfactorily at 50 percent catenary voltage, albeit at reduced power. All auxiliaries are driven by standard industrial design (modified for traction) three-phase motors.

The electrically-driven compressor will run at constant speed independent of engine speed or catenary voltage. When the main reservoir air pressure is within the specified limits, the compressor will run unloaded. The constant delivery of the compressor will be 140 cfm at 140 psi.

The existing equipment blower will be retained, engine driven in the diesel mode via a clutch. In the electric mode, the clutch will disengage and the auxiliary alternator will become the equipment blower motor.

The existing engine driven 10- or 18-kw auxiliary generator will be electrically replaced by a three-phase transformer-rectifier to provide the 74-v supply required by battery charging, lighting, and control loads.

Since the engine will probably be shut down, and at least idling, during electric-mode operation, cold weather protection is required to ensure that damage does not occur to the engine. A commercially available kit is proposed which, with slight modification, can provide heating and circulation for lubricating oil, fuel oil, and engine water.

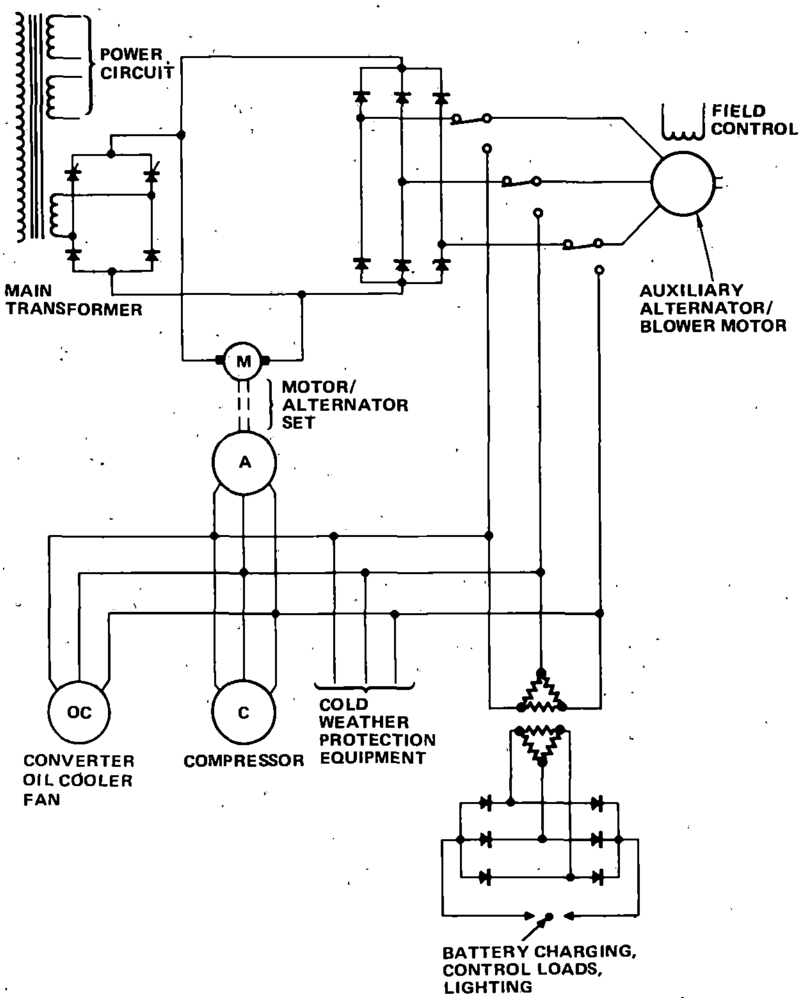


Figure 3-11. DML Auxiliary Scheme

SERVICE LIFE

Economic obsolescence is the sole criterion for scrapping a locomotive. Technically, the locomotive can be periodically rebuilt to bring it to its original condition, and, in many cases, the product improvements made since the original locomotive was built can be incorporated in the rebuild. The power and auxiliary equipment is designed for ease of replacement, while the underframe, trucks, and cabs last an extremely long period of time.

The addition of the DML electric mode equipment will have little effect on locomotive life and may even extend it slightly due to the reduced vibration, since the diesel engine does not operate as often.

Typically, railroads depreciate their locomotives over a period of 15 yr, but it is quite possible that a diesel locomotive will last in excess of 30 yr with regular maintenance and a rebuild every 10 to 15 yr.

MAINTENANCE REQUIRMENTS

One of the major benefits normally derived from railroad electrification is the significant reduction in locomotive maintenance attributed to the use of electric rather than diesel locomotives. The lack of moving parts, particularly in a modern electric locomotive with thyristor control reduces the cost per mile of locomotive maintenance on a one-for-one basis by more than 50 percent. In addition, the significant reduction in locomotive fleet size can result in electric locomotive fleet maintenance costs one quarter or one fifth that of a diesel locomotive fleet required to do the same work.

The DML, however, due to the retention of the diesel engine, does not have a significant advantage on a one-for-one basis compared with a diesel locomotive, although the reduction in fleet size does result in an overall reduction in locomotive maintenance costs when the DML is deployed. The actual cost per mile of maintaining a DML is dependent on the duty cycle. If the locomotive is used predominantly in the diesel mode, then the maintenance cost is higher than it is if the locomotive is used predominantly in the electric mode.

The level of skill required to maintain a fleet of DML's will be similar to that required for diesel locomotive maintenance. To achieve this, the two major maintenance items, the transformer and the converter, require special attention in the design stage.

<u>Transformer</u>

The transformer should be hermetically sealed to prevent the ingress of dirt and moisture. Oil expansion should be taken into account for using a proven technique. This approach will eliminate preventive maintenance and in the event of a failure, it would probably be necessary to replace the transformer assembly since the failure would most likely cause damage to the transformer construction.

<u>Converter</u>

The introduction of power and control electronics into the locomotive environment is recognized as an area of uncertainty that must be fully addressed. To avoid increasing the maintenance personnel skill level required, and to improve on present experience with locomotive electronics, it is necessary to consider the introduction of microprocessors into the electronic control unit (ECU) control boards. These boards would have a self-check feature that depends on the requirements of the railroad, and could indicate that the ECU assembly requires changing or that individual boards require changing.

SECTION 4

PRELIMINARY DESIGN DEFINITION

CONFIGURATION OF SELECTED CANDIDATE LOCOMOTIVE

It was recommended that the prototype DML be configured using an SD40-2 locomotive as a base because it is highly compatible with the DML concept and, more importantly, it is the most common locomotive in the United States.

The design that was evolved during this study was based on a 25- and a 50-kv locomotive. It is not intended that the locomotive will be able to operate from either voltage, although this could be readily accomplished using a high voltage switching arrangement, as shown in Figure 4-1. Such a switch would seriously impact the volume required for the transformer, and while it may be feasible to incorporate such a switch within the available volume, it is recommended that such a development should be pursued subsequent to the demonstration of the baseline concept if it is established that a significant amount of run-through operation from 25- to 50-kv (and vice versa) areas will take place.

The locomotive design will consider only 60-Hz operation since 25 Hz would require a transformer almost 2.4 times heavier and larger in volume than the 60-Hz transformer. The exclusion of 25 Hz will not seriously impact the applicability of the DML, since DOT is committed to 60 Hz.

For the purposes of comparison, however, the relative size of the transformer required for the 60/25 Hz, 25 kv/11 kv is reported later in the study. Using these data, an installation analysis can be readily accomplished.

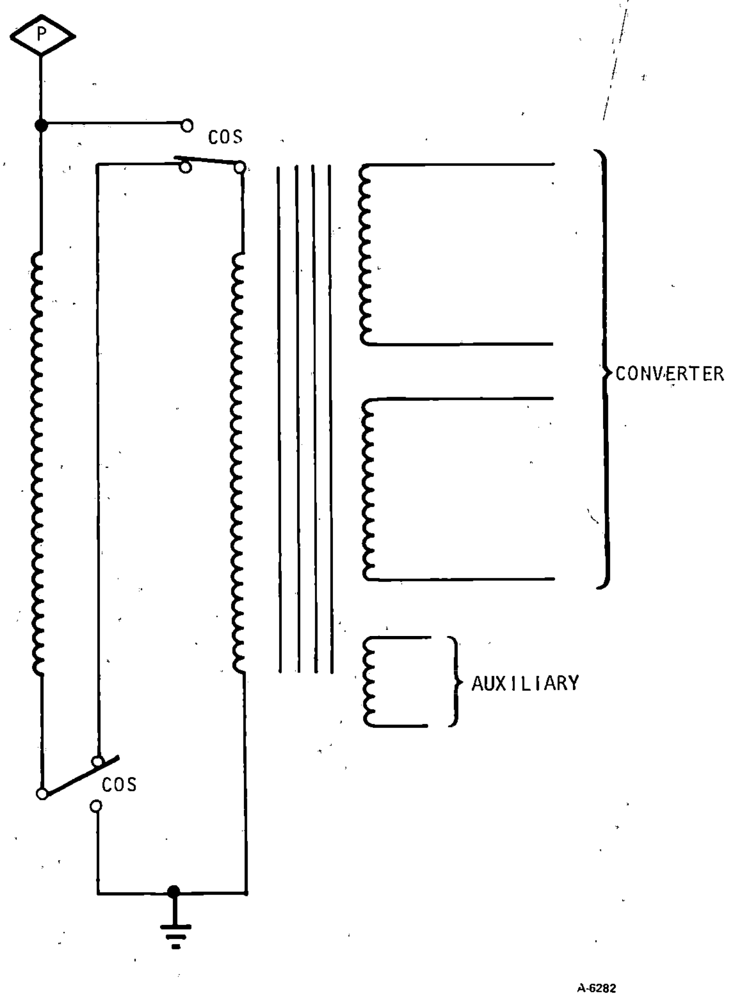


Figure 4-1. Principle of Operation of 50-kv/25-kv Primary Transformer (Shown in 50-kv Position)

For the prototype locomotive, the objectives will be to maintain the overall locomotive weight within the 395,000-lb requirement previously identified, and to restrict the maximum static axle load to 68,000 lb.

The fuel tank capacity will be 3000 gal, giving a typical locomotive range in excess of the base locomotive. The range is, of course, subject to the extent of the catenary and will increase as electrification proceeds.

The maximum locomotive height with the pantograph down will be unchanged in the case of the 25-kv version, and a concerted effort will be made to maintain the same height in the case of the 50-kv version. Any increase in height will have some effect on the availability of the locomotive. The impact will vary from railroad to railroad, but as far as main lines are concerned the impact will be relatively small since the heights of the trailing loads are far in excess of the locomotive height.

The baseline concept identified in Task 2 showed the impact of providing a regenerative capability in the DML. This preliminary design definition of the DML will assume that a regenerative DML is required since this will result in the larger equipment sizes. It is doubtful, however, whether the regenerative capability will be utilized during the initial testing periods since the 60-Hz catenaries available in the timeframe under consideration will have, at best, low receptivity.

The power rating of the DML in the electric mode will be predicated on a traction motor input rating of 536 kw, giving an overall locomotive rating of approximately 3880 rhp. It is possible that by the time the fleet deployment of DML's takes place, the standard diesel-electric traction motor (D77, GE752) will have a higher rating than 536 kw, but a conservative approach in the first place is desirable to confirm anticipated commutation quality when operating from controlled, rectified pulsating current.

MODIFICATION TO LOCOMOTIVE CONTROLS

As a matter of principle, the operation of the locomotive in the diesel mode has, as far as possible, been unchanged. Where necessary, interfaces will be achieved using high quality components that have a proven record in traction applications. The interfaces required between existing locomotive equipment and the electric mode equipment are shown in Figure 4-2. As far as possible, modifications have been limited to series or parallel relay contacts in existing circuits. Modification to the existing printed wire assembly boards (PWA's) is not required.

A list of control components is given in Table 4-1.

Mode Changeover Initiation

As previously stated, mode changeover may be accomplished either automatically or manually depending on the requirements of the railroad. The interface between the wayside and locomotive equipment is shown in Figure 4-3. The only difference between the automatic and manual options is the method of operating MCO. If manual mode changeover is used, MCO is a switch on the control stand operated by the engineer. If automatic mode changeover is required, MCO is used in a polarity sensitive circuit, which is set up by track magnets located on tie ends.

Engine Start Control

Assuming that the diesel engine is shut down during electric mode operation, a procedure must be devised where the diesel engine can be restarted automatically without the usual attention of the engineer. This has proven to be the most complex of the interfaces to satisfactorily achieve and must, realistically, be subject to modification following service experience.

The recommended engine starting procedure for the SD40-2 locomotive is given in Reference 7, and is as follows:

1. Check oil levels in the engine governor and air compressor. Check engine coolant level. Open the square cover of the engine oil strainer and make certain that the strainer housing is full of oil.

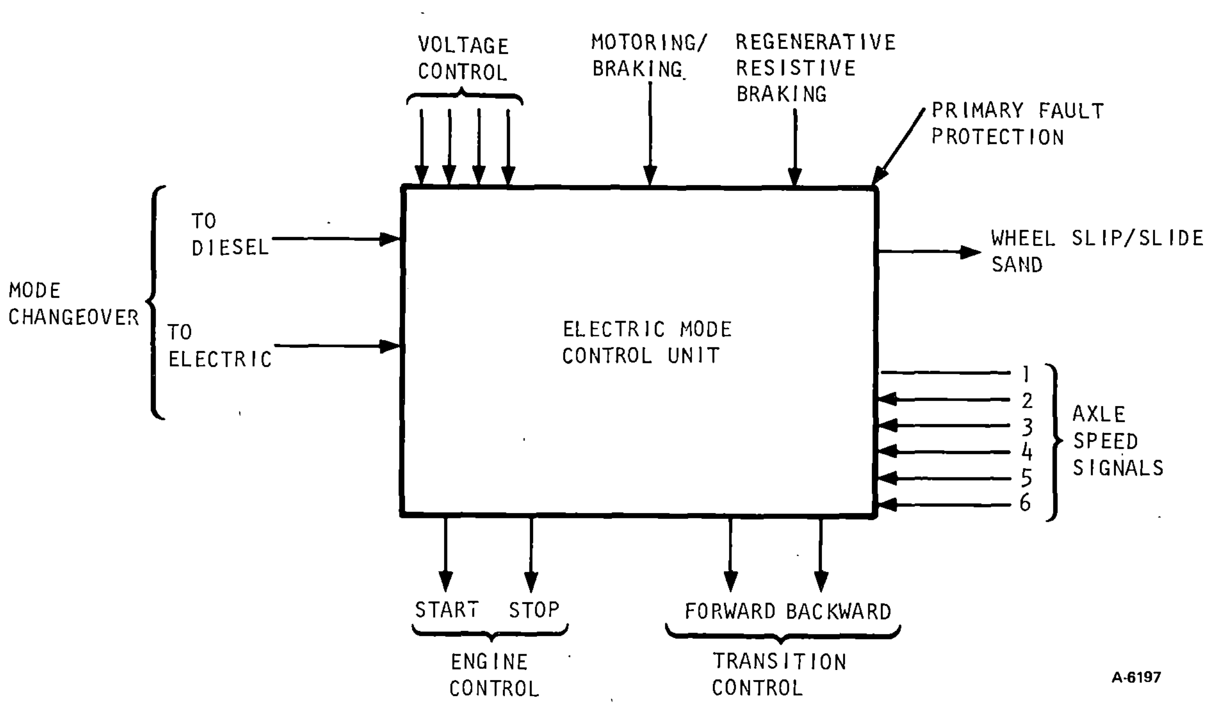


Figure 4-2. Electric/Diesel Mode Interfaces

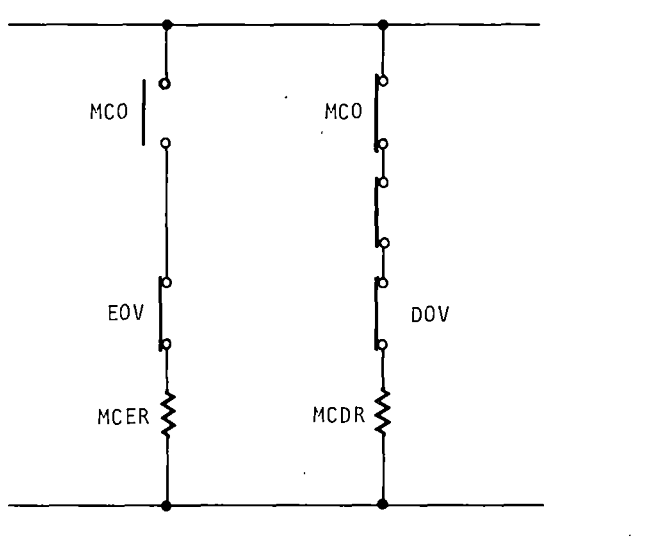


Figure 4-3. Mode Changeover Initiation Circuits

TABLE 4-1

ADDITIONAL CONTROL COMPONENTS

Location	Component	Contacts	Time Delay
Low roof	APS - Air pressure switch 100 lbs/sq in.	3NO	-
Elec cabt	DOV - Diesel output volts	1NC	-
Elec cabt	EBTR - Electric backward transition	1NO	-
Elec cabt	EFTR - Electric forward transition	1NO	-
Elec cabt	EOV - Electric output volts	1NC	1NC, 120 sec
Elec cabt	ESOR - Engine start override relay	1NO	-
Elec cabt	ESPR - Engine start prime relay	2NO 2NC	1NO, 15 sec
Elec cabt	ESR - Electric sand relay	1NO	-
Elec cabt	ESRR - Engine start run relay	2NO	1NC, 20 sec 1NO, 6 sec
Elec cabt	ISB - Isolation switch bypass	7NC 1NO	
Elec cabt	MCDR - Mode changeover to diesel relay	1NO	
Elec cabt	MCO - Mode changeover (switch)	-	
Elec cabt	NVR - No volt relay (existing)- extra contract)	1NC	
Engine	OPS - Oil pressure switch 10 lbs/sq in.	1NO	
Low roof	POR - Primary overload relay	1NC	
Low roof	PVR - Pantograph valve relay	1NO	1NO, 10 sec
Engine	RA - Rack actuator	-	-
Elec cabt	SMP - Starter motor protection	1NC	1NO, 120 sec
Low roof	SCMV - Vacuum circuit magnet valve	-	-

2. Open cylinder test cocks and bar over the engine at least one revolution; observe for leakage from test cocks. Close the test cocks.

3. Check that all fuses are installed and in good condition.

CAUTION: MAKE CERTAIN THAT THE STARTING FUSE IS THE CORRECT RATING AS INDICATED ON THE PANEL

4. Verify that the main battery switch is closed and that the ground relay switch is closed.

5. Check that all circuit breakers in the black area of the circuit breaker panel are in the on (up) position.

6. Check that the control and fuel pump switch on the control stand is in on (up) position.

7. Check that generator field and engine run switches are in the off (down) position.

8. Check that the isolation switch on the engine control panel is in the START position.

9. At the equipment rack in the engine room, place the fuel prime/engine start switch in the PRIME position until fuel flows in the return fuel sight glass clear and free of bubbles (normally 10 to 15 sec).

CAUTION: IF ENGINE IS EQUIPPED WITH PURGE CONTROL SYSTEM, DO NOT PUSH INJECTOR RACK CONTROL LEVER (LAYSHAFT) UNTIL ENGINE HAS CRANKED FOR SIX SECONDS.

10. Position the injector rack manual control lever at about one-third rack (about 1.6 on the scale), then move the fuel prime/engine start switch to the START position (not more than 20 sec). Hold the switch in the START position until the engine fires and speed increases.

11. Release the injector control lever when the engine comes up to idle speed. Do not advance lever to increase engine speed until oil pressure is confirmed.

12. Check the low water reset button within 50 sec after engine start. The low water detector will often trip during engine starting, especially on starting after filling a completely drained system. It may also trip after starting a cold engine or one that has had cooling system pressure released. The detector should be reset soon after the engine starts and is idling, or the engine will shut down after a time delay established by the engine governor.

    NOTE: If the detector is difficult to reset after engine start, position the injector control lever to increase engine speed for a short time, then press the reset button. The reset button on some detectors will not latch in when the engine is shut down. If such a condition exists, the detector will probably function correctly if it can be reset after engine start.

13. Check that cooling water level, lube oil pressure, and governor oil level are satisfactory.

It will be noted that the above procedure requires a good deal of human involvement, a situation that would not be satisfactory during the mode changeover process of the DML. It was necessary therefore to derive a system that fulfilled the above requirements automatically. The following paragraphs describe such a system and identify the areas requiring further development.

The above instructions apply to a locomotive engine being started after a significant shutdown period during a layover, and certain maintenance-type checks clearly do not apply to DML operation over the road. A diagrammatic summary of the differences between conventional and over-the-road starting procedures is given in Figure 4-4.

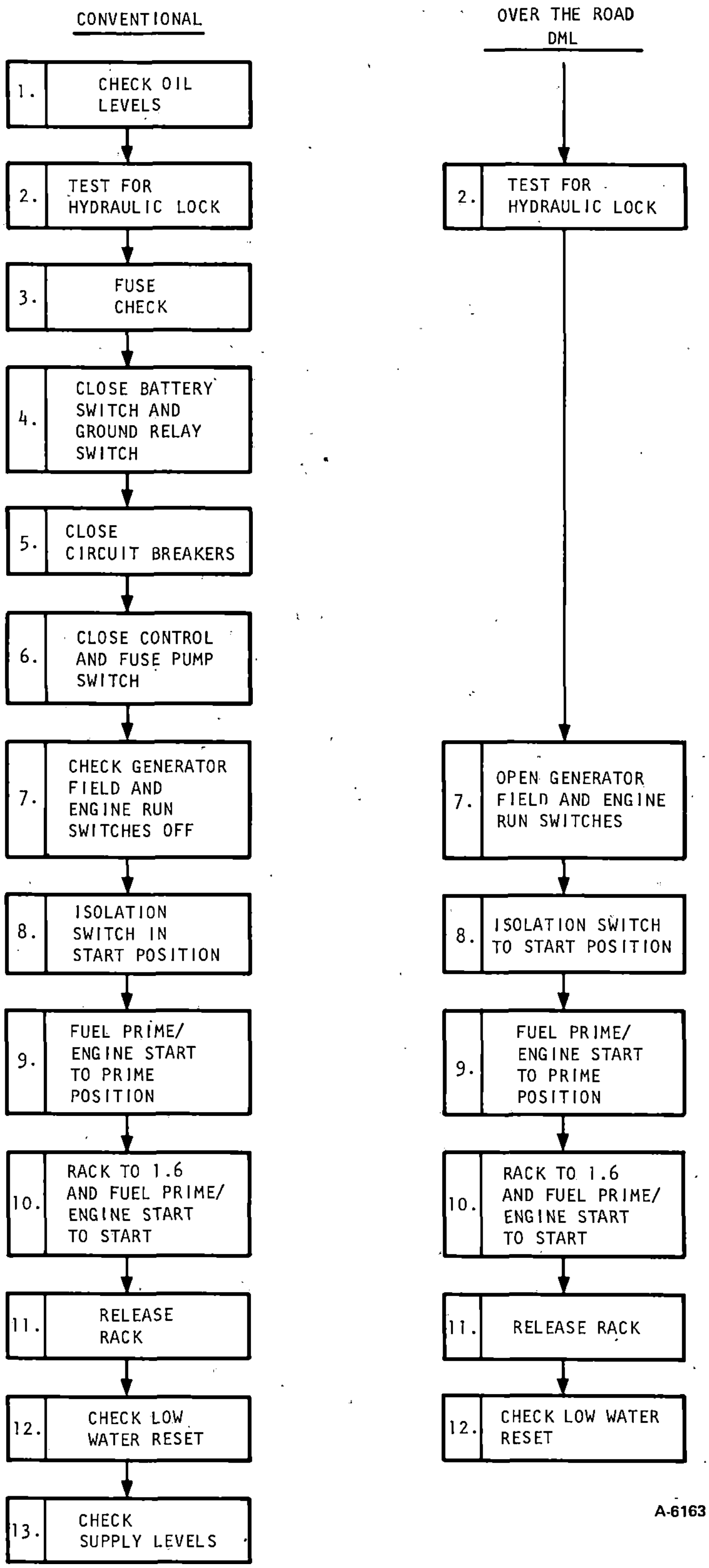


Figure 4-4. Comparison of Conventional and Over-The-Road Engine Starting Procedures

The susceptibility of the 645E3 engine to hydraulic lock due to seal leakage has become a significant problem over the years, and various modifications have not been successful in eliminating the problem. The starting technique employed on the DML will require some method of avoiding major engine damage during starting. A suitable system is described in Reference 8, which states that provided the cranking speed is kept below 30 rpm, damage due to hydraulic lock will not occur. The engine purge system maintains engine cranking speed between 25 and 30 rpm for at least one revolution by keeping a resistance in series with the starter motors for six seconds. Following the completion of the purge cycle, normal cranking speed is permitted during the remainder of the start cycle.

Step 7 requires that the generator field and engine run switches be in the open position during starting, thus ensuring that the engine does not overspeed during starting and that a start attempt is not made under load. The equivalent function is accomplished by relay MCDR in Figure 4-5, which opens the feed to GFC.

The function of the isolation switch (IS) required by step 8 is accomplished using relay ISB. The fuel pump/engine start (FP/ES) switch function is accomplished using relays ESPR and ESRR, which are controlled as shown in Figure 4-6.

Mode changeover is initiated by MCDR, which in turn picks up ESOR to initiate the engine starting procedure. As ESPR is energized, ISB picks up to simulate IS and fuel priming occurs for the specified period of 15 sec, after which the time delay contact on ESPR allows ESRR to pick up and engine cranking is initiated for the permitted period of 20 secs when SMP is energized, thereby inhibiting an attempt to restart for 2 min to permit starter motor cooling. When ESRR drops out, the feed to SMP is maintained by SMP time delay contacts. Reset of SMP is caused by the opening of the time delay SMP contacts, which drops the feed to ESPR and therefore opens the circuit to SMP.

ESRR also provides a feed to RA, which positions the engine rack at the specified starting position 6 sec after engine cranking started, thus ensuring that purging has been completed. NVR contacts in the feed to ESOR prevent relay cycling once the engine has started.

Pickup of NVR will release the engine rack by opening the circuit to RA.

Engine Control Stop

With converter output voltage in excess of AR10 output voltage established, the feed to GFC is interrupted by EOV, thus causing loss of main generator excitation and load shedding. EOV also opens the feed to ER, which causes the engine to drop to idle speed. To facilitate gradual engine cooling, EOV time delay contacts will maintain the engine at idling speed for a specified period (2 min is currently recommended) before shutdown. At the end of the idling period, the feed to FPCP is dropped and the engine stops.

Electrical Equipment Control

Operation of MCO to put a feed on to MCER initiates the raising of the pantograph and setup of electric mode equipment as shown in Figure 4-7. PV energizes to allow air to enter the pantograph motor and overcome the pantograph lowering springs, provided that APS is closed by a minimum of 100 lb/sq in. in the main air reservoir. Within 10 sec of PV being energized, the pantograph will be in contact with the catenary, and the magnet valve VCMV is energized, which allows the VCB to close and energizes the transformer. Converter output voltage is ramped up to match the AR10 output voltage, at which stage EOV operates to unload the engine and initiates the shutdown procedure and denergizes MCER ready for the next mode changeover command.

Operation of MCO to put a feed onto MCDR initiates the engine start procedure as previously described. When it is established that the output voltage from the AR10 is equivalent to the engineer's command level, the converter output voltage is gradually reduced to zero. As the converter voltage falls below the AR10 voltage, DOV energizes to open the circuit to VCMV, thereby opening the VCB and de-energizing MCDR ready for the next changeover command.

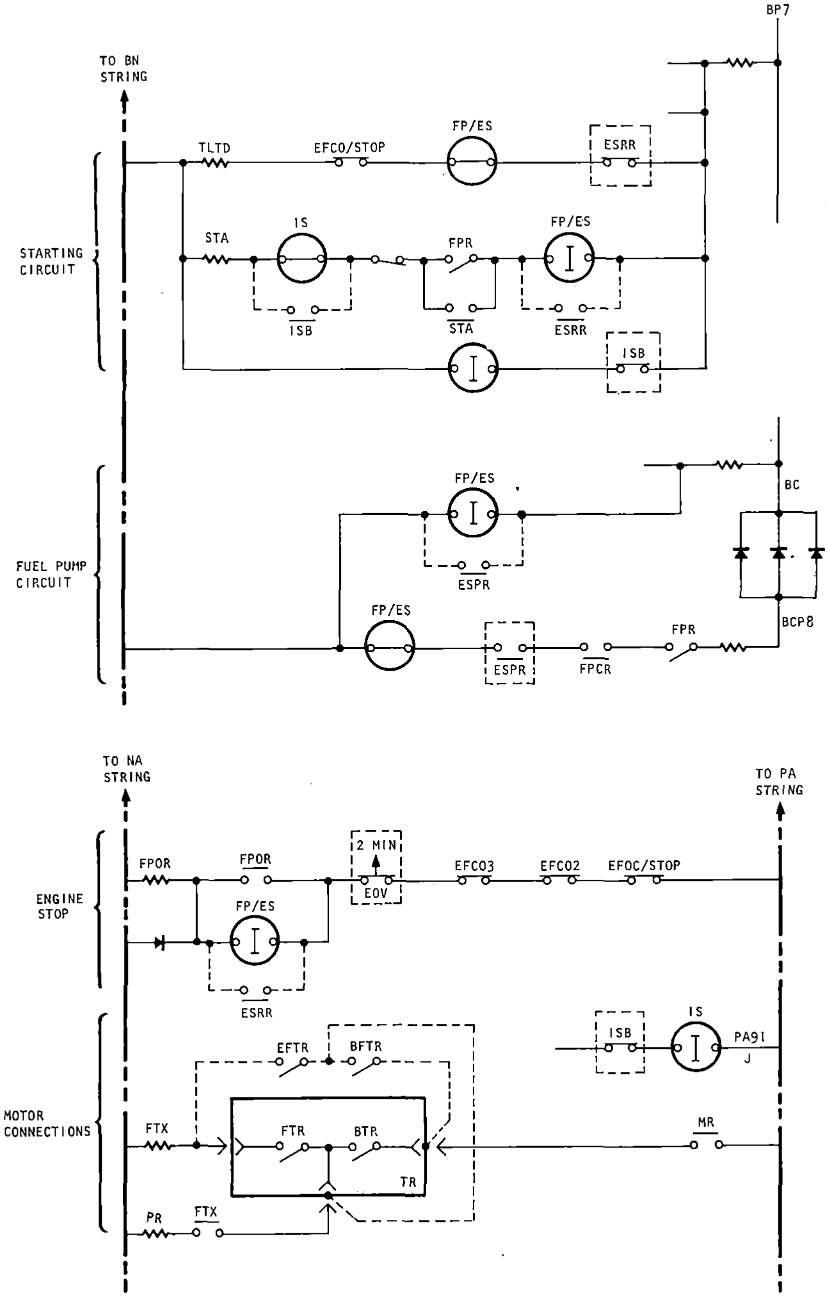
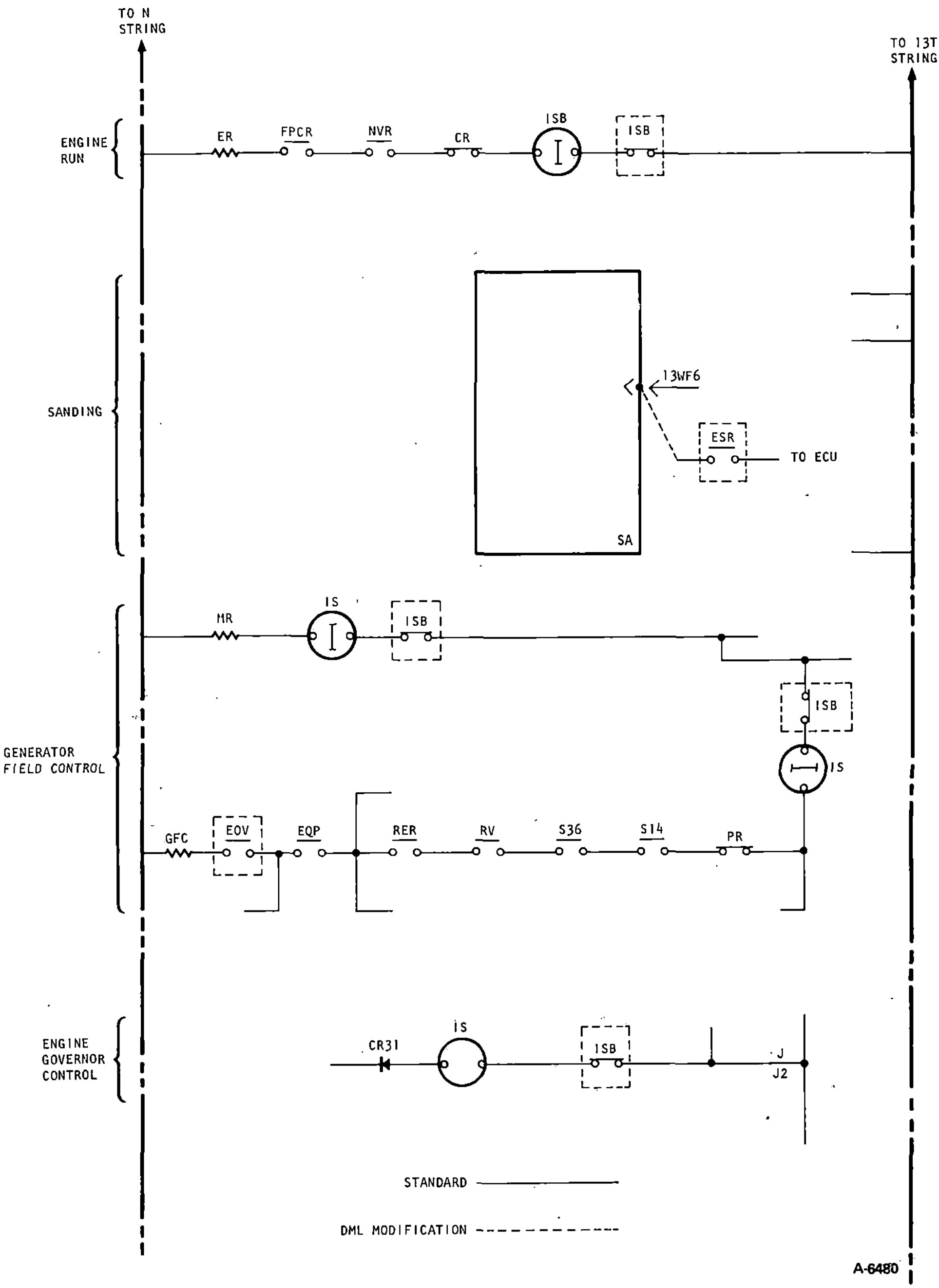


Figure 4-5. DML Control



Interface with Diesel Mode

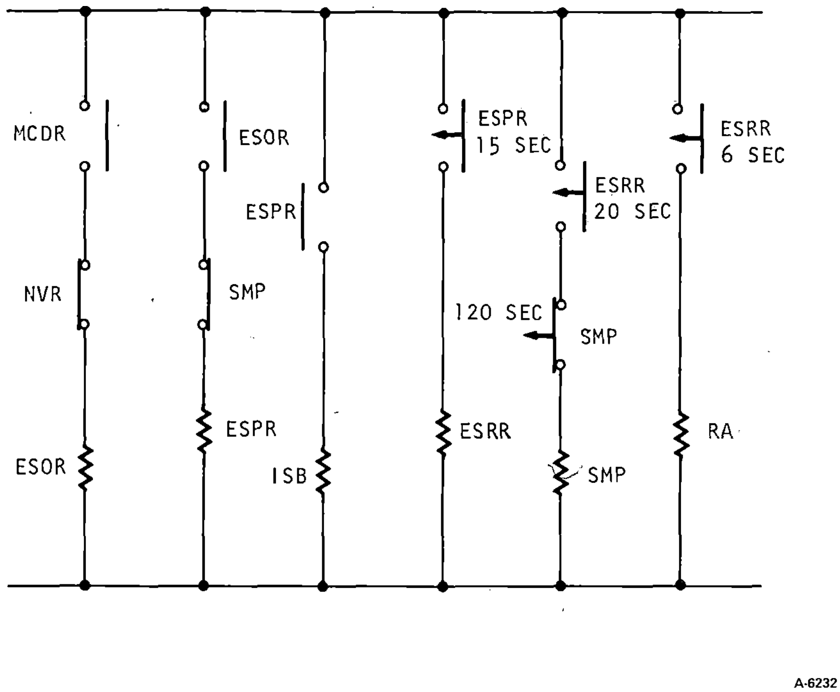


Figure 4-6. Electric-Diesel Modes Control Interface

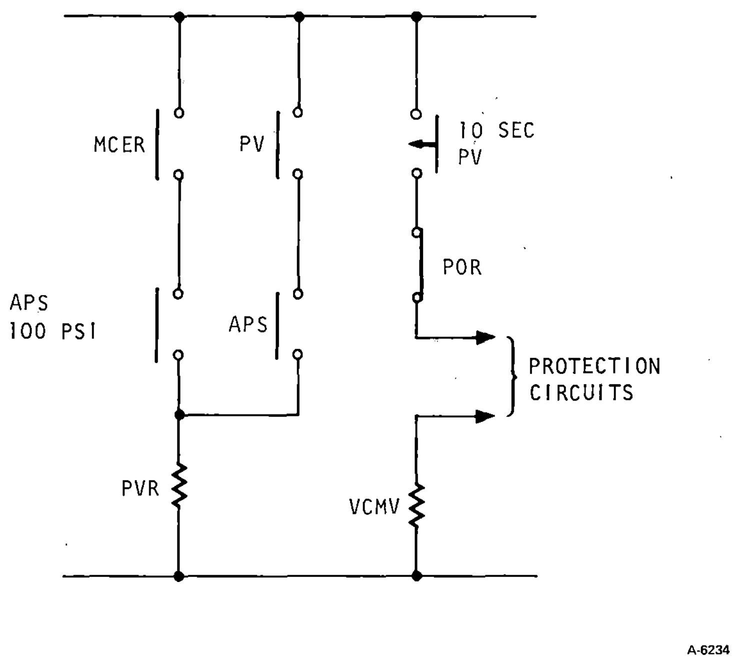


Figure 4-7. Electric Mode Setup Circuits

Motor Connections

Forward and backward transition of motor connections are accomplished by relays EFTR and EBTR, respectively, which simulate the external operation of the transition module TR as shown in Figure 4-5. Pickup and drop-out of EFTR and EBTR are controlled by logic within the main converter during electric mode operation.

Wheelslip Control

The existing wheelslip control on EMD locomotives utilizes current/voltage balance to detect wheelslip. This method suffers from the disadvantages of being intolerant of differing equipment tolerances such as wheel diameter, traction motor characteristics, and cable lengths.

A more satisfactory method is to measure wheel speeds and compare speed relative to other wheels and to absolute acceleration. Such a system requires only minor modification to the existing locomotive equipment, and makes use of a magnetic pickup mounted on the gearcase over the gear wheel. The only control interface with the existing locomotive equipment is in the sanding control, which requires the addition of a supply via ESR to supply the feed to the SA module. This is shown in Figure 4-5.

PRELIMINARY DESIGN

Once a preliminary design definition has been established, it is possible to derive preliminary designs of the components required to achieve the modification of an SD40-2 locomotive to the DML configuration. The following data are based on the DML baseline configuration and will reflect the 50- and 25-kv locomotives. Schedules of equipment required to achieve the modification are given in Tables 4-2 and 4-3 for the 50- and 25-kv versions, respectively.

Pantograph

Two pantograph types have been considered in this study and both represent the most widely accepted and proven pantograph designs available. The pantographs, manufactured by Faiveley and GEC Traction, are shown in Figures 4-8 and 4-9, respectively.

Both pantographs have copper braid shunting to minimize the current carried by bearings located at joints, and weight has been minimized to improve the dynamic response of the pantograph head to irregularities in the contact wire.

At high speed, the current collection characteristics of the GEC Traction pantograph are superior to the Faiveley due to the symmetrical design resulting in aerodynamic forces being the same in both directions. This is not a significant factor in the DML design since the maximum speed of the locomotive is to be 65 mph. The requirements of the DML—low weight, minimum length—favor the use of the Faiveley pantograph and an installation analysis was based on that pantograph.

As an option, a minor modification to the pantograph could be accomplished to provide an automatic pantograph down facility in the event of the collector head becoming damaged. This feature prevents excessive damage to the overhead installation.

Vacuum Circuit Breaker

The vacuum circuit breaker (VCB) is used to provide on-board fault protection and isolation for maintenance purposes. A VCB is preferred to an air blast breaker since the latter requires much more maintenance and is noisier in operation.

The VCB recommended for use on the DML is the GEC model available in both 25- and 50-kv versions, as shown in Figures 4-10 and 4-11, respectively. The 25-kv breaker has two vacuum interrupters in series, operated by two opposed pistons that move apart when air is admitted, compressing springs and allowing the contacts to close. The basic construction of a single interrupter bottle is shown in Figure 4-12. Releasing the air pressure allows the springs to expand and the contacts to part. The interrupters have a nominal voltage rating of 15 kv and 600 amp, and therefore the two in series have a capability of 30 kv. The impulse voltage withstand is 170 kv.

TABLE 4-2

SCHEDULE OF EQUIPMENT FOR 50-kv VERSION

Item	Quantity	Location	Weight, lb
Pantograph	1	Low roof	264
Vacuum circuit breaker	1	Low roof	815
Grounding switch	1	Low roof	50
Lightning arrestor	1	Low roof	144
Roof insulators	3	Low roof	315
Main transformer	1	Carbody, beneath low roof	15,650
Main converter assembly	1	Carbody, rear of locomotive	4,300*/4,100
Smoothing inductor	1	Carbody, rear of locomotive	2,500
+ Cold weather protection	1	Carbody, free end of engine	400
Motor-alternator set	1	Underframe, between trucks	4,000
Compressor	1	Carbody, in place of existing compressor	790
Control relays	16	Electrical cabinet	25
* Power contactors	5	Electrical cabinet	50
Axle-end ground brushes	3	Truck	30
Axle speed probes	6	Gear case	10
+ Rack actuator	1	Engine	5
+ Low water reset solenoid	1	Engine	5
APC receiver	2	Truck	150
Power cable	-	Various	500 (Power cable and Control cable)
Control cable	-	Various	
Auxiliary alternator	1	Carbody, beneath low roof	2,000
Auxiliary transformer/rectifier	1	Air brake compartment	235
Auxiliary drive clutch	1	Auxiliary alternator shaft	30
+ Operator control switches	1	Cab	1
Operator indicators	2	Cab	1
* Field shunting thyristors	6	Electrical cabinet	200
Air pressure switch	1	Low roof section	2
* Dynamic brake blower assembly	2	Dynamic brack hatch	1,400
Stand-off insulators	10	Truck/underframe	20
Safety ground straps	4	Truck/underframe	8
Oil cooler - transformer	1	Carbody, beneath low roof	200
Oil cooler - converter	1	Carbody, in radiator A	200
Primary air filter	1	Carbody, beneath low roof	200

* Regenerative option only

\+ Engine shutdown in electric mode option only

TABLE 4-3

SCHEDULE OF EQUIPMENT FOR 25-kv VERSION

Item	Quantity	Location	Weight, lb
Pantograph	1	Low roof	264
Vacuum circuit breaker	1	Low roof	262
Grounding switch	1	Low roof	30
Lightning arrestor	1	Low roof	75
Roof insulators	3	Low roof	231
Main transformer	1	Carbody, beneath low roof	12,563
Main converter assembly	1	Carbody, rear of locomotive	4,300*/4,100
Smoothing inductor	1	Carbody, rear of locomotive	2,500
Cold weather protection	1	Carbody, free end of engine	400
Motor-alternator set	1	Underframe, between trucks	4,000
Compressor	1	Carbody, in place of existing compressor	790
Control relays	16	Electrical cabinet	25
* Power contactors	5	Electrical cabinet	50
Axle-end ground brushes	3	Truck	30
Axle speed probes	6	Gear case	10
+ Rack actuator	1	Engine	5
+ Low water reset solenoid	1	Engine	5
APC receiver	2	Truck	150
Power cable	-	Various	} 500
Control cable	-	Various	
Auxiliary alternator	1	Carbody, beneath low roof	2,000
Auxiliary transformer/rectifier	1	Air brake compartment	235
Auxiliary drive clutch	1	Auxiliary alternator shaft	30
+ Operator control switches	1	Cab	1
Operator indicators	2	Cab	1
* Field shunting thyristors	6	Electrical cabinet	200
Air pressure switch	1	Low roof section	2
* Dynamic brake blower motor	2	Dynamic brake hatch	1,400
Stand-off insulators	10	Truck/underframe	20
Safety ground straps	4	Truck/underframe	8
Oil cooler - transformer	1	Carbody, beneath low roof	200
Oil cooler - converter	1	Carbody, in radiator A	200
Primary air filter	1	Carbody, beneath low roof	200

* Regenerative option only

\+ Engine shutdown in electric mode option only

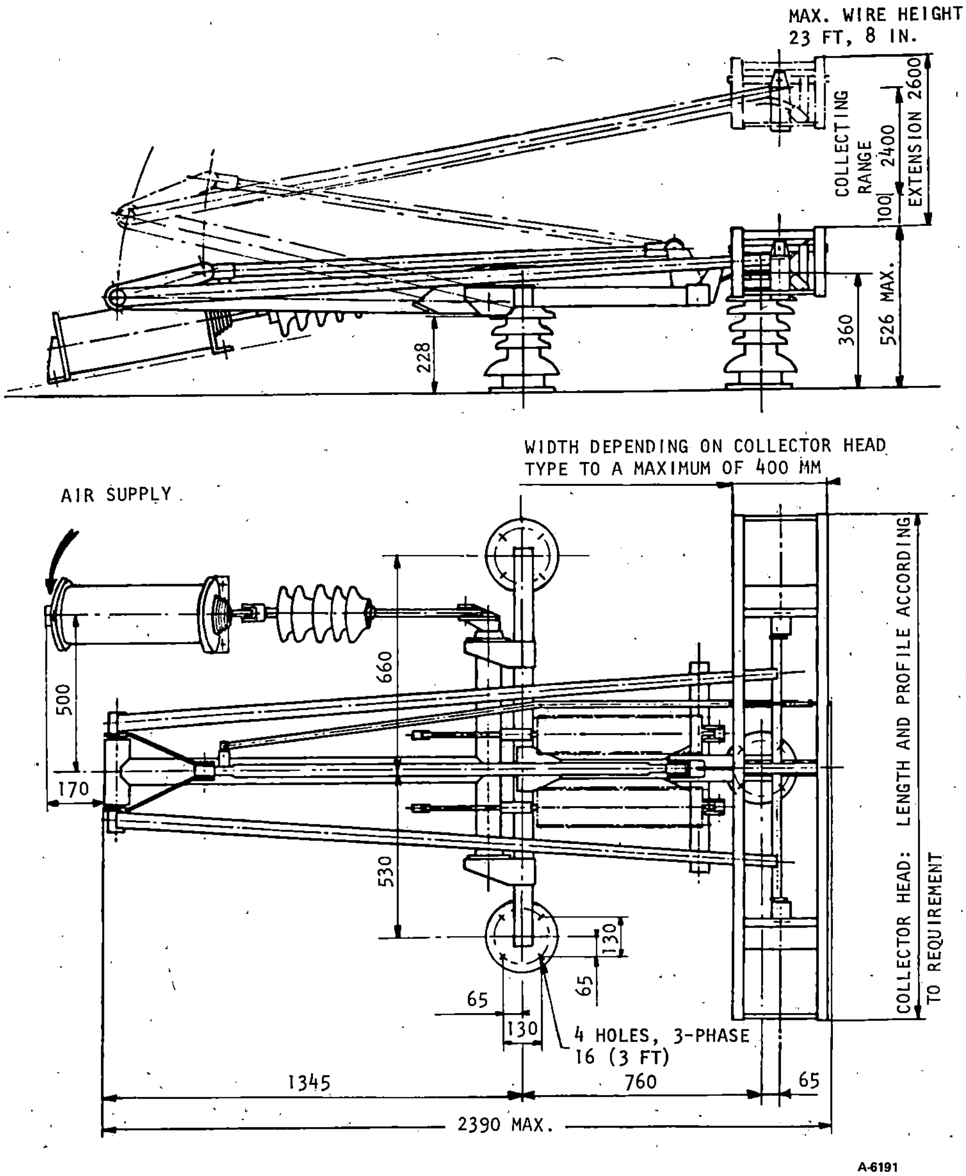


Figure 4-8. Faiveley Pantograph

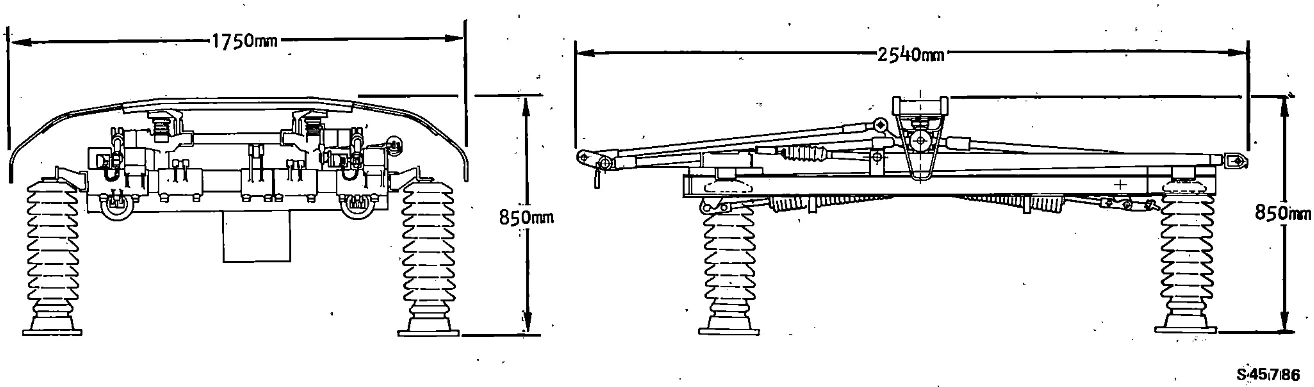


Figure 4-9. GEC Traction Pantograph

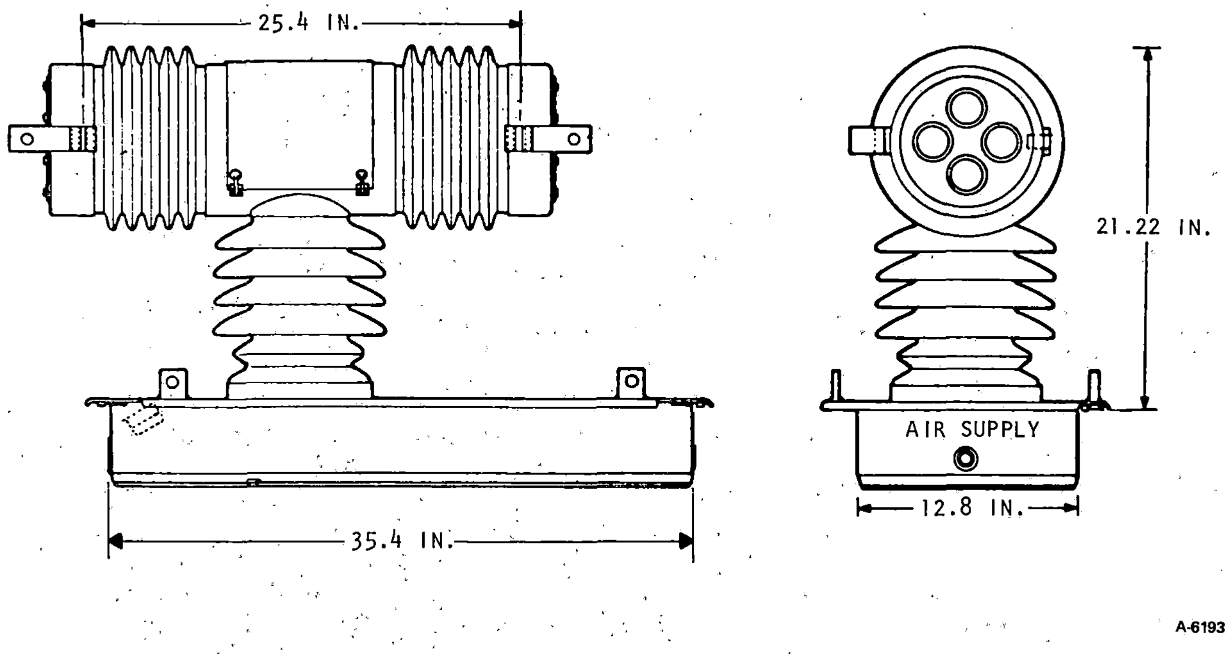


Figure 4-10. 25-kv Vacuum Circuit Breaker

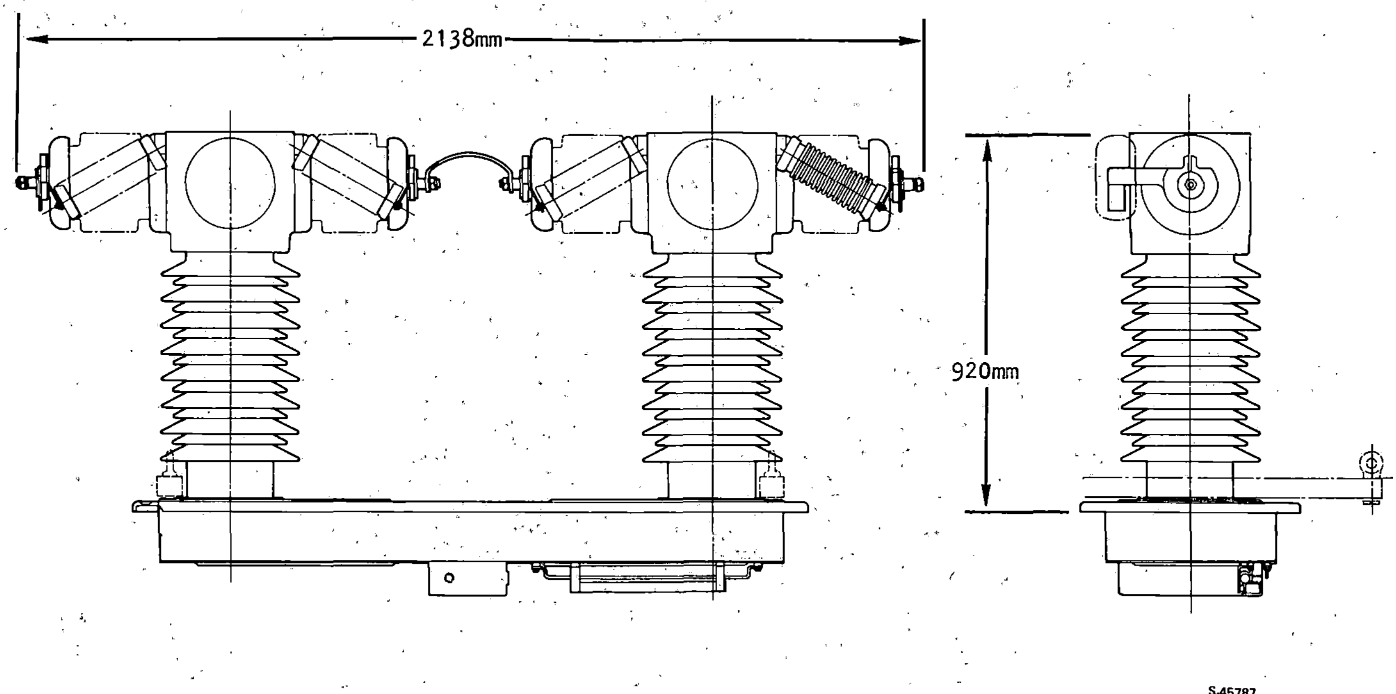


Figure 4-11. 50-kv Vacuum Circuit Breaker

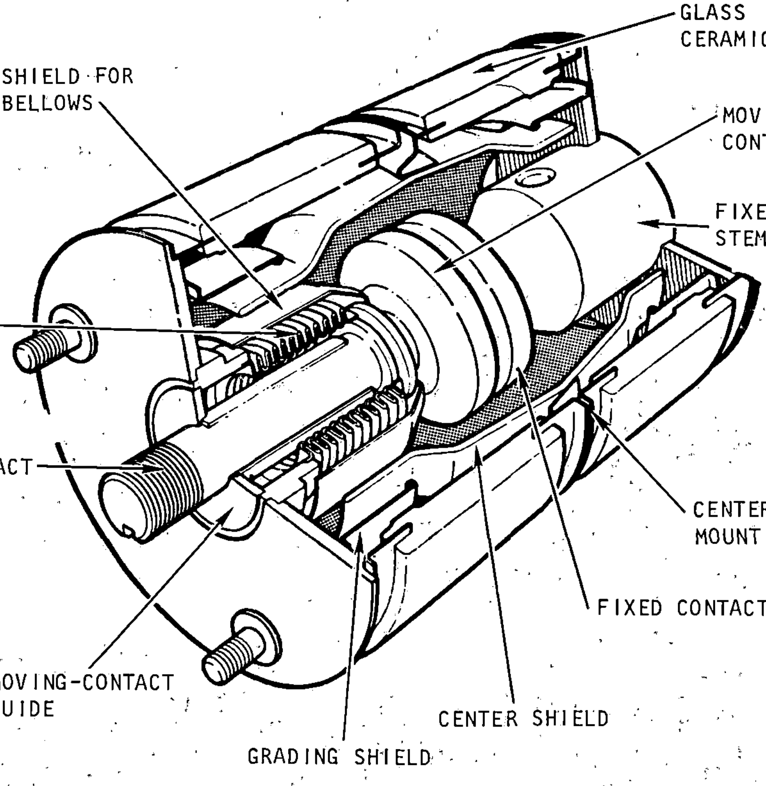


Figure 4-12. Basic Construction of a Single Interrupter Bottle

The 25-kv breaker is used as the basis of the 50 kv version, which employs four interrupters arranged in two series bottles. Externally mounted capacitors are required to control the voltage distribution of the four breakers in series. With an operating time of 5 cycles from fault detection, the VCB is well suited to local, on-board fault detection and isolation. The VCB incorporates within the assembly fixed contacts for the manually operated grounding switch.

The air supply to the VCB should be clean and dry and therefore a moisture separator is required immediately before the VCB. Closure of the VCB is initiated by energizing a magnet valve that feeds a fast acting servovalve. The air is fed via the servovalve to the actuator, causing the actuator piston to move and close the interrupter contacts. The compressed springs open the contacts when air pressure is removed.

A pressure switch monitors the air system and automatically opens the breaker when low air pressure is detected, thereby preventing locomotive operation with insufficient air. A bypass arrangement with suitable safety interlocks can be provided, if required by the railroad, to allow operation of the compressor from the catenary to re-establish the air supply.

A regulating valve provides a constant air pressure of 70 lbf/sq in., and a small reservoir and check valve ensures that a sufficient volume of air is always available at closure.

<u>Grounding Switch</u>

The grounding switch is connected in parallel with the VCB interrupters. Its purpose is to enable the lowered pantograph and vacuum circuit breaker to be grounded before maintenance personnel carry out any work on the locomotive. The grounding switch also prevents the pantograph from being raised.

The design of the grounding switch operating mechanism will be such that the switch can be operated by personnel standing on the locomotive platform in the area adjacent to the lowered roof. Provision will be made for a number of padlocks to lock the grounding switch in the grounded position, thereby affording protection to maintenance personnel.

Lightning Arrestor

A lightning arrestor is required to provide protection against line voltage transients that may be caused by lightning or station switching, and basically consists of a series arrangement of spark gaps and nonlinear resistors shown typically in Figure 4-13. In the event of a voltage surge, the spark gap flashes over and puts a ground fault on the system for the duration of the surge. The power follow current that will flow through the arrestor is limited by the series nonlinear resistors to a value that can be cleared by the gaps. The series resistors must withstand both the passage of the surge energy to ground and the subsequent application of the full system voltage for the remainder of the half-cycle on which the surge occured. The arrestor gaps then clear just before zero voltage.

A typical lightning arrestor is shown in Figure 4-13.

Roof Equipment Insulators

Roof equipment insulators are required to support equipment at the same voltage as the catenary while still maintaining the clearance required for safe operation. These clearances are summarized in Table 4-4 and are derived from the International Union of Railways (UIC) Code 606 OR. The code deals with 25 kv only; the 50-kv clearances have been derived by doubling the 25-kv dimensions. Polluted atmospheres are generally defined as proximity to the ocean and extremely heavy industrial pollution.

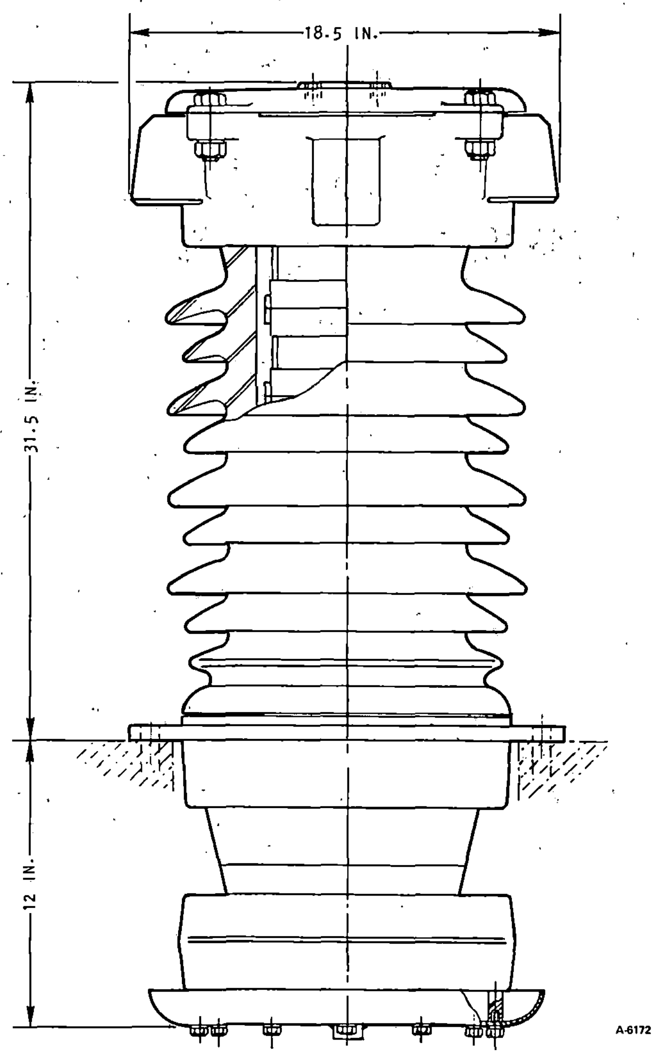


Figure 4-13. Typical Lightning Arrestor

TABLE 4-4

ELECTRICAL CLEARANCES FOR 25- AND 50-kv SYSTEMS

Condition	Clearance, in.			
	25 kv		50-kv	
	Normal	Minimum	Normal	Minimum
Passing - nonpolluted	4.32	-	8.64	-
Passing - polluted	5.59	-	11.18	-
Static - nonpolluted	6.8	5.0	13.6	10.6
Static - polluted	8.0	6.5	16.0	13.0

During the roof equipment design, the objective should be to achieve at least the normal (polluted) clearance, which allows for a significant safety margin. Then, if it is necessary to reduce a clearance below the values given in Table 4-4, this can be evaluated in the specific case.

Insulators for this application are available from many sources. Figures 4-14 and 4-15 show typical insulators from Ohio Brass, which are suitable for the 25- and 50-kv applications.

The insulators are a maintenance item. To provide adequate insulation, periodic cleaning is required. The frequency of cleaning is completely dependent on the operating environment and, in particular, the air contaminants prevalent in the area of operation.

Main Transformer

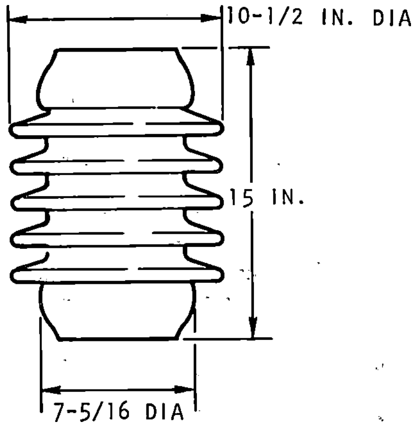
The main transformer represents the most difficult of the electric mode components to accommodate within the anticipated stringent volume and weight constraints. For this reason, European technology has been utilized and, in particular, the technology that has been developed for the construction of transformers for locomotives on British Rail (BR) and South African Railways. It was previously established by discussion with two North American electric locomotive suppliers that the construction of a transformer to meet the volume and weight restraints imposed by the DML was beyond the North American state of the art, and this was confirmed by one manufacturer at the DML second quarterly review.

It is the constraints of BR's loading gage and axle load limitations that have led their suppliers to develop an expertise beyond that necessary for the normal North American market. The relevant parameters of the two gages are summarized in Table 4-5. BR's axle load limit for a 3000-kw, 170-km/h electric locomotive is 20.5 tons compared with the maximum North American axle loads for freight locomotives of 35.0 tons.

TABLE 4-5

COMPARISON OF SALIENT FEATURES OF AAR PLATE C
AND BRITISH RAIL L1 GAGE

	AAR Plate C	BR L1 Gage
Maximum locomotive height, mm	4724	3977
Maximum locomotive width, mm	3250	2670

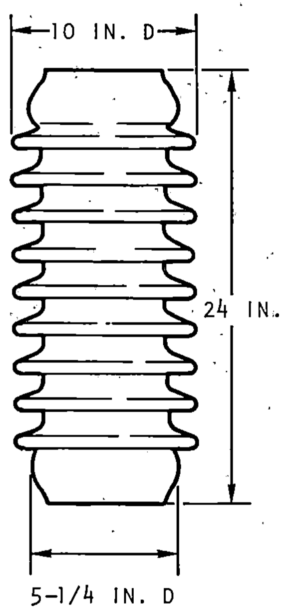


LEAKAGE DISTANCE	24 IN.
BIL	150 kV
60 Hz WITHSTAND (10 SEC WET):	60 kV
WEIGHT	77 LB

A-6236

Figure 4-14. 25-kv Insulator

LEAKAGE DISTANCE:	43 IN.
BIL:	250 kV
60 Hz WITHSTAND (10-SEC WET):	100 kV
WEIGHT:	105 LB



A-6202

Figure 4-15. 50-kv Insulator

With the reason for the advanced state of the art in traction transformer design established, it is necessary to determine whether direct technology transfer is feasible, or whether modifications are necessary to suit the arduous conditions encountered in North America. The basic questions are: (1) method of rating, (2) strength of construction, and (3) method of cooling.

It has been reported that the DML transformer has been rated to continuously supply the six D77 traction motors at their total continuous rating plus the required auxiliary loads. The mechanical design of the transformer is compatible with vibration levels in excess of 5 g, which are beyond that encountered even in heavy North American practice.

The method of cooling the transformer has become a crucial question recently following the ban on polychlorinated biphenyls (PCB's). The accepted transformer coolant had been askerel, but the ban on PCB's has necessitated the use of other nontoxic coolants. Some countries use mineral oil but its extreme flammability makes it generally unacceptable in North America. Conrail recently undertook an investigation of the feasibility of replacing askerel with silicone fluid, an inert liquid, which, although more flammable than askerel, is not as flammable as mineral oil and is generally gaining acceptance for traction transformers throughout the world. Conrail found that using silicone fluid resulted in the need to derate the transformer (originally designed for cooling with askerel) by 30 percent. This has been recognized in the transformer design proposed for the DML and particular attention has been paid to coolant flow patterns. These design techniques have already been proven in railroad service.

The primary and secondary windings are constructed of paper-wrapped copper conductors, formed on bakelized paper cylinders, with the cylinders mounted on the core legs and held in position by axial wedges running the full length of the winding. Detailed attention to the mechanical integrity of the windings ensures that the windings can withstand the mechanical forces associated with a short circuit.

The magnetic core is built up of low-loss, cold-rolled, grain-oriented silicon steel laminations that are fully annealed after punching. The leg/yoke joints are mitered to give optimum magnetic performance. Ultimate mechanical strength is provided by core bolts, limited in number so that they do not impair the magnetic performance achieved by the mitered joints and high-grade steel. Extra rigidity of the core clamping framework is obtained by bonding together the outer packets of the core with epoxy resin. The resultant design provides a robust, rigid core with low loss and magnetizing current, even at maximum input voltage.

The design of the high-voltage connection is mounted on top of the transformer tank so that the actual connection is to the shedded bushing protruding through the roof. Low-voltage connections are tinned copper cast in a resin moulding. Outlines of the 25- and 50-kv transformers are shown in Figures 4-16 and 4-17.

Main Converter Assembly

The main converter assembly contains the following subassemblies:

(a) Phase delay rectifier

(b) Electronic control unit

(c) Power factor correction capacitors

(d) Single-phase auxiliary rectifier

(e) Three-phase auxiliary rectifier

(f) Field power supply

The main converter processes and controls the ac power from the main transformer to provide dc power for the traction motors. The converter basically consists of an input power factor correction filter assembly, input fuse assembly, eight thyristor subassemblies, electronic control unit (ECU) assembly, and oil cooling system for the thyristor subassemblies. The converter is housed within a 60 in. by 50 in. by 71 in. steel enclosure and weighs approximately 4300/4100 lb for the regenerative/non-regenerative options. The equipment layout is shown in Dwg. L2016782.

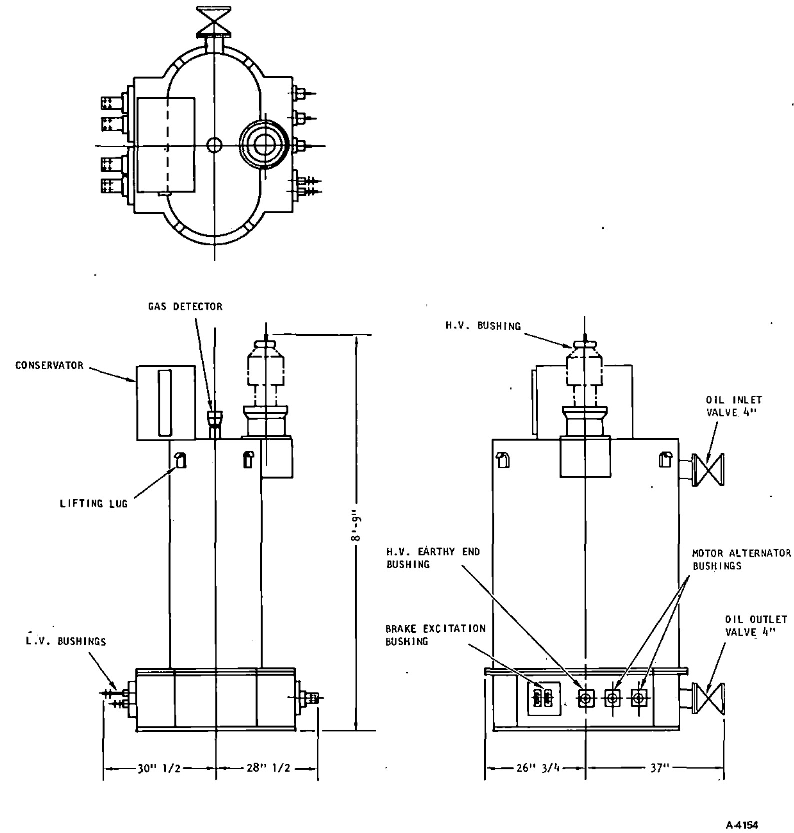


Figure 4-16. 25-kv Transformer

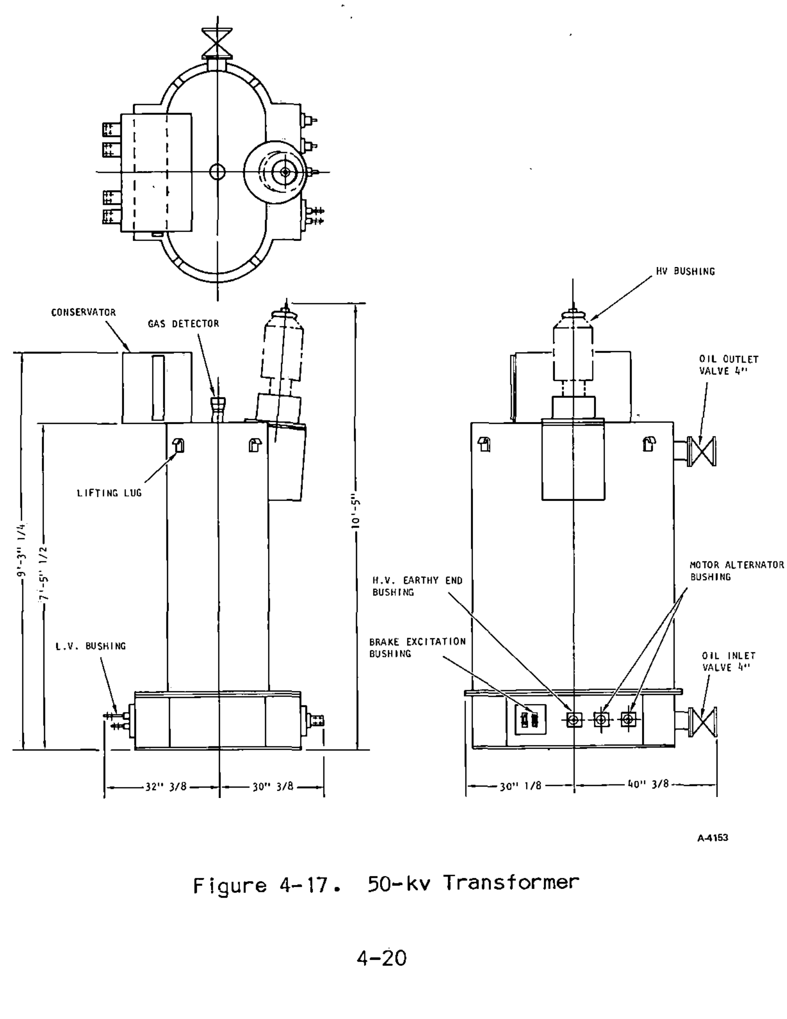


Figure 4-17. 50-kv Transformer

Electrical connections within and between the various power assemblies, as well as external power connections, are via tin-plated aluminum bus bars. The bus bars are designed to limit their temperature rise to 30°C over 40°C ambient temperature conditions. Connections between the ECU and the internal power or external interface circuits are via electrical connectors using standard copper insulated wire or cable.

1. Phase Delay Rectifier

The thyristors form two identical bridges, each consisting of four thyristor subassemblies that are electrically connected in series. Each thyristor subassembly contains two electrically paralleled thyristors, resulting in a total of 16 thyristors being used for power conversion. Each thyristor is mounted between two oil-cooled heat sinks whereby the maximum thyristor junction temperature is limited to 212°F based on an oil flow of 6 gpm at 145°F. In addition, each thyristor subassembly contains two suppression networks for voltage transient protection, two inductors for current stress control, and two gating networks for turning on or firing the thyristors. The thyristor subassembly networks, inductors, and thyristor heat sinks are mounted on an insulated panel for ease of manufacture and maintenance.

The dc current and voltage output characteristics are shown in Figure 4-18, from which it can be seen that the maximum current requirement is determined immediately after transition. To minimize the main transformer rating, it will be assumed that the 5000-amp requirement is for no more than one hour at a time. The phase delay rectifier has to be designed for 5000 amp continuous, although in the 11- to 19-mph range, the 1050 amp per motor will be a 1-hr rating due to traction motor limitations.

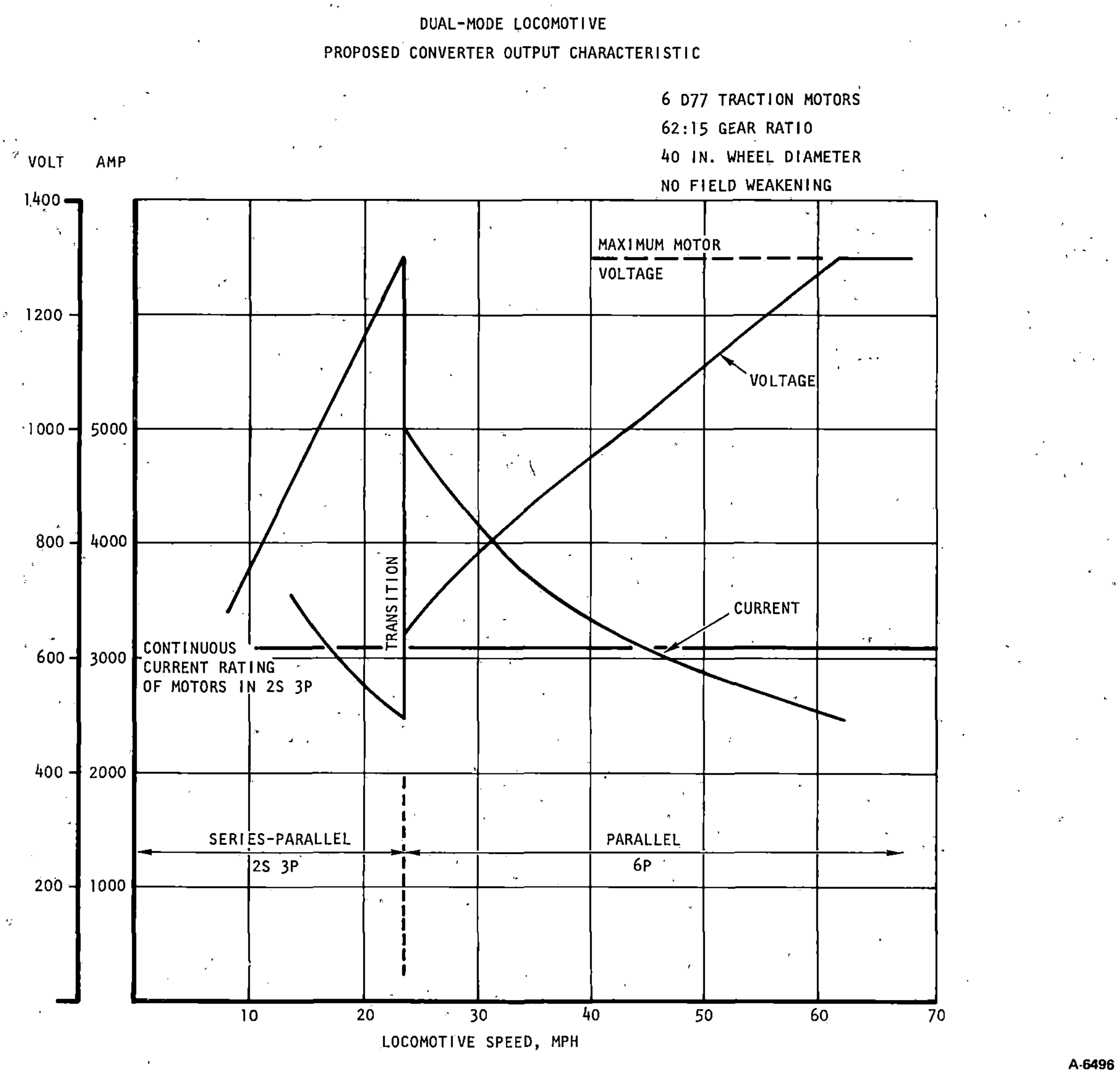


Figure 4-18. Output Characteristics of DML Converter

2. Electronic Control Unit (ECU)

The ECU consists of 7 printed wire assembly (PWA) cards, control relays, and interface wiring/connectors, all contained within an aluminum chassis. The PWA cards and control relays are plug-in units. The chassis wiring is based on established wire wrap techniques currently used in all Garrett transit vehicle applications. The ECU is mounted independent of the power assemblies to provide minimum electrical interference levels and to allow servicing of the ECU via an external access door of the converter enclosure.

Also mounted within the main converter assembly are the auxiliary rectifiers, which utilize the same oil cooling circuit as the main converter. For the regenerative converter the field power supply is also included.

3. Capacitor Bank

The power factor correction assembly consists of 12 capacitors, each with a series fuse for protection purposes. Six capacitor/fuse combinations are connected in parallel across each set of the main transformer input bus bars.

The fuse assembly is integral with the bus bar arrangement, with each fuse accessible for inspection or replacement without further disassembly. Each fuse is equipped with an indicator for inspection purposes.

4. Auxiliary Rectifiers

There are two auxiliary recitifiers contained within the main converter assemblies, a half-controlled single-phase rectifier for the electric mode, and a fixed three phase rectifier for the diesel mode. The required ratings are shown in Table 4-6. The diodes and thyristors are oil cooled using the same oil circuit as the main phase delay rectifier.

TABLE 4-6

DML AUXILIARY LOADS

Electric Mode, kw	Load	Diesel Mode, kw
30	Compressor (loaded)	30
2	Oil cooler blower motor	
91	Equipment blowers (maximum)	-
24	Engine heating	-
20	Battery charging, etc.	20
167	TOTAL (peak)	50

5. Field Power Supply

The regenerative option requires a field power supply (FPS) semiconverter fed from an auxiliary winding of the main transformer. FPS responds to control signals from the four voltage control trainlines during braking to give the required level of braking effort. Output characteristics of FPS are:

Output current (maximum)	1000 amp
Output voltage (normal)	40 v
Output voltage (forcing)	60 v

Cold Weather Protection Equipment

In order to provide the railroads with the option of shutting down the diesel engine during electric mode operation, it is necessary to ensure that the engine and associated systems are not damaged during cold weather operation. A system has been identified that provides the protection required and is available from Kim Hotstart Manufacturing Company, Spokane, Washington.

The system, as presently available, can handle any two of three fluids--lube oil, coolant, or diesel fuel. To provide low temperature protection for all three fluids, the system requires merely an additional heating chamber, pump, and control gear. A two-fluid system is shown in Figure 4-19, and the palletized equipment is shown in Figure 4-20. In support of this study, Kim Hotstart have prepared outline designs for the three fluid system.

The system requires a standard 60-Hz, three-phase supply that is usually available at locations where locomotives are normally stored. In the case of the DML, the three-phase, 60-Hz supply is available from the motor alternator set.

Auxiliary Transformer-Rectifier

The auxiliary transformer/rectifier is required to provide the electrical loads presently supplied by the auxiliary generator for lighting, control loads, D14 excitation, and miscellaneous loads.

The output of the auxiliary generator is controlled over the full speed range of the engine to 74 vdc and this would be the output of the auxiliary transformer-rectifier. The standard auxiliary generator is rated at 10 kw, and the auxiliary transformer-rectifier will be similarly rated at 10 kw.

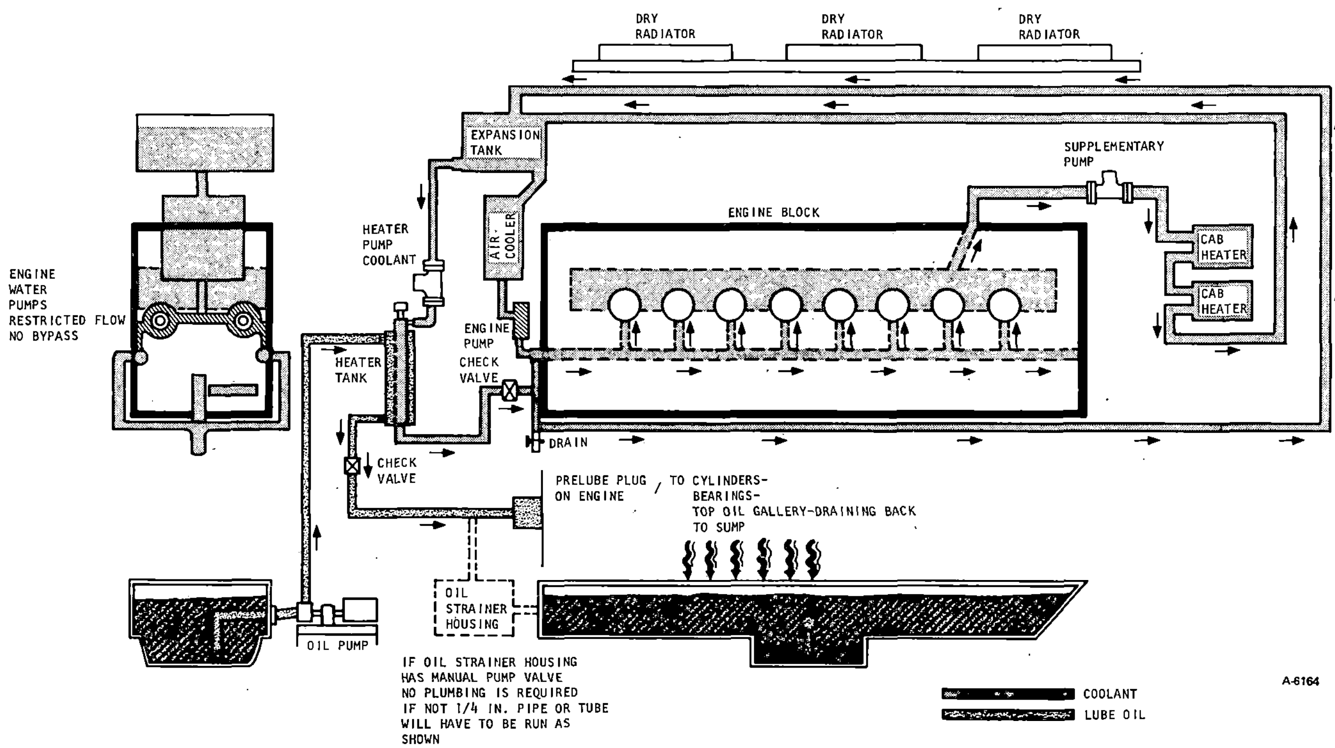
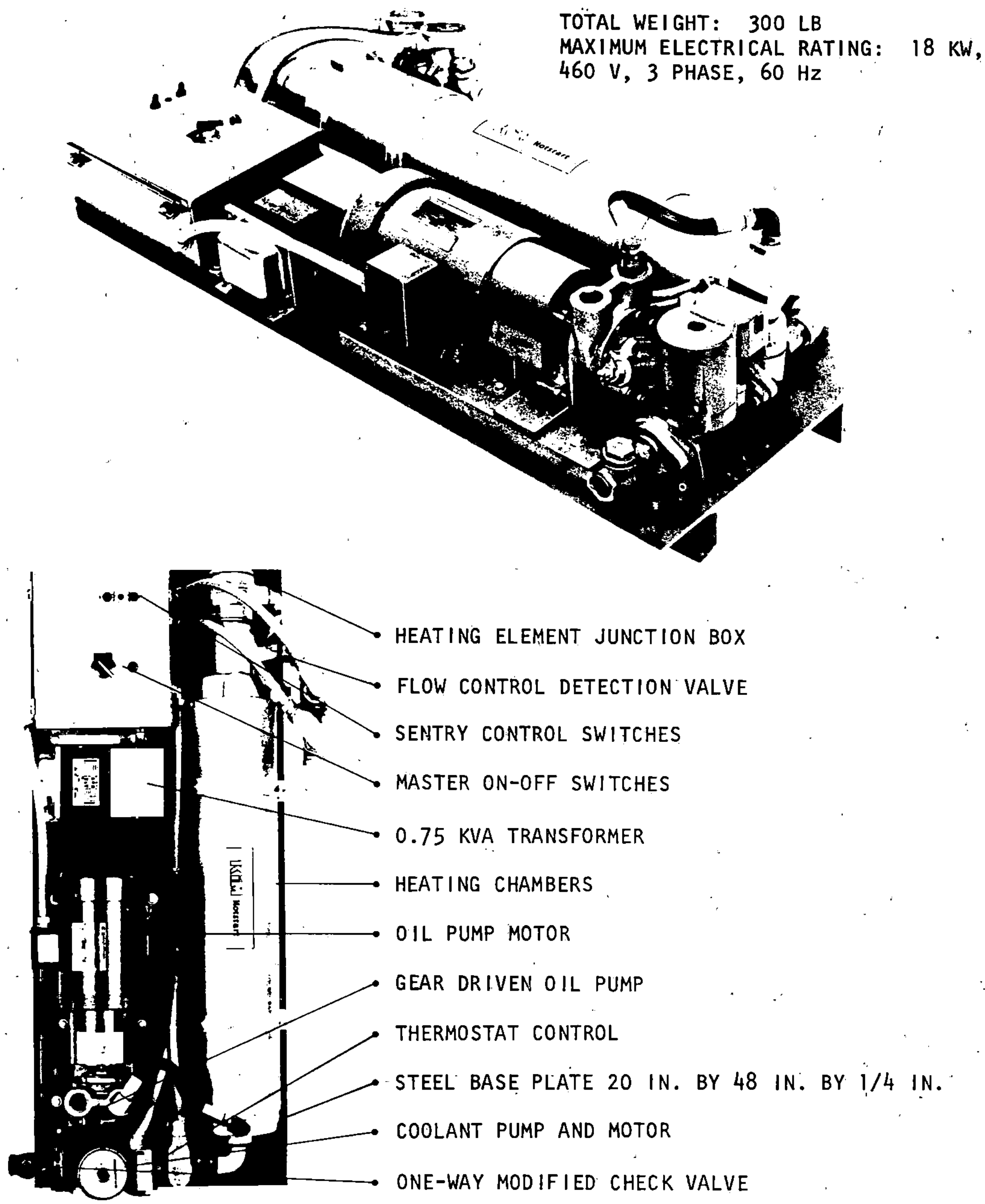


Figure 4-19. Typical Kim Hotstart Two-Fluid System



F-32714

Figure 4-20. Kim Hotstart Equipment (Two Fluid)

These units are available from many commercial suppliers. A typical model has been identified as available from General Electric with dimensions of 24 in. by 16 in. by 24 in. and a weight of 235 lb.

Compressor

An electrically driven compressor is required to supply compressed air in the electric mode, whether or not the diesel engine is allowed to idle, since the compressor delivery at engine slow idle speed would be inadequate for train needs. The adoption of an electrically driven compressor could also have a favorable impact on the overall operation of the locomotive, eliminating, for example, the operation of the engine at high speed (notch 5) in order to pump up a train since the electrically driven compressor would be a constant speed machine.

The standard compressor on the SD40-2 has a displacement of 254 cfm at 900 rpm, which results in approximately 180 cfm delivered when operating at 140 lbf/sq in. Therefore, a constant speed machine would require a delivery somewhat less than that of the existing compressor. Since the maximum engine speed permitted by EMD for pump-up operations is that equivalent to notch 5 (645 rpm), it is considered that the electrically driven compressor delivery should be 135 cfm or higher.

Two basic options are available for the compressor, reciprocating or screw. The reciprocating compressor has been the traditional compressor used on locomotives for many years and has been well developed. It does suffer from a number of disadvantages, however, such as significant maintenance requirements and noisy operation. The screw compressor offers much less maintenance and has seen many applications at duty cycles similar to that required by the DML.

A suitable compressor is available from the Sullair Corporation, which is 48 by 29 by 36 in. and weighs 790 lb. The compressor is driven by a 40-hp, three-phase, 460-v machine, and has a delivery of 140 cfm at 140 psi.

Equipment Blower Drive

The existing equipment blower and drive system is shown in Figure 4-21(a). The auxiliary generator and blower are driven at approximately three times engine speed. To provide for traction motor cooling during electric mode operation, it is necessary to devise a method of operating the equipment blower when the diesel engine is shut down or idling. The arrangement shown in Figure 4-21(b) achieves this. The existing AG10 or AG18 generator is replaced by a belt-driven three-phase alternator/motor and clutch, so that in the diesel mode, the electrical machine is an auxiliary alternator supplying power for the compressor and battery charging; and in the electric mode, the electrical machine is a motor and is used to drive the blower. The clutch allows the blower to turn when the diesel engine is shut down.

EQUIPMENT LAYOUT

The equipment layout is shown in Figures 4-22 and 4-23 for the 50- and 25-kv locomotives, respectively. It can be seen that in order to accommodate the roof equipment, it has been necessary to move the cab and electrical cabinet forward 6 ft and relocate the primary air filter. The transformer is mounted directly below the roof equipment, thus facilitating the high voltage connection.

Cables connect the transformer and main converter assembly, which is located toward the rear of the locomotive and adjacent for the inductor. Cables from the converter and inductor connect to the electrical cabinet toward the front of the locomotive.

A 3,000-gal fuel tank is centrally located on the underframe. In the space made available by the shortened fuel tank, a motor-alternator set for auxiliary loads is located.

The existing engine driven compressor has been replaced by the constant speed electrically driven compressor. The auxiliary alternator/equipment blower motor is located in place of the original auxiliary generator.

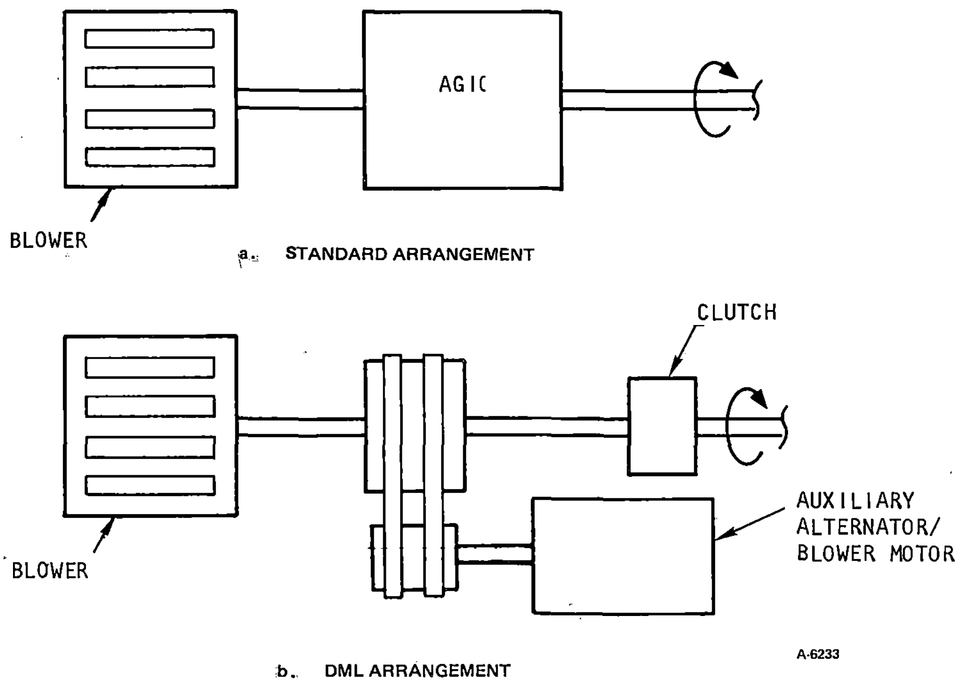


Figure 4-21. Standard and Modified Traction Motor Blower Drive Systems

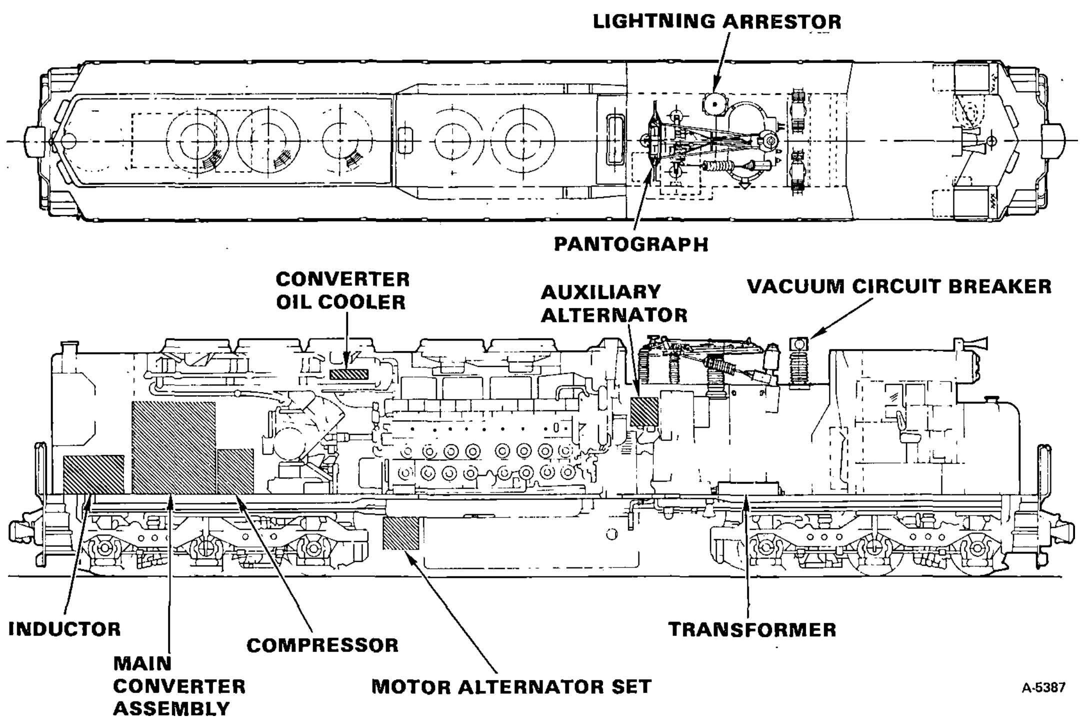


Figure 4-22. DML Equipment Layout - 50 kv

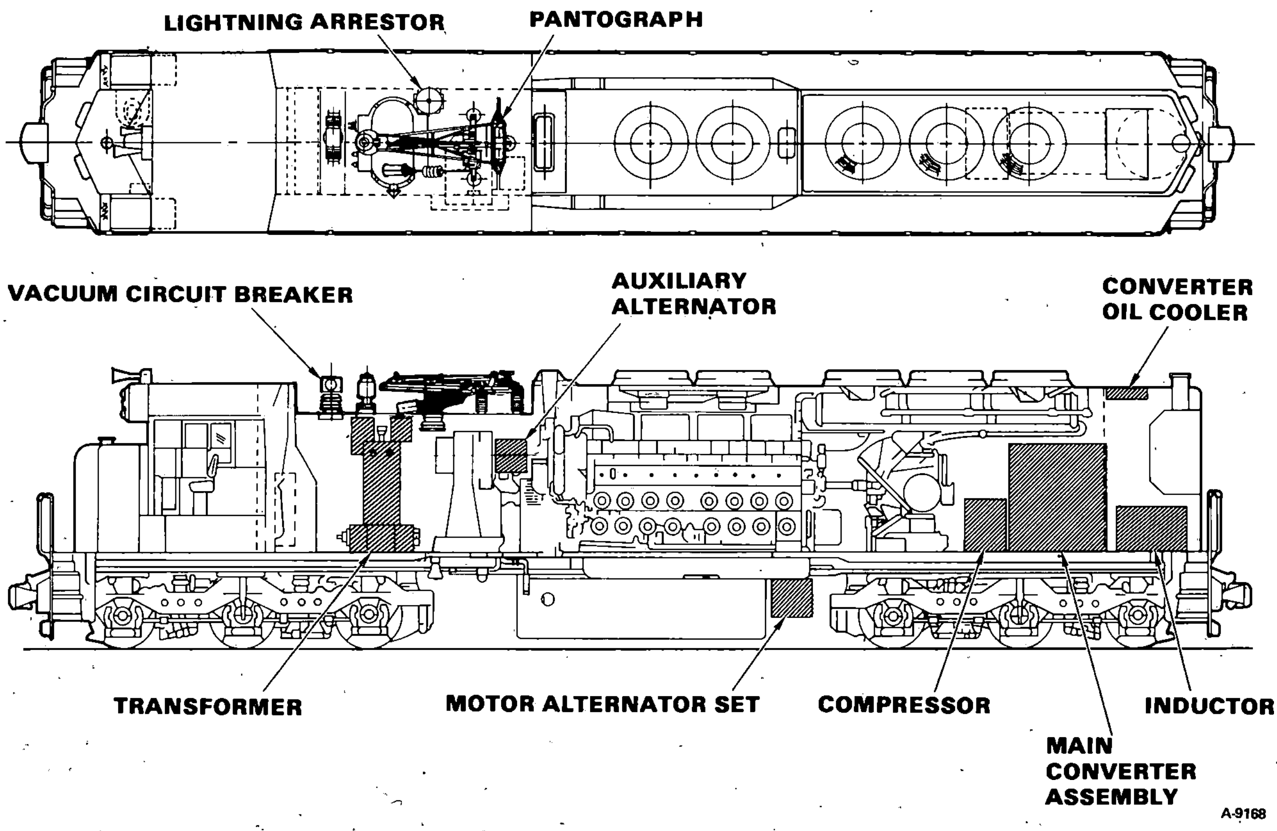


Figure 4-23. DML Equipment Layout - 25 kv

The transformer oil cooler is located in the main air intake, thus avoiding the need for an additional auxiliary machine.

The equipment diagrams used to determine bolster loads are shown in Figures 4-24 through 4-27, and the calculations for locomotive balance are contained in Appendix C. The calculated bolster loads do not vary beyond the normally accepted 5,000 lb, and therefore balancing ballast is not considered necessary. The weights of the DML options are summarized in Table 4-7.

TABLE 4-7

SUMMARY OF DML WEIGHT CALCULATIONS

Option	Weight, lb
50 kv, regenerative	397,806
50 kv, nonregenerative	397,605
25 kv, regenerative	394,059
25 kv, nonregenerative	393,888

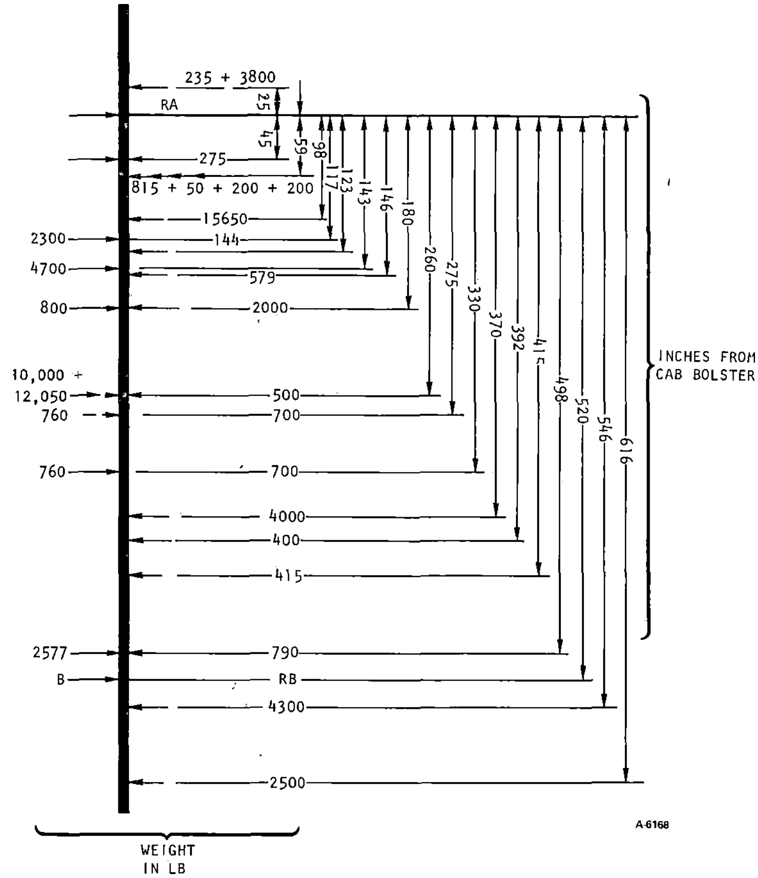


Figure 4-24. Equipment Location Diagram for 50-kv Regenerative

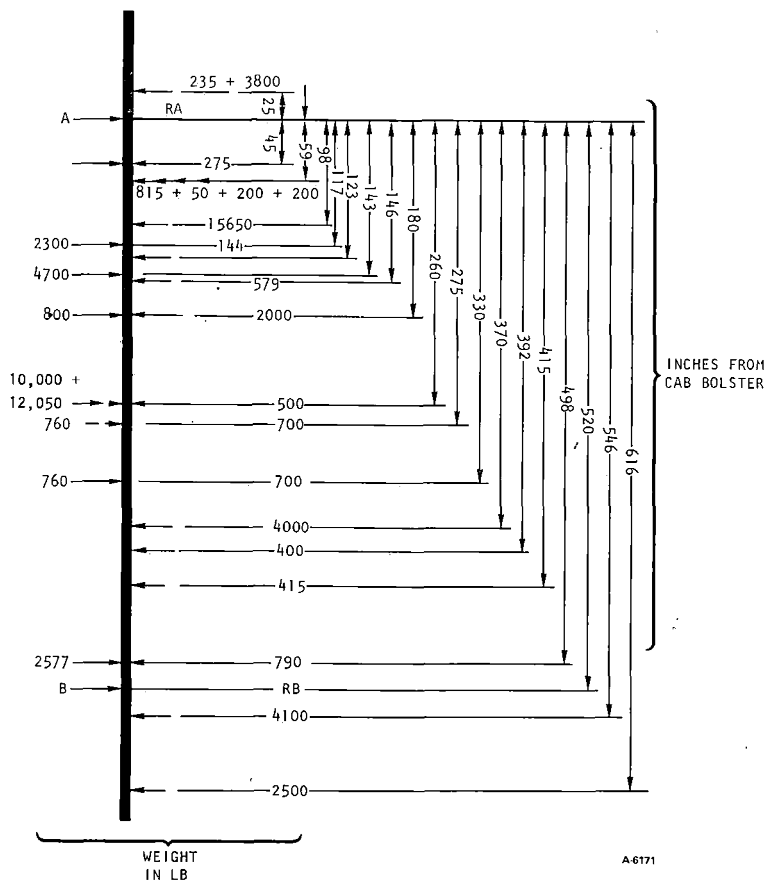


Figure 4-25. Equipment Location Diagram for 50-kv Regenerative

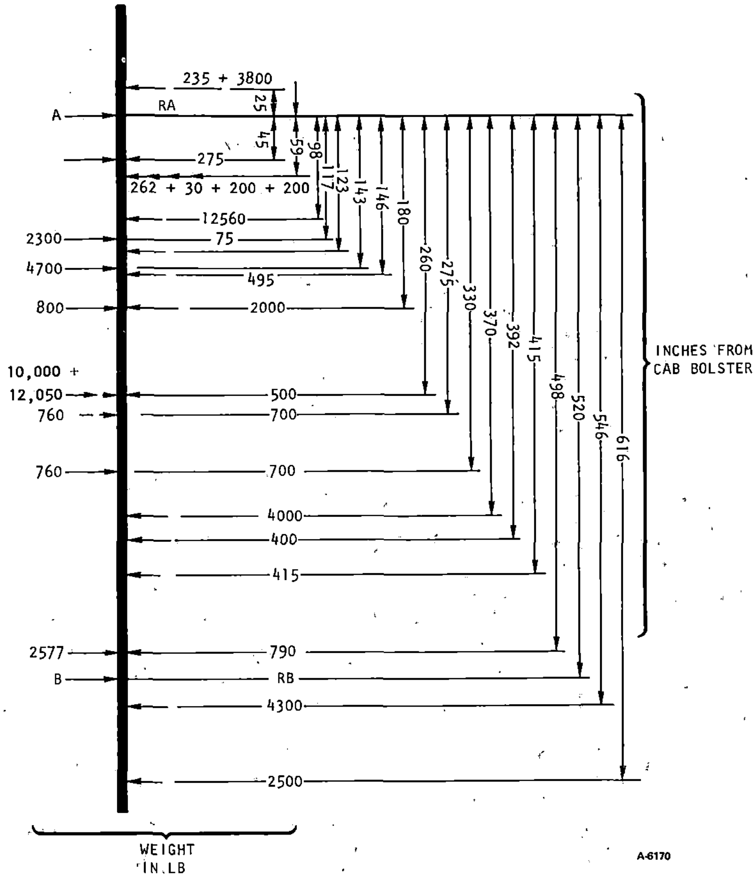


Figure 4-26. Equipment Location Diagram for 25-kv Regenerative

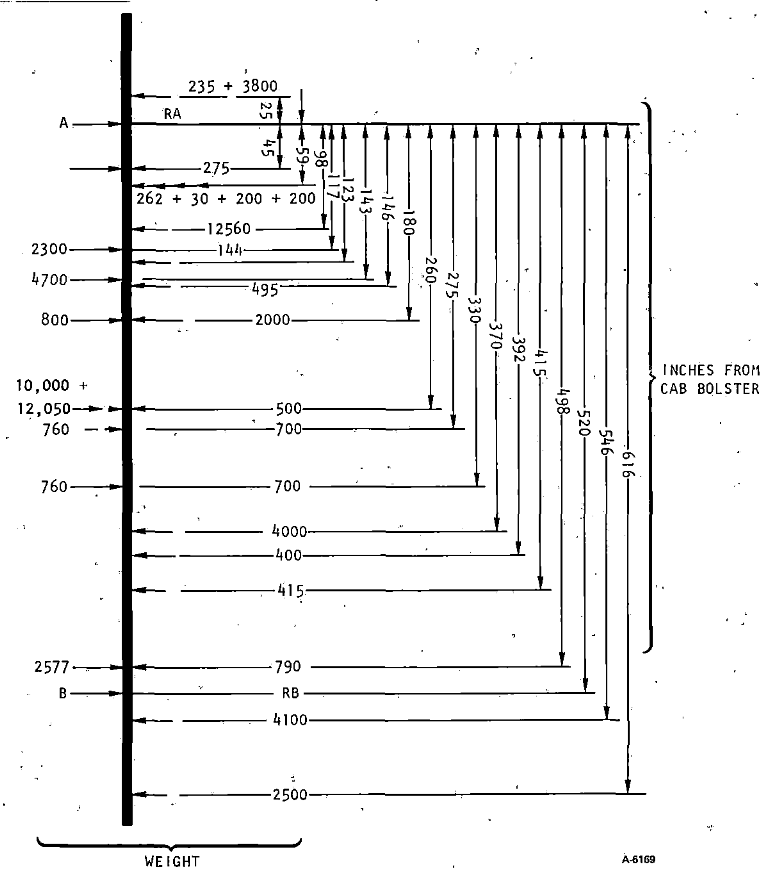


Figure 4-27. Equipment Location Diagram for 25-kv Nonregenerative

SECTION 5

SYSTEM PERFORMANCE SPECIFICATIONS

INFRASTRUCTURE PARAMETERS

Catenary Voltage

A variation in catenary voltage is primarily caused by the following factors:

Loading--At times of high current loading, the supply source characteristics are such that voltage inherently drops, and at times of low current loading, voltage rises.

Impedance--As the distance from the nearest substation increases, so the impedance and hence the voltage drop increases.

Emergency Feeding--If a substation is out of service, electrical supply must be maintained over longer distances.

To ensure satisfactory operation of equipment under all probable conditions, it is proposed to handle catenary voltage variations as follows.

1. Equipment Insulation

The equipment insulation must be able to withstand the maximum probable steady-state voltage, which is typically 110 percent of the nominal value. In addition, the transformer is designed to withstand 170-kv BIL on a 25-kv (nominal) system and 250 kv on a 50 kv (nominal) system.

2. Locomotive Performance

To maintain conservative performance parameters, locomotive performance has been calculated on the basis of 96 percent of the nominal catenary voltage. In the case of the proposed DML design, however, with maximum motor voltage being reached at almost maximum locomotive speed, the effect on performance characteristics is only experienced at speeds above 59 mph.

3. Locomotive Auxiliaries

The major and often limiting factor in the operation of an electric locomotive at reduced catenary voltage is the performance of the locomotive auxiliaries and, in particular, the compressor and equipment blower. Under conditions of emergency feeding, significant loss of voltage on the catenary is possible, and therefore the locomotives auxiliaries must be able to maintain full performance operation to 50 percent of nominal voltage.

These considerations are summarized in Table 5-1.

TABLE 5-1

ASSUMED CATENARY VOLTAGE LEVELS

	25-kv System, kv	50-kv System, kv
Nominal	25	50
Equipment insulation	27.5	55
BIL	170	250
Locomotive performance	24	48
Locomotive auxiliaries	12.5	25

Maximum Axle Load

The axle load of a locomotive is often a tradeoff between the confidence level of the adhesion value assumed, and the track maintenance required by a given axle load. A given locomotive design has a basic minimum weight determined by two factors:

(a) Weight of equipment, including locomotive frame, truck assemblies, power equipment, cab equipment, hoods, and auxiliary equipment

(b) Ballast to obtain pivot balance, which means that judicious location of equipment can minimize or eliminate the ballast required to obtain balance. Ballast compensates for the lack of a steam generator in a multipurpose design locomotive.

Modern practice is to drive all axles, thereby maximizing the tractive effort capability of the locomotive. This has been made possible by improvements in truck design, starting with the steam locomotive and reduction in power equipment weight, allowing a reduction in the number of axles for a given power level while still maintaining an acceptable axle load. Pony wheels were originally required on steam locomotives to steer the locomotive frame round curves; this practice was perpetuated on the early diesel locomotives, with the pony wheel steering the truck. Improvements in truck designs, and in particular the self-steering capabilities, have made the pony wheel obsolete. Therefore, all the weight of a modern locomotive is adhesive weight, historically referred to as "weight on drivers".

The locomotive is not part of the net payload of a train and from that viewpoint its weight should be minimized. Furthermore, the heavier the locomotive, the higher the track maintenance. As discussed earlier, there is a minimum locomotive weight and this weight (with full variable supplies) is considered to be the baseline. In practice, the locomotive will never use all the variable supplies (fuel, sand, lubricating oil) but it is probable that the locomotive, under certain circumstances, could consume 80 percent of the variable supplies. An analysis of the weight of an SD40-2 is contained in Table 5-2.

TABLE 5-2

ANALYSIS OF SD40-2 WEIGHT

	Minimum, lb	Maximum, lb
Full weight	368,000	416,000
Variable supplies (80 percent)		
Fuel	17,306	21,632
Lubricating oil	317	1,318
Sand	16,800	16,800
"Empty" weight	333,577	376,250

The axle load chosen by a railroad for a given locomotive depends on a number of factors, including:

Bridge strength--Railroads with old bridges may have to impose an axle load limit to operate the locomotives within the capabilities of the bridge. This is not usually a problem for railroads whose bridges were designed for some of the larger steam locomotives.

Adhesion--The level of adhesion assumed directly affects the amount of ballasting requested by a railroad. Figure 3-10 showed that in the minimum condition the SD40-2 incurred an adhesion limitation from 4 to 13 mph, whereas a locomotive ballasted to 395,000 lb incurred an adhesion limitation only between 10 and 12 mph. The significance of these adhesion limitations is dependent on the method of operation employed by each railroad. A high-speed railroad operating above 15 mph at all times would not be unduly restricted by the adhesion limitation, whereas a railroad using extensive drag operation would require a significant amount of ballast to eliminate the adhesion limitation. The question of adhesion is more fully addressed later in this section of the report.

Track Maintenance--It has been suggested (Reference 6) that the cost of track maintenance is linked to the gross tons carried by the rail; typically, the life of heavy rail is quoted as 650×10^9 gross tons. This is, however, a simplification (justified in the context of that report) since the relatively high unsprung mass associated with a locomotive plays a significant part in track damage. The objective is to minimize the locomotive weight to minimize track costs, but other criteria usually predominate up to a fundamental limitation imposed by the ability of the track bed to carry such loads.

The above factors are used by railroads to determine the axle load best suited to their operation. The heaviest axle load currently in use in the U.S. is that of the GE U50C's, which carry 208.5 tons on 6 axles for an average axle load of 69,500 lb. For unrestricted interchange between all railroads, AAR specifies a maximum axle load of 65,750 lb. The design objective of the DML is to meet this criterion. At this axle load, however, the DML will incur an adhesion limitation between 10 and 18 mph. In order to minimize this limitation, the DML can also be ballasted to the 69,300 lb axle load currently used by BN for their SD40-2 locomotives.

Adhesion Limits

This report does not try to establish the adhesion limitations that should be applied to the DML. It does however, show that the DML concept is impacted by the adhesion level assumed, and that it is necessary to report the state of the art with respect to adhesion and its implementation by U.S. railroads.

The operation of a locomotive (electric or diesel) at low speed is limited by one of two factors--traction motor capability and coefficient of friction between wheel and rail.

The capability of the traction motor is a design parameter determined by the builder, based on the requirements of the railroads and the known use to which the locomotive is to be put.

The coefficient of friction between the wheel and the rail is not the assumed adhesion level. The static coefficient of friction between clean dry steel and clean dry steel is 0.78. If this coefficient of friction exists between the wheel and the rail, then the traction motor may be able, subject to other limitations, to transmit the tractive effort corresponding to the product of the coefficient of friction and the weight on drivers. It is well known, however, that a number of factors act either singly or in unison to reduce the coefficient of friction below its theoretical maximum. These factors can include:

(a) Rain--Low coefficients of friction are most frequently experienced in wet weather, as shown in Figure 5-1 (Reference 9). During an adhesion survey, light rain was encountered and the coefficient of friction (measured by determining the force required to slow a rolling wheel) was immediately halved.

(b) Tunnels--The effect of tunnels on the coefficient of friction is dependent on the characteristics of the tunnel (wet, dry, sandy, etc.). Reference 9 gives some typical effects, which are shown in Figure 5-2.

(c) Leaves--The effect of leaves was also reported in Reference 9, and the results are presented in Figure 5-3.

(d) Speed--There have been many attempts to determine the relationship between the coefficient of friction and speed. The data published by Reference 9, and contained in Figure 5-4, is in general agreement with many of the empirically derived relationships.

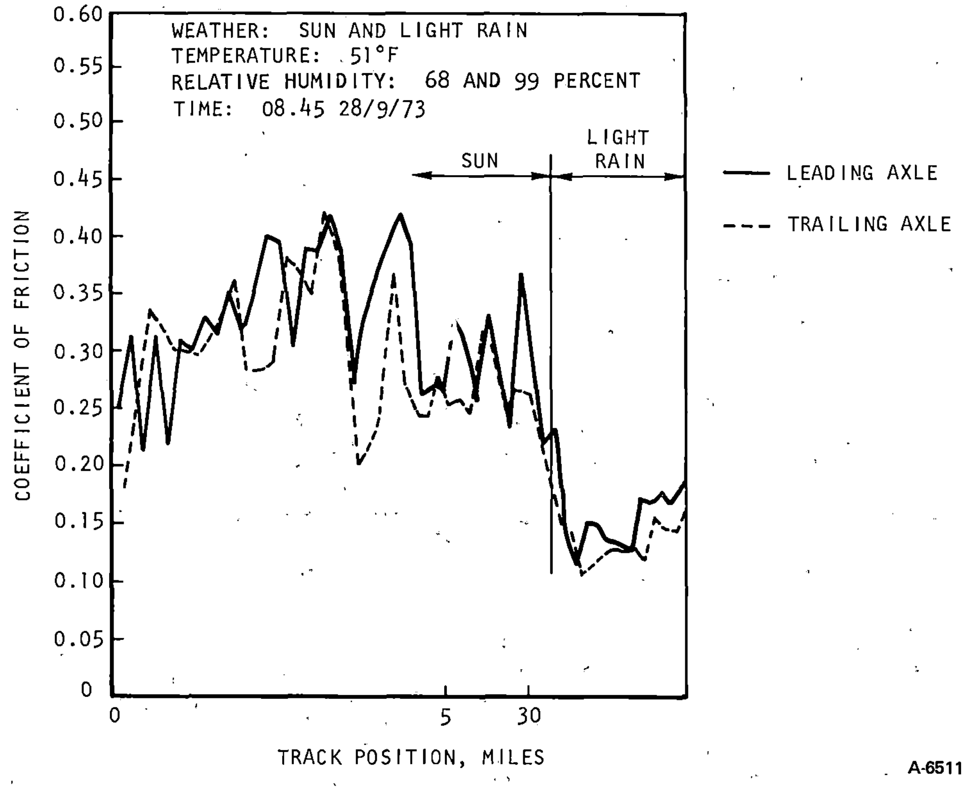


Figure 5-1. Variation of Coefficient of Friction with Weather Conditions

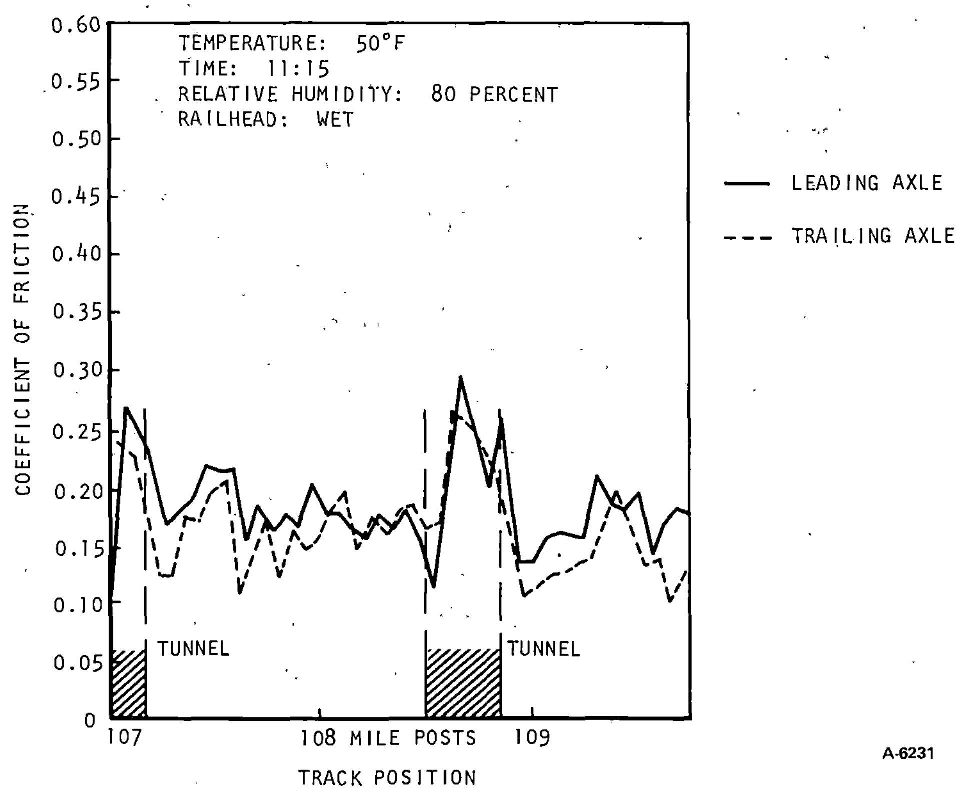


Figure 5-2. Variation of Coefficient of Friction in Tunnels

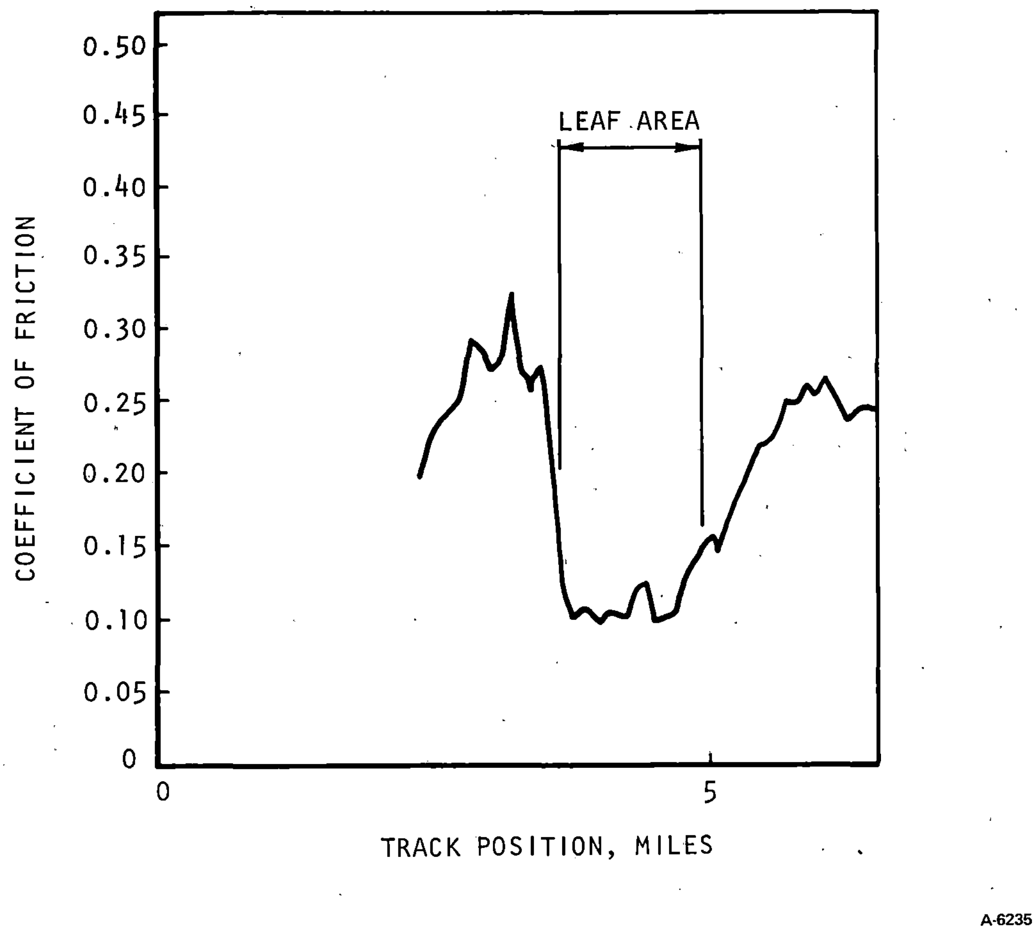


Figure 5-3. Variation of Coefficient at Friction with Leaves

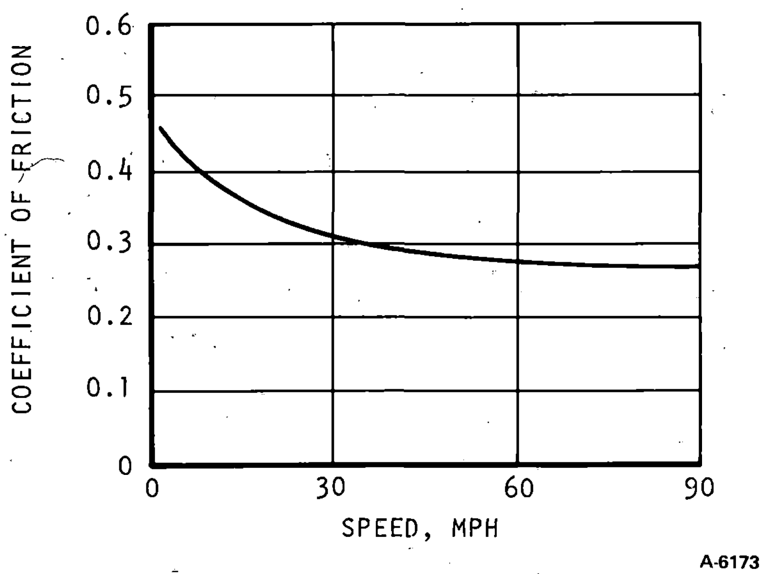


Figure 5-4. Variation of Coefficient of Friction with Speed

From the above, it can be seen that a number of independent factors can, almost at random, affect the coefficient of friction between the wheel and rail. In addition, when determining the coefficient of friction to be assumed for traction purposes, i.e. the adhesion level, there are two locomotive characteristics that must be considered:

Weight variation--As variable supplies are consumed, the locomotive weight could vary from 416,000 to 376,250 lb (9.5 percent) or from 368,000 to 333,577 lb (9.4 percent) as shown in Table 5-2. This weight variation means that to maintain a minimum confidence level of a given adhesion level, the baseline coefficient of friction should be reduced by 9.4 percent. In the case of the DML, the reduced fuel tank load will result in a weight variation of 7.6 percent and a corresponding reduction in the baseline coefficient of friction.

Weight Transfer--Weight transfer is the redistribution of weight as the locomotive accelerates. The degree of weight transfer is solely dependent on the traction motor/truck and truck/locomotive geometry. Careful attention, in particular, to the arrangement of the traction motors is extremely important. The weight transfer characteristics of a typical EMD locomotive are shown in Figure 5-5, which shows the variation in axle load as a function of the tractive effort applied at the wheel rim. Considering the case of starting tractive effort and assuming operation at the continuous rating of the D77 traction motor on an axle with a static load of 69,000 lb, the actual axle loads will vary from 67,061 lb (No. 4 axle) to 70,939 lb (No. 3 axle) (±2.8 percent). The No. 1 axle is the most likely to slip; i.e., under the above starting conditions, it experiences a weight transfer of -1.6 percent. The No. 4 axle is never exposed to virgin rail and therefore the cleaning action of axles 1, 2, and 3 improves the operating environment of the No. 4 axle. Experience shows that on leading locomotives, the No. 1 axle slips most frequently and on trailing locomotives, it is the No. 4 axle.

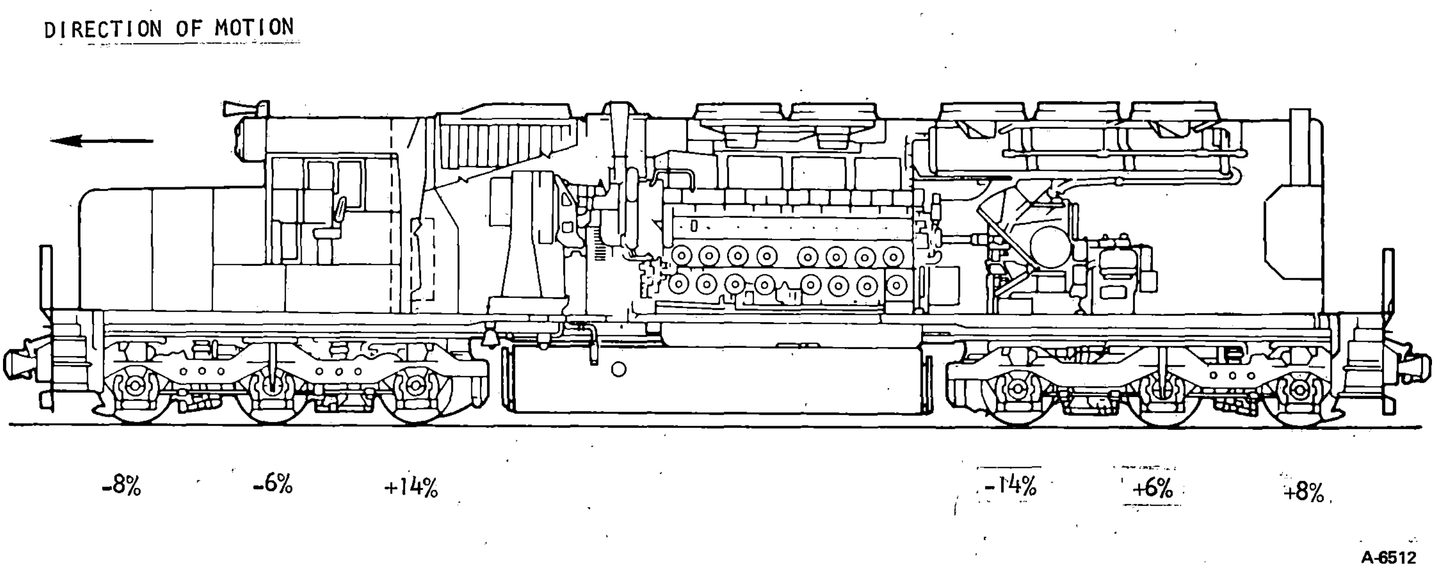


Figure 5-5. Weight Transfer Characteristics of a Typical C-C Locomotive

Therefore, to maintain the same minimum confidence level of not slipping, the baseline coefficient of friction must be reduced by the No. 1 axle weight transfer, 1.6 percent. In addition, the coefficient of friction has been shown to vary with the type of rail, whether welded or jointed, mainly due to dynamic forces caused by the vertical rail profile; as estimated from Reference 3, it reduces the coefficient of friction at 12 mph by 7 percent.

The final factor, which has not been quantified, is the effect of curvature. Reference 3 suggests that a 4-deg curve could result in 50 percent loss of adhesion. This appears to be excessive but does indicate the importance of investigating curvature effects.

The above discussion centered around the characteristics of the railroad operation that will reduce the base coefficient of friction, assuming well used, clean, welded rail, and reflected values of adhesion that could typically be used under the stated conditions. It will be noted, however, that there is no factor of safety included in the calculation, an omission that cannot be tolerated in the real world. It is not impractical, however, to operate under conditions of zero slip risk and therefore a compromise is usually reached. The Southern Railway (Reference 10) have estimated conservatively that adhesion at starting can be assumed to be 0.235 and 0.185 at 60 mph.

The remaining aspect of adhesion centers around the consequences of a wheel spin; it is this aspect that is impacted by the locomotive control equipment. The wheel slip protection (WSP) systems commonly in use on diesel locomotives in the U.S. detect slip based on current/voltage imbalance and reduce torque on all motors when such a slip is detected. This method of control has a relatively large tolerance band in order to take account of differing wheel diameters, traction motor tolerances, and differing traction motor cooling airflows, resulting in traction motors of different temperatures and hence differing resistances and current flows.

An alternate method of detection is to measure axle speed directly, using toothed wheels and a magnetic probe similar to the locked wheel detection system provided to order by EMD on road locomotives, or to use the existing gear wheel teeth and a probe located in the gear case. The problem with this method is determining the correct axle speed and which axles are slipping. A tolerance band is still required to take account of differing wheel diameters but other compensation is not required. There are two methods of determining the true locomotive speed. Some newer locomotives utilize the Doppler effect to obtain a reference by bouncing a signal off the track. This requires sophisticated equipment not yet fully proven in traction service. The more conventional method is to assume that if tractive effort is being applied to the wheels, the lowest speed is the true locomotive speed and if braking effort is being applied, then the fastest speed is the true locomotive speed. This method is still subject to wheel diameter tolerance. WSP is then based on speed difference between axles and acceleration of axles.

The axle speed method of WSP is recommended for the DML in the electric mode. To avoid unnecessary modification of the existing equipment, WSP in the diesel mode will be based on current/voltage balance. At a later stage in the development, it may be desirable to integrate the two systems.

Conventional electric locomotives often control motors on a per truck, per pair, or individual axle basis, which means that the consequences of a slip are not as severe as in the case of the all-axle control available in the diesel locomotive and the DML. Therefore, an electric locomotive can be allowed to operate at a higher slip risk for the same overall effect on the system than a diesel or DML.

An advantage conventional electric locomotives share with the DML in the electric mode is the speed of response of the power source to the WSP signal. The opening of the field contactor in the diesel mode results in a relatively slow decay of alternator field and hence output. In the electric mode, converter output can be reduced to zero within one-half cycle (8.3 msec). This quick response justifies operating the locomotive with a greater risk of slip, since the axle can be restored to the non-slip condition and tractive/braking effort reapplied with the minimum of delay.

Operational Speeds

It is necessary for the railroad operation to be power limited for a significant section of the route to take full advantage of the benefits of the DML. This condition occurs typically under two circumstances: (1) when operating in mountainous territory, and (2) when operating at a low power-to-weight ratio.

Under these circumstances, the DML can be operated at a significantly higher power rating in the electric mode than in the diesel mode. The speeds at which the candidate locomotives become power limited in the diesel mode are shown in Table 5-3.

TABLE 5-3

LIMITATIONS OF CONSTANT POWER OPERATION
(with 62:15 Gear Ratio)

Locomotive type	Engine output, hp	Rail power, hp	Tractive, effort	Minimum speed for full power, mph
SD38	2000	1730	83100	7.8
SD40	3000	2600	83100	11.1
SD45	3600	3120	83100	14.1

The six-axle DML becomes power limited (by the rating of the traction motor) at approximately 18 mph. Therefore, to obtain full benefit from deployment of the DML, a railroad must operate at speeds typically above 18 mph. A partial benefit will still result if speeds fall below 18 mph, but in this case particular attention must be given to the tractive effort requirements over the slow speed section.

A summary of the existing operating practices with respect to minimum speeds of a number of railroads is given in Table 5-4.

A comparison of Tables 5-3 and 5-4 shows that the majority of railroads operate in a predominantly power limited mode and can therefore take full advantage of the increased power rating of the DML in the electric mode. In addition, it is probable that a railroad choosing to deploy DML's would optimize their operation to the benefit of the DML.

TABLE 5-4

MINIMUM SPEED ON RULING GRADE

Railroad	Minimum Speed, mph		
	Drag	Medium	Manifest
AT & SF	12.5	17.5	20
Chessie	10-12	15-18	25-30
CMSP & P	11	>11	>11
Conrail	11	11	20
D & RGW	11	>11	>11
Mopac	11	>11	>11
SCL	11	>11	>11
Southern	11	20	25
SP	7	11	NA
UP	11-14	14-17	20-25
WP	11	>11	>11

It must be stressed, however, that this aspect of railroad operation, which is crucial to the method of deployment of DML's, is highly site specific. Each railroad and each of its divisions must be analyzed separately and in detail to derive the specific advantages of the DML.

Head-End Brake Limitation

It has been established (Reference 1) that the head-end brake limitation used by all railroads contacted is 240,000 lb, which currently corresponds to 24 motored axles. Two considerations have lead to the adoption of this limitation--mechanical strength of the coupler and train handling.

The grade B AAR coupling in common use in the U.S. has a strength in compression of 250,000 lb, and therefore the head-end braking force at the first coupling between the rear locomotive and the first car must not exceed 250,000 lb. Other couplings are available with higher strength materials (grade C - 350,000 lb and grade F - 500,000 lb), but other considerations prohibit the utilization of these properties during dynamic brake.

Experience has shown that excessive force concentrated at any one point in the train can cause the couplings to ride up over each other and result in a derailment. This problem is accentuated on curves and at turnouts and switches. To keep within the guidelines established by the industry as a result of many years of experience, it is not proposed to increase the maximum braking effort per traction motor (10,000 lbf). Performance of the dynamic brake in the nonregenerative version of the DML will be the same as the standard locomotive performance shown in Figure 5-6.

The limitation of dynamic brake performance at slow speed is the resistance of the braking grids and its ability to be varied. The steady reduction in braking effort below 24 mph can be avoided by use of the extended range dynamic brake. This also shown in Figure 5-6. When braking regeneratively in the electric mode, braking effort can be maintained down to approximately 2 mph, provided that the line is receptive.

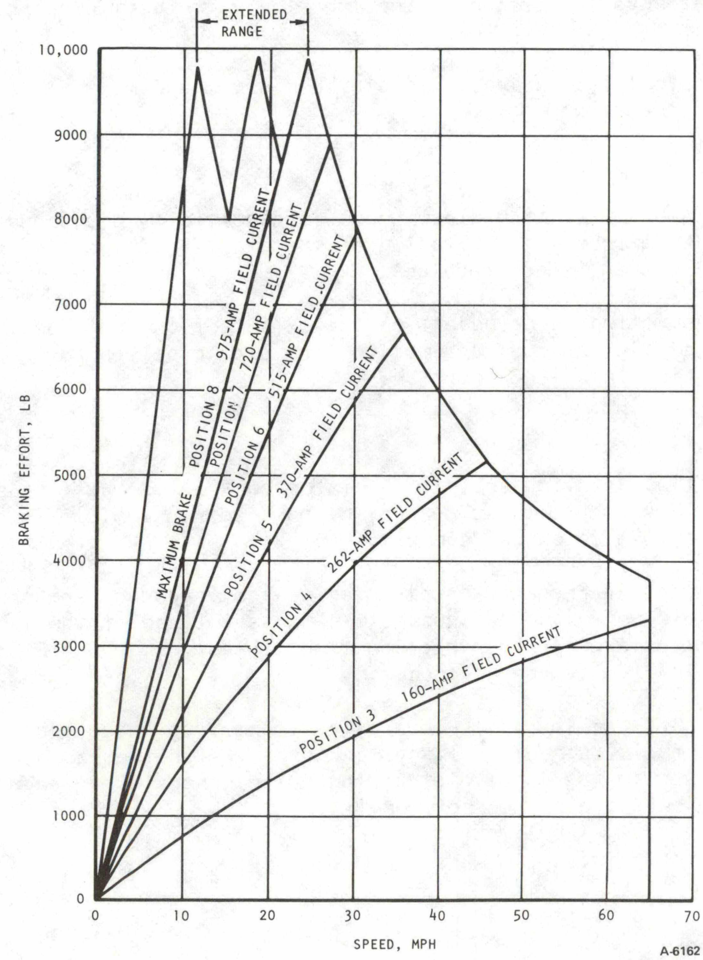


Figure 5-6. Dynamic Brake Performance

LOCOMOTIVE PARAMETERS

Performance

The work previously described will allow the tractive performance of the DML to be more fully defined in its final form, taking the following into account:

(a) Traction motors--To be operated at 536-kw input with a maximum continuous current of 1050 amp and a maximum voltage of 1300 v. The cooling air flowrate will be 3200 cfm per motor. There will be no weak field operation.

Transformer--To minimize the transformer size, the maximum continuous dc current will be limited to 4000 amp. This will result in a slight degradation in continuous output from 24 to 31 mph, but has great advantages in terms of transformer size and weight.

Locomotive weight--Variable between 394,000 and 416,000 lb (dependent on the option and ballast), although the reduction due to variable supplies will be reduced by 7,210 lb.

Assumable Adhesion--Derived for the DML so that the slip risk, and consequences thereof, are the same in the diesel and electric modes and are equivalent between a DML and a conventional base locomotive.

Figure 5-7 shows the overall locomotive tractive performance. The adhesion levels shown for diesel and electric modes reflect the improved control available in the electric mode due to the fast response of the thyristor converter.

The constant power curves shown are the limitations of operation in the respective modes. Diesel mode operation is at 2600 rhp (unchanged) and electric mode operation is at 3880 rhp. The limitation on continuous tractive effort available is imposed by the traction motor continuous current rating of 1050 amp.

The adhesion limits are calculated on the basis of the minimum and maximum locomotive weights and the assumed adhesion level for each mode.

Power and Energy Consumption

The energy consumption of the DML in the diesel mode is essentially unchanged, and the decreased efficiency of the auxiliary system (due to utilization of the electric drive system) is compensated for by the use of lower power constant speed machines.

The electrical energy consumption is dependent on the extent of the catenary. Since the catenary is initially located at sites of high energy consumption, the electrical energy consumption would appear to be high relative to diesel fuel consumption.

Interference

Any form of electric traction, particularly if thyristor controlled, will cause some interference to adjacent telephone cables. The psophometric current of an electric vehicle is a measure of how much interference it will cause to a telephone circuit.

Any electric vehicle generates harmonic currents over a wide frequency spectrum. Each of these harmonics will couple with a telephone line and generate a noise voltage at the identical frequency. To the human ear, some frequencies are more distracting than others. Figure 5-8 shows the weighting curve used to identify the distractivity versus frequency.

At any instant, a tapchanging- or thyristor-controlled locomotive has a specific harmonic current spectrum. Multiplying each harmonic current by its psophometric weighting factor and summing them gives a single value that relates to the total distracting noise generated in an adjacent telephone circuit. This is known as the psophometric current or I_{ps}.

$$I_{ps} = \sqrt{\sum_{n=0}^{\infty} I_n^2 \ P_n^2}$$

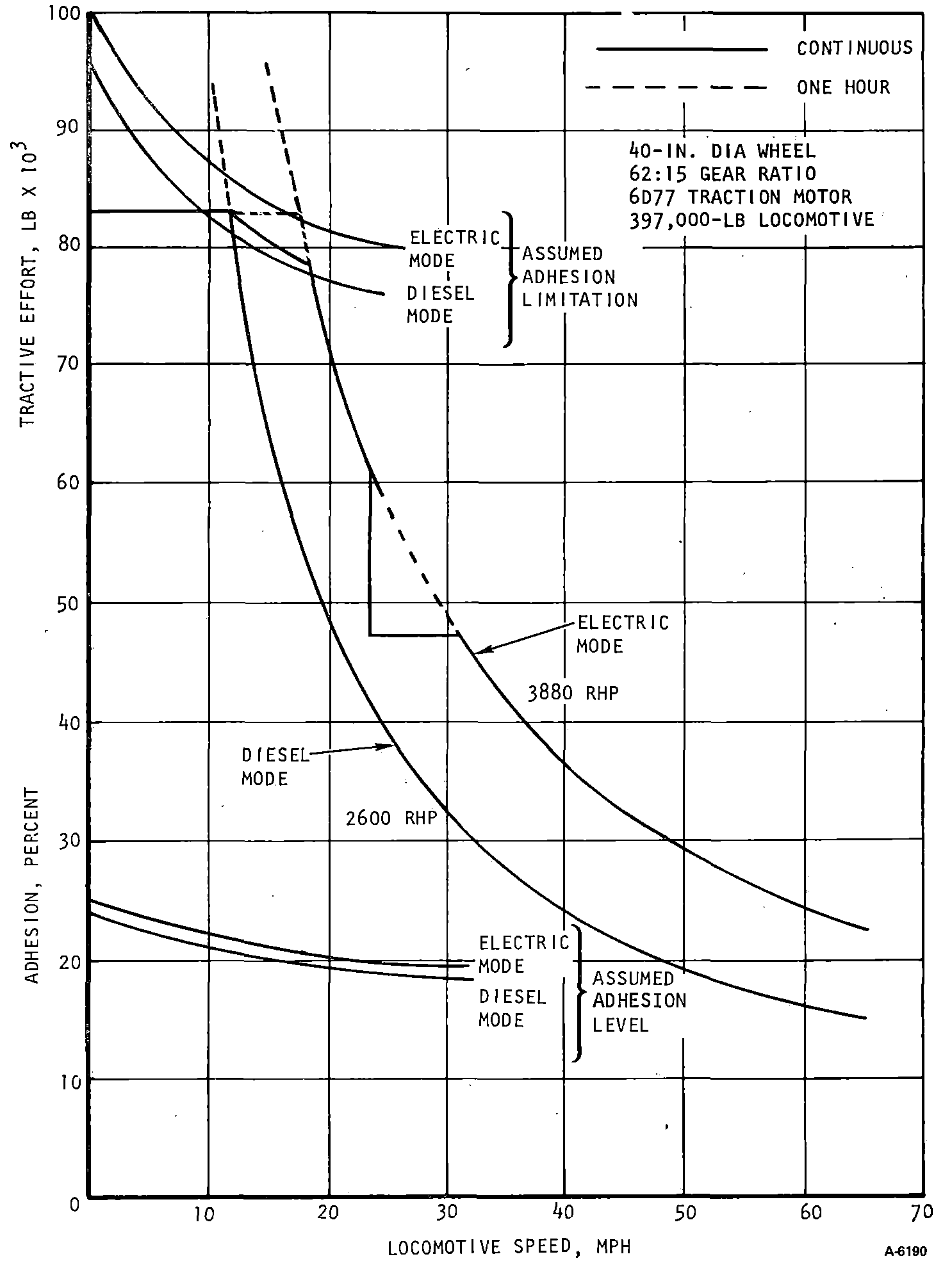


Figure 5-7. Revised DML Tractive Performance

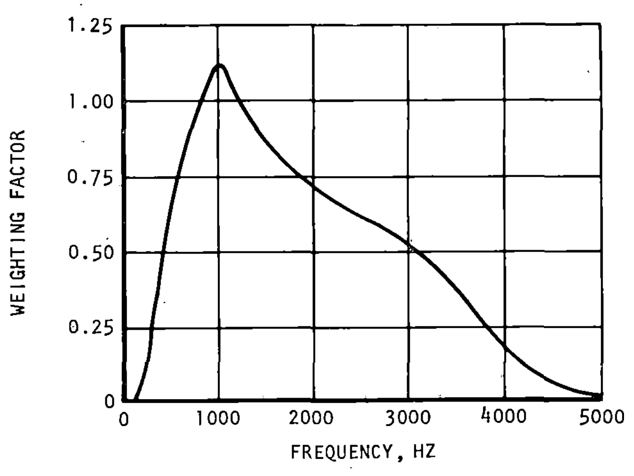


Figure 5-8. Psophometric Weighting Curve

where n = harmonic number

P_n = psophometric weighting factor of nth harmonic

I_{ps} depends not only on the absolute value of current, but also on its spectral distribution, so I_{ps} will vary with time but in quite a different manner to the RMS line current.

The relationship between I_{ps} and the actual noise voltage appearing across a telephone earpiece is site specific and depends on many parameters including:

(a) Mutual inductance between distribution and telephone circuits

(b) Length of exposure

(c) Use of telephone shunt filters

(d) Use of twisting and grounded sheaths

Unless all the site specific parameters, (multivariable, nonlinear, or frequency dependent) are shown however, I_{ps} cannot directly be related to an absolute value of generated noise voltage.

I_{ps} is used mainly as a simple "goodness factor". If locomotive A has twice the psophometric current of locomotive B at a specific instant, then it will cause twice as much noise (neglecting nonlinearities).

The variation of I_{ps} with speed for the DML is shown in Figure 5-9.

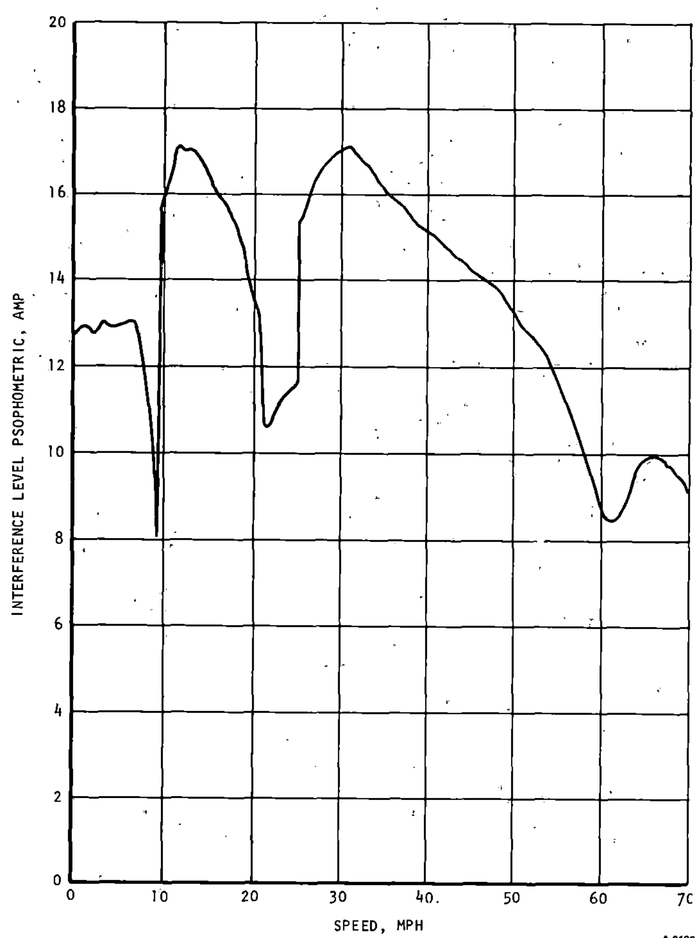


Figure 5-9. Variation of Psophometric Current with Speed

Power Factor

The power factor prediction for the DML with and without the correction capacitors is shown in Figure 5-10. The capacitance included in the current design increases the average power factor by 8 percent, which would decrease the transformer rating by 8 percent. During the locomotive detail design, this reduced transformer rating would also reduce the transformer weight by 8 percent (1200 lb).

There is still some space available to improve the power factor by an average of another 8 percent, which would significantly affect the transformer design and the characteristics of the load seen by the utility. This would be evaluated during subsequent phases of the DML design program.

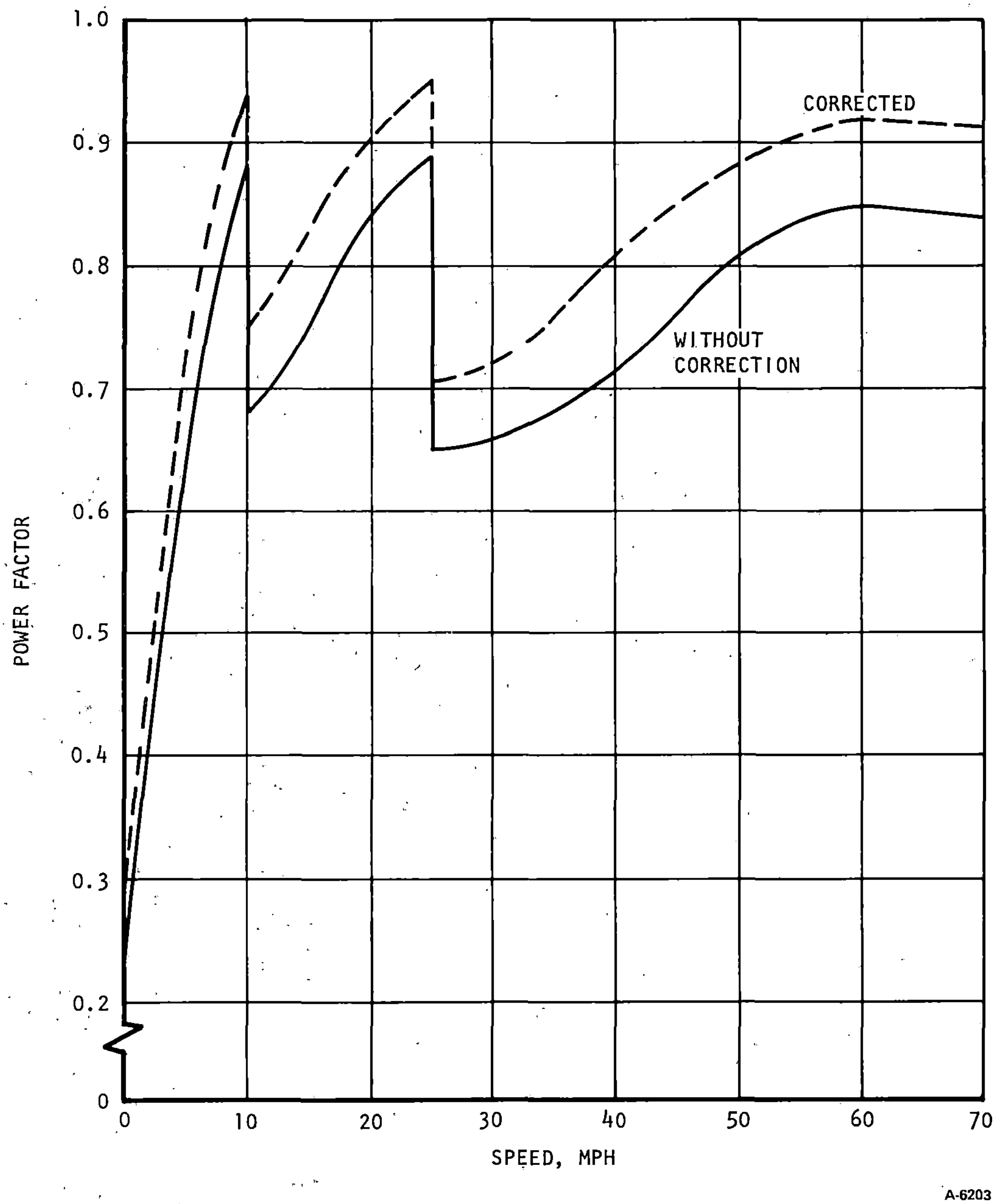


Figure 5-10. DML Power Factor Characteristic

SECTION 6

EQUIPMENT PERFORMANCE SPECIFICATIONS

The concept of the DML has been developed to the level of detail described in the earlier sections of this report; it is now possible to define the performance requirements for the equipment required to achieve the modification. Where standard items have been identified that can be used on DML with little or no modification, they have been identified specifically. Schedules of equipment were given in Table 4-2 and 4-3, and these are to be used as equipment lists for equipment performance specifications.

During this study, the emphasis has been on establishing the feasibility of the DML concept, and on identifying a single source for the necessary equipment. No attempt has been made to identify multiple sources or to optimize source locations. This would be accomplished during the FRA-proposed detail design, phase II.

PANTOGRAPH

A Faiveley pantograph, type LV2600 is recommended for this application in both the 25- and 50-kv versions. At the option of the railroad, the only possible modification would be a device to automatically drop the pantograph in the event that the collector strips or pantograph head becomes dislodged.

VACUUM CIRCUIT BREAKER

The 21CB2B and 20CB vacuum circuit breakers supplied by GEC Traction Limited should be specified for the 50- and 25-kv versions, respectively. These items can be used without modification.

GROUNDING SWITCH

Purpose-designed ground switch arrangements are required for the DML--one for the 50-kv version and one for the 25-kv version. The switch should be capable of being locked in the grounded position and should be interlocked with a pantograph isolating valve so that the pantograph cannot be raised while the locomotive system is grounded.

LIGHTNING ARRESTOR

The lightning arrestor is a standard utility item with mechanical (vibration) strength modifications for traction applications. Equipment with proven traction experience is available from Bowthorpe-EMP and has been identified as follows:

50 kv	LHCM3.5U60FM
25 kv	BM32S

ROOF INSULATORS

The roof insulators are standard parts available from suppliers such as Ohio Brass; their part numbers would be:

50 kv	41524
25 kv	41015

MAIN TRANSFORMER

Purpose built transformers are required for the DML and have been developed by GEC traction as follows:

50 kv	Dwg. No. S1659S1839
25 kv	Dwg. No. S1659S1838

MAIN CONVERTER ASSEMBLY

The main converter assembly comprises the following subassemblies:

(a) Phase delay rectifier

(b) Electronic control unit

(c) Power factor correction capacitors

(d) Single-phase auxiliary rectifier

(e) Three-phase auxiliary rectifier

(f) Field power supply (regenerative option only)

A main converter assembly incorporating the above subassemblies is shown in Garrett Dwg. L2016782, part number 2016782-1.

SMOOTHING INDUCTOR

The smoothing inductor should be air cored, oil immersed with an inductance of 2.5 mh. This inductor would be available from Power Energy Industry or Matra Electric Inc.

COLD WEATHER PROTECTION

This equipment is available from Kim Hotstart, but must be modified for a three-fluid capability rather than the two normally supplied.

MOTOR ALTERNATOR SET

There are many suppliers of suitable electrical machines, but the current installation analysis has been based on the G784AZ available from GEC Traction.

COMPRESSOR

Rotary and reciprocating compressors are readily available. For this analysis, the Sullair Series 10, 40-hp compressor unit has been used.

CONTROL RELAYS

Standard locomotive equipment relays manufactured by either Square D or American Standard are to be used in the DML conversion.

POWER CONTACTORS

Standard locomotive power contactors manufactured by Cutler Hammer or Allis Chalmers are to be used in the DML conversion.

AXLE-END GROUND BRUSHES

A Morrison-Knudsen axle-end ground brush that was used on FL-9 locomotives is to be used for the DML.

RACK ACTUATOR

A new design 64-v solenoid actuated plunger has been purpose-designed for the DML installation. The assembly is to be mounted on the engine and should have a stroke sufficient to move the rack to the required position. A method of stroke adjustment is required.

LOW WATER RESET SOLENOID

The low water reset solenoid, operated from the 64-v supply, is a new design for the DML. The solenoid plunger should have sufficient stroke to prevent a low water trip during engine starting, but should not interfere with the engine protection system during normal operation.

AUXILIARY ALTERNATOR

The three-phase auxiliary alternator, which is to be used as both a motor and an alternator, has the following ratings:

Motor	100 kw at 3000 rpm
Alternator	50 kw at 1500 to 3000 rpm

AUXILIARY TRANSFORMER/RECTIFIER

This auxiliary transformer/rectifier unit, should meet the following specification:

Input:

Power - 20 kva

Voltage - 3 phase, 60 Hz, 230 v

Output:

Voltage - 74 vdc

These units are available from a number of suppliers. The installation analysis has been based on a unit available from GE.

AUXILIARY DRIVE CLUTCH

The auxiliary drive clutch will be a new design for the DML and will consist of an electromagnetically controlled clutch that engages or disengages the equipment blower drive as required.

OPERATOR CONTROL SWITCHES

These switches, required only if manual mode change over is required by the railroad, will be standard locomotive switches.

OPERATOR INDICATORS

The operator indicators (VCB CLOSED, ELECTRIC MODE FAULT) will utilize standard locomotive hardware.

FIELD SHUNTING THYRISTORS

Required only for the regenerative option, these devices are to be air cooled and rated at 1200 amp each.

AIR PRESSURE SWITCH

A standard air pressure switch, set to operate at 70 lb/sq in. and available from square D, will be used in the DML.

DYNAMIC BRAKE BLOWER ASSEMBLY

Required only for the regenerative option, these blowers will be standard EMD radiator blowers modified to incorporate a heat shield to protect the fan motors.

STANDOFF INSULATORS

Required to prevent only leakage currents from passing through the locomotive/truck frames, suitable insulators are available from the Glastic Corporation.

SAFETY GROUND STRAPS

The safety ground straps are manufactured from copper braid with reinforced tinned ends. Each strap must be able to carry full primary current in the event of a fault developing (300 amp).

OIL COOLERS

The oil cooler for the main converter assembly and transformer will be identical parts, and will be capable of dissipating 90 kw at 9,000 cfm with 1.1 in water static pressure.

PRIMARY AIR FILTER

The repositioned primary air filter is an assembly of 20 polypropylene inertia filters available from GE and is used as standard equipment on most GE locomotives.

SECTION 7

PRELIMINARY COST ESTIMATE

After Tasks 1 through 5 of the contract statement of work were completed, it was possible to estimate the cost of the DML modification with more accuracy than previous estimates. In addition, a reassessment of viability of the DML using updated economic data was completed.

During the period of performance of this study, economic data became available from Conrail (Reference 11) and the Transportation System Center (Reference 12). This updated data, shown in Table 7-1, has been used in the final economic analysis presented in this section.

FINAL COST SCHEDULE

DML Modification Cost

The cost of material required to achieve the DML modification is shown in Tables 7-2 through 7-5 for the 50-kv regenerative, 50-kv nonregenerative, 25-kv regenerative, and 25-kv nonregenerative, respectively.

The labor hours have been estimated on the basis of the modification being carried out at a locomotive rebuild when the locomotive power equipment would have been removed. Using this approach, the labor hours are estimated as shown in Table 7-6. It is felt that since a great variation in locomotives exists, a variance in the number of hours required to achieve the modification will also exist. Furthermore, the labor content can be minimized by careful attention to the scheduling of work. The labor rate used in the analysis was obtained from a number of cooperating railroads and an average taken at $16.00/hr.

The total cost of modifying an SD40-2 to the chosen DML configuration at rebuild is shown in Table 7-7.

DML Maintenance

The proposed DML maintenance schedule is given in Table 7-8, and is based on a conservative 30-day maintenance cycle. Inspections could take place on a more acceptable 90-day cycle, but this would have to be verified by actual operation. The estimated scheduled maintenance is 120.5 manhours, which will require approximately $300 in material. Assuming a labor rate of $16/hr, this gives a total annual scheduled maintenance of $2228.

In addition to the scheduled maintenance, there will be unscheduled maintenance arising from equipment failure. The most likely source of failure, because of its large number of components, is the main converter assembly which has within it two major subsystems--the electronic control unit (ECU) and the power conditioning unit (PCU).

1. ECU Failure

A more complex ECU manufactured by Garrett is used in the standard light rail vehicles (SLRV's) now in revenue transit service in Boston and San Francisco. A service history is shown in Figure 7-1; the SLRV ECU, with 20 printed circuit boards, tends toward a mature mean miles between service failures (MMBSF) of 80,000 miles, which at an average speed of 14 mph represents over 5,700 SLRV operating hours.

The DML ECU contains only six printed circuit boards and therefore it can be conservatively estimated that mean hours between a service failure will be at least twice that of SLRV, or 11,400 operating hours. Assuming 20 hr/day operation for 300 days/yr, this results in approximately one service failure per locomotive per two years. Typically, the total cost to repair a failed printed circuit board is $250, which is an annual cost of $125.

TABLE 7-1

FINAL SCHEDULE OF COSTS (1980 DOLLARS)

Item	Cost	Source
Locomotives		
Initial		
DML conversion	$367,014 to 414,097	This study
SD40-2 locomotive	$ 791,000	Transportation Systems Center (Reference 12)
E60C locomotive	$1,540,000	Transportation Systems Center (Reference 12)
Maintenance		
DML	$1.37/mile	This study
Diesel	$1.33/mile	Transportation Systems Center (Reference 12)
Electric	$0.65/mile	Transportation System Center (Reference 12)
Electrification		
Design, management, etc.	$30,000/trackmile	Conrail/G&H Study (Reference 11)
Initial, including substations and signalling		
Single track	$473,000/route mile	Transportation System Center (Reference 12)
Two track	$780,000/route mile	Transportation Systems (Reference 12)
Three track	$1,059,000/route mile	This study
Four track	$1,100,000/route mile	This study
Maintenance	$4,400/route mile	Transportation System Center (Reference 12)
Energy		
Diesel fuel (average)	$1.00/gal	This study
Electricity, including demand	$0.042/kwh	Conrail/G&H Study (Reference 11)

TABLE 7-2

DML EQUIPMENT COST FOR 50 kv, REGENERATIVE

Item	Supplier	Cost, 1980 dollars
Pantograph	Faiveley	5,000
Vacuum circuit breaker	GEC Traction	18,973
Lighting arrestor	GEC Traction	3,021
Roof insulators	Faiveley	Included in pantograph
Main transformer	GEC Traction	122,660
Main converter assembly	Garrett	85,480
Smoothing inductor	PEI	5,000
Cold weather protection	Kim Hotstart	3,975
M-A set	Westinghouse	15,000
Compressor	Westco	10,988
Power contactors	EMD	5,000
Auxiliary alternator	GE	8,000
Auxiliary transformer/rectifier	GE	3,000
Dynamic brake blower	EMD	3,000
Oil coolers	Dunham Bush	7,200
Miscellaneous	M-K	21,800
		TOTAL $318,097

TABLE 7-3

DML EQUIPMENT COST FOR 50 kv, NONREGENERATIVE

Item	Supplier	Cost, 1980 dollars
Pantograph	Faiveley	5,000
Vacuum circuit breaker	GEC Traction	18,973
Lighting arrestor	GEC Traction	3,021
Roof insulators	Faiveley	Included in pantograph
Main transformer	GEC Traction	122,660
Main converter assembly	Garrett	76,480
Smoothing inductor	PEI	5,000
Cold weather protection	Kim Hotstart	3,975
M-A set	Westinghouse	15,000
Compressor	Westco	10,988
Power contactors	EMD	5,000
Auxiliary alternator	GE	8,000
Auxiliary transformer/rectifier	GE	3,000
Dynamic brake blower	EMD	3,000
Oil coolers	Dunham Bush	7,200
Miscellaneous	M-K	21,800
		TOTAL $309,097

TABLE 7-4

DML EQUIPMENT COST FOR 25 kv, REGENERATIVE

Item	Supplier	Cost, 1980 dollars
Pantograph	Faiveley	4,550
Vacuum circuit breaker	GEC Traction	6,819
Lighting arrestor	GEC Traction	931
Roof insulators	Faiveley	Included in pantograph
Main transformer	GEC Traction	99,271
Main converter assembly	Garrett	85,480
Smoothing inductor	PEI	5,000
Cold weather protection	Kim Hotstart	3,975
M-A set	Westinghouse	15,000
Compressor	Westco	10,988
Power contactors	EMD	5,000
Auxiliary alternator	GE	8,000
Auxiliary transformer/rectifier	GE	3,000
Dynamic brake blower	EMD	3,000
Oil coolers	Dunham Bush	7,200
Miscellaneous	M-K	21,800
		TOTAL $294,708

TABLE 7-5

DML EQUIPMENT COST FOR 25 kv, NONREGENERATIVE

Item	Supplier	Cost, 1980 dollars
Pantograph	Faiveley	4,550
Vacuum circuit breaker	GEC Traction	6,819
Lighting arrestor	GEC Traction	931
Roof insulators	Faiveley	Included in pantograph
Main transformer	GEC Traction	99,271
Main converter assembly	Garrett	76,480
Smoothing inductor	PEI	5,000
Cold weather protection	Kim Hotstart	3,975
M-A set	Westinghouse	15,000
Compressor	Westco	10,988
Power contactors	EMD	5,000
Auxiliary alternator	GE	8,000
Auxiliary transformer/rectifier	GE	3,000
Dynamic brake blower	EMD	3,000
Oil coolers	Dunham Bush	7,200
Miscellaneous	M-K	21,800
		TOTAL $285,708

TABLE 7-6

BASIC TIME AND MATERIALS ESTIMATE FOR DML BASED ON SD-40-2

Modification	Miscellaneous Materials, dollars	Labor, hr
Remove cab, short nose, and electrical cabinet including airbrake, batteries, ballast, etc.	0	500
Repackage short nose/cab and accessories and filter compartment in new installation	2,000	400
Install transformer.	500	100
Install new primary air filters and oil cooler.	100	200
Install VCB/lightning arrestor, pantograph, and copper buses.	1,500	500
Remove existing auxiliary generator and blower and install new auxiliary generator/alternator for driving accessories.	500	100
Rebuild carbody in clean air compartment area.	500	400
Remove, modify, and reinstall fuel tank of reduced volume.	50	200
Install motor alternator set in prefabricated support structure.	100	50
Remove long hood, existing compressor, and reinstall electrically driven compressor.	300	100
Install main converter assembly.	200	100
Install inductor (smoothing choke).	200	100
Modify long hood structure, raise sand box, and install the converter oil cooler.	2,000	400
Install new traction motor cabling and all new high and low voltage wiring.	12,000 (both items)	935
Install additional 16 ea. 1325/24 cabling from HV cabinet to converter and from inductor to HV cabinet. 4(+) and 4(-) each way.		100
Install Kim Hotstart.	200	70
Install relay panels in HV cabinet area.	100	50
Axle end ground brushes (3 ea.)	850	225
Speed probe mounted in traction motor gear case for counting bullgear teeth. (6 ea.)	-0-	100
Install magnetic rack activator.	50	60
Low water reset modification.	50	60
Install slow speed cranking.	400	50
Dynamic brake modification (regenerative only).	200	200
TOTAL	21,800	6,000

TABLE 7-7

SUMMARY OF DML MODIFICATION COSTS

Option	Cost, 1980 dollars
50 kv, regenerative	414,097
50 kv, nonregenerative	405,097
25 kv, regenerative	376,014
25 kv, nonregenerative	367,014

TABLE 7-8

DML MAINTENANCE SCHEDULE

Item	Manhours	Frequency	Annual Manhours*
Roof Equipment			
Clean insulators	0.5	30 days	5
Inspect pantograph	0.5	30 days	5
Change pantograph carbons	2.0	annual	2
Clean ground switch	0.5	30 days	5
Inspect VCB	0.2	30 days	2
Main transformer			
Clean cooler matrix	1.0	30 days	10
Main converter assembly			
Clean cooler matrix	1.0	30 days	10
Inductor	-	-	
Motor alternator set			
Inspect brushes and holders	0.5	30 days	5
Change brushes	1.0	annual	1.0
Compressor			
Clean air filter	0.5	annual	5.0
Check oil level	0.2	30 days	2
Axle-end ground brushes			
Check	2.0	30 days	20
Change	3.0	annual	3.0
Miscellaneous Operations	5.0	30 days	50
		TOTAL	120.5

*300 days/year

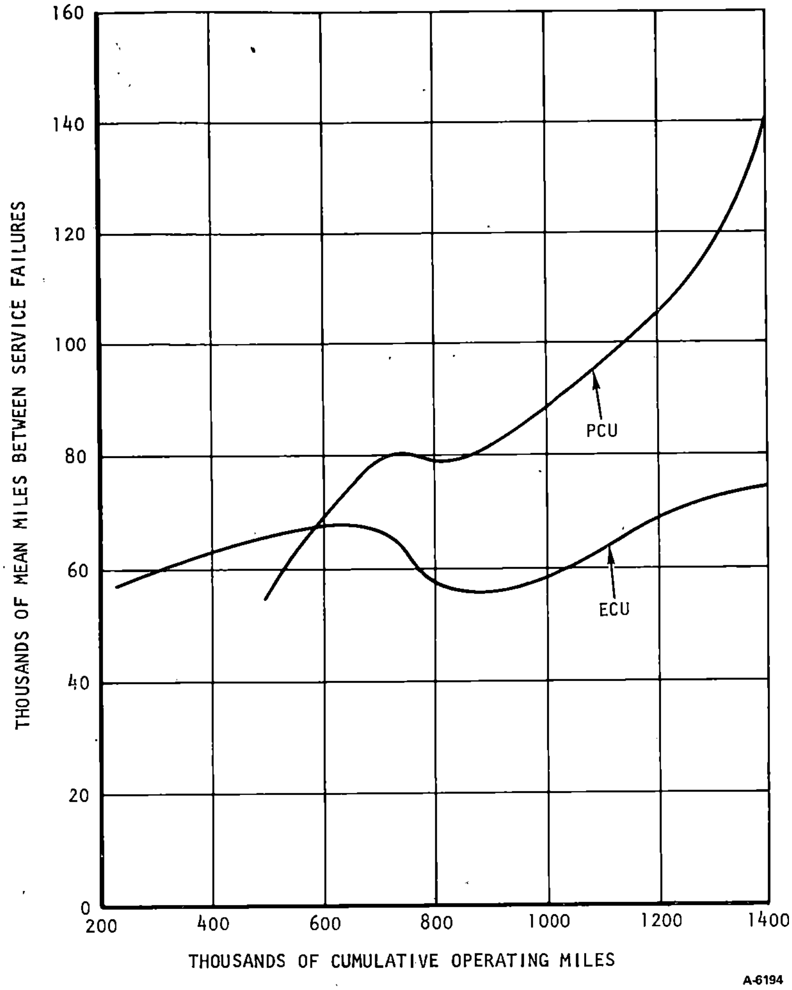


Figure 7-1. SLRV Failure History

2. PCU Failure

The SLRV PCU failure rate is also shown in Figure 7-1. The SLRV is a chopper equipment requiring forced commutation and is therefore more complex that the DML in some respects. The SLRV PCU mature MMBSF is anticipated to be approximately 200,000, or 14,300 SLRV operating hours, which equates to one failure per locomotive for every 2.4 years.

It is estimated that the cost of repairing a PCU would be $2,000, although this would vary widely depending on the type of failure, and giving an annual maintenance cost of $830.

It is possible that there are other unscheduled maintenance items such as MA set bearings, etc., but these incidents should be rare relative to the main converter.

Therefore, the total annual additional maintenance cost associated with the DML is:

Scheduled	$2,576
Unscheduled	$ 995
Total	$3,571

At 150,000 miles per year, this results in an additional 2.4 cents/mile in locomotive maintenance. Allowing for other maintenance items, the 4 cents/mile assumed earlier in the study is a realistic estimate.

3. Engine Maintenance

The cost per mile of diesel engine maintenance is dependent on the extent of electrification over a given route. In order to obtain an approximation of the reduction in engine maintenance, it has been assumed that engine maintenance cost is $0.60 per mile and that the cost of the maintenance is approximately proportional to the fuel that passes through the engine. By using the value of diesel fuel saved for each case, it is possible to estimate the reduction in diesel fuel maintenance as shown in Figure 7-2.

Diesel Fuel

The cost of diesel fuel to be used in this study was reviewed with FRA and the cooperating railroads, and it was agreed that $1.00/gal was realistic in terms of today's rising prices.

To be consistent with the Conrail electrification study (Reference 11), it was decided to include an inflation factor for diesel fuel that represented the difference between general inflation and diesel fuel inflation. The figure used in this study was 2 percent per year.

REVIEW OF ECONOMIC ANALYSIS

The initial economic analysis presented in Section 2 of this report was largely based on preliminary data, which was without the benefit of the Conrail electriciation study (Reference 11). At the completion of the system engineering study, it is now possible to repeat the economic analysis using the more firm data. The sensitivity analysis can also be repeated for the cost of diesel fuel, which was shown in Section 2 to be a particularly sensitive parameter, and for the cost of the DML modification.

Baseline Analysis

The revised baseline analysis is shown in Tables 7-9 and 7-10 for the Harrisburg-Pittsburgh and Los Angeles-Salt Lake City applications. The analysis was conducted in 1980 constant dollars. The 17.35 percent ROI reported in Table 7-8 for conventional electrification compares with the 17.7 percent ROI determined by Gibbs and Hill.

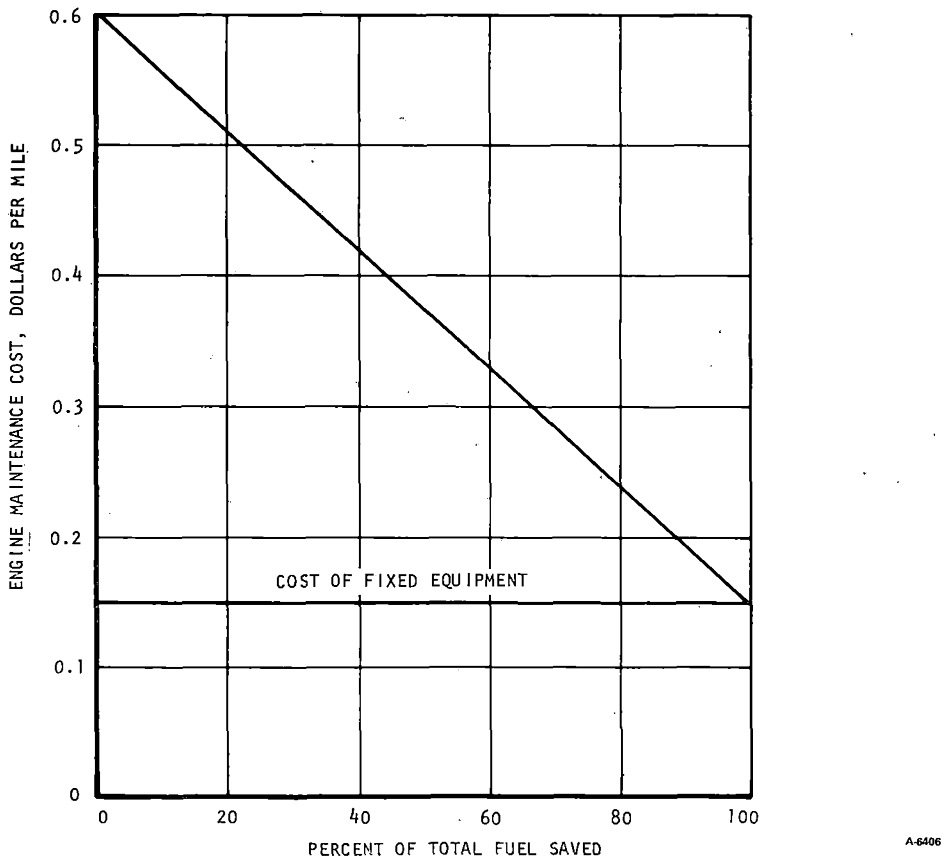


Figure 7-2. Variation of Engine Maintenance with Saving in Fuel

TABLE 7-9

REVISED ECONOMIC ANALYSIS OF APPLICATION OF DML's
HARRISBURG-PITTSBURGH BASELINE CASE
1980 DOLLARS (MILLIONS)

Cost Element	Extent of Electrification, Mileposts				Normal Electrification
	237-259	222-271	167-337	Whole Route	
Initial					
Management	2.64	5.88	16.86	50	50
Catenary, etc.	22.72	50.6	178.4	261	261
Locomotives	63.5	58.3	49.2	45.5	154
Locomotives transferred	(6.7)	(12.3)	(22.15)	(26.1)	(75)
Net total	82.16	102.48	222.31	330.4	390
Annual					
Diesel fuel saving	(10.22)	(18.3)	(42.5)	(60.8)	(62.4)
Electrical energy	3.65	6.2	15.2	20.2	21
Locomotive maintenance	(3.04)	(6.06)	(12.03)	(13.66)	(17.4)
Catenary maintenance	0.10	0.22	0.75	1.1	1.1
Savings in locomotive replacement	(0.9)	(1.63)	2.95)	(3.48)	(10.0)
Net savings	10.41	19.51	41.53	56.64	67.7
ROI, percent	12.7	19.1	18.7	17.1	17.35

TABLE 7-10

REVISED ECONOMIC ANALYSIS OF APPLICATION OF DML's
LOS ANGELES-SALT LAKE CITY BASELINE CASE
1980 DOLLARS MILLIONS

Cost Element	Extent of Electrification, Mileposts					Normal Electrification
	68-107 211-254	48-17 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole route	
Initial						
Management	3.63	6.48	14.16	23.1	29	29
Catenary, etc.	50.7	95.7	216.1	352.4	396.6	446
Locomotives	55.1	51.4	48.6	46.6	46.2	117
Locomotives transferred	(13.4)	(17.0)	(19.8)	(21.8)	(22.1)	(67)
Net total	96.03	136.58	259.06	400.3	449.7	525
Annual						
Diesel fuel saving	(21.52)	(32.6)	(54.97)	(75.89)	(81.2)	(81.4)
Electrical energy	4.67	8.87	15.5	22.56	24.53	24.5
Locomotive maintenance	(12.23)	(15.79)	(20.4)	(22.5)	(22.7)	(29.5)
Catenary maintenance	0.36	0.78	1.88	3.08	3.4	3.5
Saving in locomotive replacement	(1.79)	(2.26)	(2.64)	(2.9)	(2.95)	(9.0)
Net savings	30.51	41.0	60.63	75.65	78.92	91.9
ROI	31.7	30.0	23.4	18.9	17.5	17.5

Sensitivity Analysis

The sensitivity analysis reported in Section 2 showed that the ROI was not particularly sensitive to any one cost element with the exception of the price of diesel fuel. It is recognized, however, that there may also be some concern surrounding the cost of the DML, and because of this the sensitivity of the ROI to both diesel fuel and DML cost were tested. The results are shown in Tables 7-11 through 7-14.

1. Diesel Fuel Sensitivity

For the purposes of sensitivity, the cost of fuel was assumed to rise at 4 percent per annum above the general price level instead of the 2 percent used in the baseline analysis. Tables 7-11 and 7-12 show that, as in the original analysis, the ROI increased significantly as a result of the relatively minor change in fuel cost, demonstrating the extreme sensitivity of the result to fuel cost.

2. DML Cost Sensitivity

The DML cost was assumed to increase by 50 percent, the same sensitivity used in the original analysis and the results are shown in Tables 7-13 and 7-14, which confirm the results of the previous analysis. Other cost elements have the effect of making a DML cost increase relatively insignificant in terms of its effect on the overall ROI.

REVIEW OF DML COST ESTIMATE HISTORY

The cost estimate originally produced in the wayside energy storage study (Reference 1) was $211,000 in 1977, which becomes $296,153 in 1980 dollars for the 50 kv, regenerative version of the DML. The current estimate, given in Table 7-7 for the same option, is $414,097, a difference of $117,944 (28.5 percent). The major causes of the cost increase are:

(a) The DML was originally costed assuming that the traction motors could operate in the weak field mode. This was found to be impossible without modifications to the motors that could make them nonstandard. The result was an increase in the transformer kva and converter output voltages, both of which resulted in larger component sizes. In order to accommodate this, the locomotive had to be reconfigured.

(b) The labor estimate previously prepared by Garrett did not take into account the reconfiguration required by the larger transformer.

(c) Inflation in the United Kingdom over the past two years has resulted in an increase of 40 percent for the GEC Traction estimated components, amounting to $144,654. If inflation had been similar to that in the U.S., the DML cost would have been reduced by about $10,000.

TABLE 7-11

REVISED ECONOMIC ANALYSIS OF APPLICATION OF DML's
HARRISBURG-PITTSBURGH DIESEL FUEL SENSITIVITY
1980 DOLLARS (MILLIONS)

Cost Element	Extent of Electrification				Conventional Electrification
Initial	237-259	222-271	167-337	Full electrification	
Management	2.64	5.88	16.86	50	50
Catenary, etc.	22.72	50.6	178.4	261	261
Locomotives	63.5	58.3	49.2	45.5	154
Locomotives transferred	(6.7)	(12.3)	(22.15)	(26.1)	(75)
Net total	82.16	102.48	222.31	330.4	390
Annual					
Diesel fuel saving	(13.67)	(24.48)	(56.9)	(81.4)	(62.4)
Electrical energy	3.65	6.2	15.2	20.2	21
Locomotive maintenance	(3.04)	(6.06)	(12.03)	(13.66)	(17.4)
Catenary maintenance	0.10	0.22	0.75	1.1	1.1
Savings in locomotive replacement	(0.9)	(1.63)	(2.95)	(3.48)	(10.0)
Net savings	13.86	25.69	55.93	77.24	88.8
ROI, percent	16.9	25.1	25.2	23.4	22.8

TABLE 7-12

REVISED ECONOMIC ANALYSIS OF APPLICATION OF DML's
LOS ANGELES-SALT LAKE CITY BASELINE CASE DIESEL FUEL SENSITIVITY
1980 DOLLARS MILLIONS

Cost Element	Extent of Electrification					Conventional Electrification
	68-107 211-254	48-17 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole route	
Initial						
Management	3.63	6.48	14.16	23.1	29	29
Catenary, etc.	50.7	95.7	216.1	352.4	396.6	446
Locomotives	55.1	51.4	48.6	46.6	46.2	117
Locomotives transferred	(13.4)	(17.0)	(19.8)	(21.8)	(22.1)	(67)
Net total	96.03	136.58	259.06	400.3	449.7	525
Annual						
Diesel fuel saving	(28.79)	(43.6)	(73.55)	(101.55)	(108.65)	(108.9)
Electrical energy	4.67	8.87	15.5	22.56	24.53	24.5
Locomotive maintenance	(12.23)	(15.79)	(20.4)	(22.5)	(22.7)	(29.5)
Catenary maintenance	0.36	0.78	1.88	3.08	3.4	3.5
Saving in locomotive replacement	(1.79)	(2.26)	(2.64)	(2.9)	(2.95)	(9.0)
Net savings	37.78	52.02	79.21	101.31	106.37	119.4
ROI	39.3	38.1	30.6	25.3	23.7	22.7

TABLE 7-13

REVISED ECONOMIC ANALYSIS OF APPLICATION OF DML's
HARRISBURG-PITTSBURGH, DML SENSITIVITY
1980 DOLLARS (MILLIONS)

Cost Element	Extent of Electrification				Conventional Electrification
Initial	237-259	222-271	167-337	Full electrification	
Management	2.64	5.88	16.86	50	50
Catenary, etc.	22.72	50.6	178.4	261	261
Locomotives	95.25	87.45	73.8	68.25	154
Locomotives transferred	(6.7)	(12.3)	(22.15)	(26.1)	(75)
Net total	113.91	131.63	246.91	353.15	390
Annual					
Diesel fuel saving	(10.22)	(18.3)	(42.5)	(60.8)	(62.4)
Electrical energy	3.65	6.2	15.2	20.2	21
Locomotive maintenance	(3.04)	(6.06)	(12.03)	(13.66)	(17.4)
Catenary maintenance	0.10	0.22	0.75	1.1	1.1
Savings in locomotive replacement	(0.9)	(1.63)	2.95)	(3.48)	(10.0)
Net savings	10.41	19.51	41.53	56.64	67.7
ROI, percent	10.9	14.8	16.8	16.0	17.35

TABLE 7-14

REVISED ECONOMIC ANALYSIS OF APPLICATION OF DML's
LOS ANGELES-SALT LAKE CITY DML SENSITIVITY
1980 DOLLARS MILLIONS

Cost Element	Extent of Electrification					Conventional Electrification
	68-107 211-254	48-17 68-107 209-281 668-703	7-51 68-111 183-351 417-450 498-532 652-759	7-51 66-137 182-766	Whole route	
Initial						
Management	3.63	6.48	14.16	23.1	29	29
Catenary, etc.	50.7	95.7	216.1	352.4	396.6	446
Locomotives	82.65	77.1	72.9	69.9	69.3	117
Locomotives transferred	(13.4)	(17.0)	(19.8)	(21.8)	(22.1)	(67)
Net total	123.58	158.58	283.36	423.6	472.8	525
Annual						
Diesel fuel saving	(21.52)	(32.6)	(54.97)	(75.89)	(81.2)	(81.4)
Electrical energy	4.67	8.87	15.5	22.56	24.53	24.5
Locomotive maintenance	(12.23)	(15.79)	(20.4)	(22.5)	(22.7)	(29.5)
Catenary maintenance	0.36	0.78	1.88	3.08	3.4	3.5
Saving in low locomotive replacement	(1.79)	(2.26)	(2.64)	(2.9)	(2.95)	(9.0)
Net savings	30.51	41.0	60.63	75.65	78.92	91.9
ROI	24.7	25.8	21.4	17.9	16.7	17.5

SECTION 8

FUTURE PROGRAM PLANS

Following the determination of the technical viability and economic attractiveness of the DML concept, it is necessary to determine the optimum method of pursuing the concept through the preprototype demonstration. A subsequent four-phase program has been developed based on the program structure suggested by FRA in their DML Project Management Master Plan and Phase I RFP. The phases that follow this present Phase I System Engineering Study will make direct use of this Phase I output to analyze the chosen concept, and to build and test a preprototype locomotive.

The overall program, including this phase, is shown in Figure 8-1. This plan shows that a fully proven DML locomotive will be available September 1985. The details of the proposed program are given below.

PHASE II LAYOUTS AND SPECIFICATIONS

The purpose of phase II is to produce: (1) sufficient layout drawings and specifications to permit modification of an SD40-2 locomotive without the costly process of detail design; and (2) a final cost estimate. In addition, final specifications for the new components will be prepared. The specific tasks are as follows:

Layout Drawings (Task 1)--Using the general arrangement drawings available for all DML components, the following installation drawings will be made showing the new and relocated components, and identifying the methods of mounting and interfacing:

a. Roof equipment

b. Transformer compartment

c. Compressor, converter, inductor compartment

d. Converter oil cooler installation

e. Motor-alternator (MA) set installation

f. Auxiliary alternator drive system

g. Rear hood extension

h. 3,000-gal fuel tank

i. Relocation of cab

Final Component Design (Task 2)--Produce final designs of nonstandard components and prepare assembly drawings.

Final Specifications (Task 3)--Using the output available from the Phase I systems engineering study, final specifications for all equipment required to produce a DML will be produced. Where standard components are to be used without modification, these components should be identified by drawing and/or part number.

Cost Estimate (Task 4)--Using the output from Tasks 1 and 2, prepare a firm cost estimate for the modification material and labor hours required to modify locomotives to the DML configuration. The estimate should be based on the assumption that the work is completed at a locomotive 5- to 7-yr overhaul interval, when most equipment has been removed from the locomotive. The cost interval estimate should be supported by quotations and work breakdowns as appropriate, assuming quantities of 5, 50, and 150 to be ordered.

Modification Package (Task 5)--Prepare a package of specifications and drawings suitable for the modification of an SD40-2 to the DML configuration.

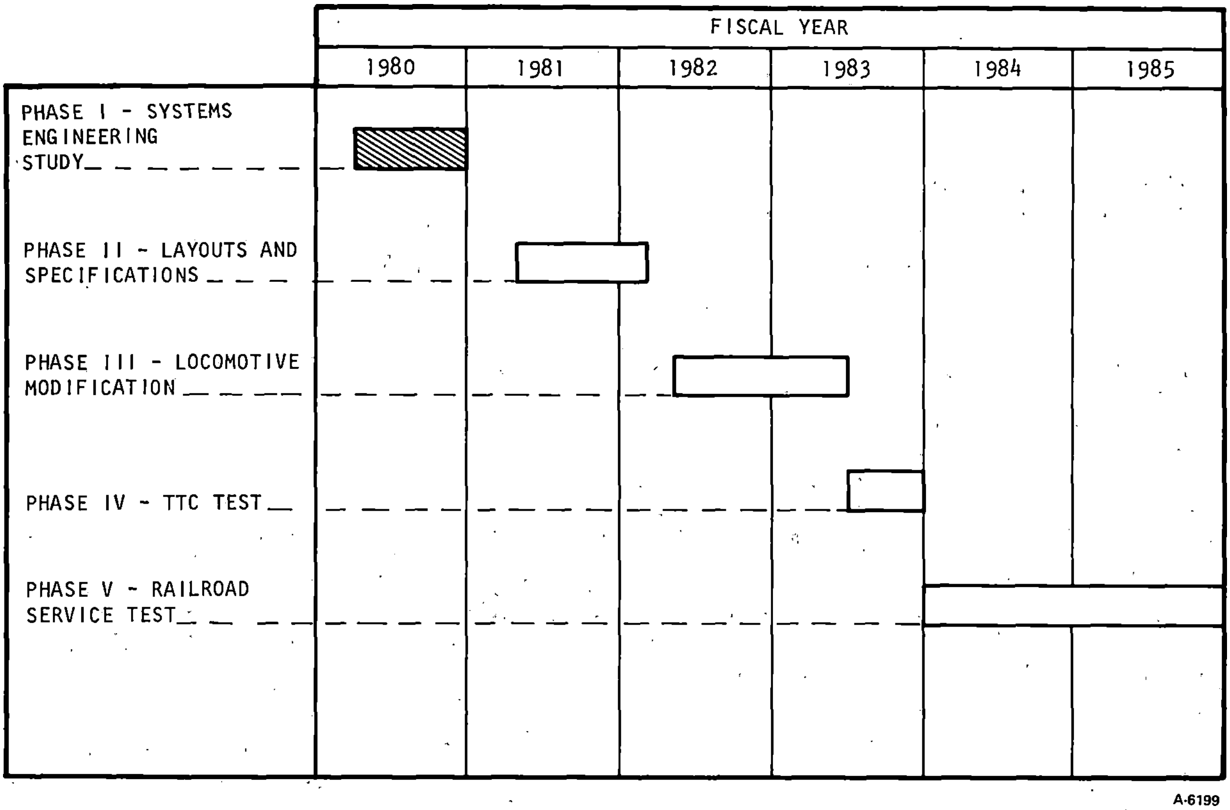


Figure 8-1. Proposed DML Program

PHASE III LOCOMOTIVE MODIFICATION

The output from this phase will be a preprototype DML based on the use of an SD40-2 locomotive, which will be suitable for testing at Pueblo and for operation in normal revenue service. The specific tasks associated with this phase are as follows:

Specifications/Design Review (Task 1)--Review the specifications and designs generated in phase II to ensure compatibility with DML concept at current status. Identify (and justify) changes, if any, considered to be necessary.

Material Procurement (Task 2)--Place orders for all long-lead items at the earliest possible time to ensure locomotive delivery on schedule. Order other material as it becomes finalized.

Installation Design (Task 3)--Review the component installation data and ensure compatibility with the installation design completed in phase II. Update installation design if necessary.

Locomotive Modification (Task 4)--Modify one locomotive to the DML configuration resulting from Task 1. All installation work should be to normal railroad standards and of a permanent nature so that the locomotive is suitable for revenue service on a cooperating railroad.

Locomotive Test (Task 5)--Test all aspects of diesel mode operation on the modified locomotive, including a test run hauling a consist of freight cars and multiple-unit (M-U) operation with unmodified locomotives. All electric mode control circuits should be tested for correct operation.

Locomotive Delivery (Task 6)--Following the completion of Task 6, deliver the DML to the Transportation Test Center (TTC) Pueblo, Colorado.

PHASE IV LOCOMOTIVE TESTING

The output from this phase will be a preprototype locomotive suitable for revenue service testing by a cooperating railroad. This phase will consist of the following tasks:

Locomotive Inspection (Task 1)--Check out locomotive following delivery to assess any transit damage and rectify as necessary.

Instrumentation (Task 2)--Provide sufficient instrumentation to test both diesel and electric mode operation. Parameters to be measured should be agreed to with FRA and Phase V railroad (if known).

Diesel Mode Testing (Task 3)--Confirm satisfactory operation in diesel mode, as determined under Task 6 of phase III.

Electric Mode Testing (Task 4)--Check out operation at normal operating voltage of catenary (either 25 or 50 kv depending on chosen configuration). Testing should include hauling a consist of freight cars and M-U operation with the DML in electric mode coupled to an unmodified diesel locomotive.

Simulated Service (Task 5)--Provide support to TTC during the simulated service testing, which will include checkout of the automatic changeover equipment; as specified in phase II, the wayside equipment is to be provided by TTC.

PHASE V REVENUE SERVICE

The purpose of this phase is to evaluate the service performance and reliability of a DML, and includes:

Locomotive Delivery (Task 1)--Deliver the DML to the cooperating railroad (to be nominated by FRA) and carry out post-delivery inspection, including operation of locomotive in both electric and diesel modes. A source of 50- or 25-kv power will be provided to the contractor.

Locomotive Testing (Task 2)--Provide test-support personnel and DML-peculiar equipment support for the DML program to ensure satisfactory locomotive operation. Operator and maintenance personnel training will be provided.

Final Report (Task 3)--Prepare a final report that gives details of the DML modification, testing, service history, spare parts listing, and recommendations for modification for later locomotives. The report should summarize the relevant data available from phase II, III, and IV reports.

PROGRAM OPTIMIZATION

The program outlined above has been based on the FRA plan. Following the completion of this study, it may be considered desirable to reduce the period of the overall program to provide a proven DML within the minimum period of time. It is estimated that, given the right conditions, a DML could be made available for test within 18 months from the go-ahead being given. This would involve completely restructuring the program to provide for the minimum of delay between program milestones.

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

The completion of the DML Systems Engineering Study has resulted in the definition of the DML concept, a determination of the DML cost, and an analysis of the economic benefits of the DML as it may be deployed on the nation's railroads as a first step toward full electrification of the major routes. In addition, a program plan has been outlined for the demonstration of a preprototype locomotive using an SD40-2 locomotive. The specific conclusions and recommendations of this eight-month study are described in the following text.

CONCLUSIONS

The conclusions reached in this study are as follows:

(a) The DML concept has been shown to be technically viable. The equipment layout has been determined to meet with the approval of the major U.S. railroads.

(b) The cost of a DML conversion can vary from $367,014 to $414,097, depending on the options and this results in the provision of approximately 1,280 additional rhp at $287/rhp to $323/rhp, compared to $304/rhp for the basic SD40-2 locomotive. A typical nonregenerative 50-kv electric locomotive cost would be $302/rhp.

(c) The DML can be deployed on U.S. railroads with ROI's in excess of that for conventional electrification. The initial investment required for the deployment of the DML's is typically one-fifth that of conventional electrification.

(d) The DML can be made available in the following options:

  (1) 50- or 25-kv catenary voltage

  (2) Regenerative or nonregenerative braking

  (3) Automatic or manual mode changeover

  (4) Engine idle or shutdown during electric operation

  (5) Ballasting to 70,000 lb axle load

(e) The DML provides a partial solution to the most commonly cited barrier to railroad electrification--the huge initial investment normally required--and allows the electrification process to proceed at a slower rate than would normally be possible. The DML is seen as a 20-yr transitional locomotive until normal electrification is established.

(f) The DML provides many intangible benefits to a railroad contemplating electrification that have not been quantified in this study. The more important of these benefits are the following:

  (1) The DML can start a journey off-wire then operate over the electrified section and complete the trip off-wire. Such operations are expected to be relatively common for many unit trains traveling from mines to utilization or tran-shipping points.

  (2) The DML can provide continuity of railroad operations during electric power outages and in the case of downed catenary.

  (3) The DML could M-U with electric locomotives on a contemplated electrified railroad in either mode.

  (4) The DML can offer training opportunities to railroad personnel unfamiliar with electric operations.

(5) The DML will use a majority of existing and proven components already in the logistics system.

(g) The DML can provide substantial advantages to the transportation sector by helping to reduce dependence on petroleum fuel and by minimizing the environmental impacts of railroad operations.

RECOMMENDATIONS

The following recommendations are made:

(a) The Phase II program described in Section 8 of this report should be promptly initiated. This program offers a minimum cost method of preparing for a DML preprototype.

(b) Initiate a design study to determine the feasibility of a 4-axle DML.

(c) The impact of the DML concept on contemplated railroad electrification programs should be considered and factored into the engineering and economic studies.

(d) The Memorandum of Understanding existing between FRA and Transport Canada should be used to transmit DML technology and information between future DML programs in the two countries.

(e) That a series of briefings on the DML concept to the senior management of the U.S. railroads that are prime candidates for electrification.

(f) Initiate a study to assess the applicability of the DML concept to passenger operations.

(g) That briefings on the impact of the DML should be provided to representatives of the Department of Energy, the Department of Commerce, and the Environmental Protection Agency regarding areas falling within their cognizance.

SECTION 10

REFERENCES

1. Lawson, L. J. and L. M. Cook, Wayside Energy Storage Study Final Report, AiResearch Manufacturing Company of California, under contract to DOT-TSC, June 1978, Report No. FRA/ORD-78/78.

2. Southern Pacific Transportation Company and St. Louis Southwestern Railway, "Locomotive Data," October 1, 1979.

3. The Air Brake Association, Management of Train Operation and Train Handling, Chicago, 1972.

4. Federal Railroad Administration, An Evaluation of the Costs and Benefits of Railroad Electrification, Draft Report, Washington D.C.

5. Cook L. M., and L. J. Lawson, Application of Wayside Energy Storage System Concepts to Canadian Railways, Final Report, Garrett Manufacturing, Ltd. under contract to Transport Canada, February 1980.

6. Scharm, E. G., Engineering Cost Data Analysis for Railroad Electrification Final Report, A. D. Little Inc., under contract to DOT-TSC, October 1976.

7. "SD40-2 Operator's Manual," Electromotive Division, La Grange, Illinois, August 1975.

8. "Engine Purge Control Maintenance Instruction MI9626," Electro Motive Division, La Grange, Illinois, November 1978.

9. Watkins, D. J., "Exploring Adhesion with British Rail's Tribometer Train," Railway Engineering Journal, July 1975.

10. Kimball, L. R. Junior, "Locomotive Working Paper," Southern Railway System, 1980.

11. "Electrification Feasibility Study," Gibbs & Hill, Inc., Volume II, 1980.

12. Spenny, C. H., "An Update of the Costs and Benefits of Railroad Electrification," Project Memorandum of Transportation Systems Center under agreement with DOT-FRA.

13. "Locomotive Specifications - SD40-2," Electro Motive Division, La Grange, Illinois, March 1978.

APPENDIX A

LOCOMOTIVE POPULATION DATA

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

BURLINGTON NORTHERN

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD24	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																				
25	1955																				
24	1956																				
23	1957																				
22	1958																				
21	1959											15									
20	1960																				
19	1961																				
18	1962	29																			
17	1963	25																			
16	1964		26																		
15	1965		14																		
14	1966							9									6		12		
13	1967							11											34		
12	1968							20											19		
11	1969																		15		
10	1970			6															24		
9	1971																25		69		
8	1972				10													15			
7	1973																	61			
6	1974				22													18			
5	1975																				
4	1976																	64			
3	1977																	66			
2	1978																	117			
1	1979																	140			
0	1980																				
	TOTAL	54	40	6	32	–	–	40	–	–	–	15	–	–	–	–	31	481	173		872
	AVERAGE	17.4	15.4	10	6.6	–	–	12.7	–	–	–	21.0	–	–	–	–	10.0	3.1	10.7		11.9

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

SANTA FE

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39-2	GP39X	GP40	GP40-2	GP40X	GP50	SD26	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																					
25	1955																					
24	1956																					
23	1957																					
22	1958																					
21	1959																					
20	1960																					
19	1961																					
18	1962	80																				
17	1963																					
16	1964																					
15	1965																					
14	1966																	19				
13	1967		156																			
12	1968																			119		
11	1969																20					
10	1970			59																		
9	1971																				78	
8	1972																					
7	1973																					
6	1974						17						79								10	
5	1975						52															
4	1976																					
3	1977						14												37			
2	1978										10											
1	1979						13												67			
0	1980																					
	TOTAL	80	156	59			96				10		79				20		104	119	88	811
	AVERAGE	17.5	14.0	10.0			4.3				2.0		5.5				11.0		1.7	12.0	7.8	8.6

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

CHESSIE

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962	70																		
17	1963	42																		
16	1964											41								
15	1965		85																	
14	1966																			
13	1967			100																
12	1968							116								83				
11	1969					20														
10	1970			30																
9	1971							100												
8	1972								2											
7	1973																			
6	1974																			
5	1975								270											
4	1976																			
3	1977																20			
2	1978																			
1	1979																			
0	1980																			
	TOTAL	112	85	130	-	20	-	216	272	-	-	41	-	-	-	83	20	-	-	979
	AVERAGE	17.6	15.0	12.3	-	11	-	10.6	5.2	-	-	16	-	-	-	12.2	3	-	-	11.4

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

CHICAGO MILWAUKEE ST PAUL & PACIFIC

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962																			
17	1963																			
16	1964																			
15	1965																			
14	1966																			
13	1967																			
12	1968																			
11	1969																			
10	1970																			
9	1971																			
8	1972																			
7	1973																			
6	1974																			
5	1975																			
4	1976																			
3	1977																			
2	1978																			
1	1979																			
0	1980																			
	TOTAL	16	11	-	16	-	-	72	-	-	-	-	-	-	-	-	89	10	-	214
	AVERAGE	16.7	14.9	-	5.8	-	-	12.7	-	-	-	-	-	-	-	-	6.6	11.6	-	11.4

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

CHICAGO & NORTH WESTERN

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962																			
17	1963																			
16	1964																			
15	1965																			
14	1966																			
13	1967																			
12	1968																			
11	1969																			
10	1970																			
9	1971																			
8	1972																			
7	1973																			
6	1974																			
5	1975																			
4	1976																			
3	1977																			
2	1978																			
1	1979																			
0	1980																			
	TOTAL	22	39	-	-	-	-	-	-	-	50	-	-	10	-	38	135	61	-	355
	AVERAGE																			

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

CONRAIL

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962																			
17	1963																			
16	1964																			
15	1965																			
14	1966																			
13	1967																			
12	1968																			
11	1969																			
10	1970																			
9	1971																			
8	1972																			
7	1973																			
6	1974																			
5	1975																			
4	1976																			
3	1977																			
2	1978																			
1	1979																			
0	1980																			
	TOTAL	82	197	281	339			265	110			46	35			115	166	173	13	1822
	AVERAGE	17.0	15.1	9.8	5.1			11.8	1.8			14.7	9.6			11.8	1.5	12.4	7.1	9.8

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

LOUISVILLE & NASHVILLE

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962	27																		
17	1963	41																		
16	1964		19									3								
15	1965											29								
14	1966							9								4				
13	1967							20												
12	1968																			
11	1969															5				
10	1970			20												15				
9	1971			30												10				
8	1972				50															
7	1973				44															
6	1974																49			
5	1975													5						
4	1976																			
3	1977																30			
2	1978																			
1	1979				34												60			
0	1980																			
	TOTAL	68	19	50	108	-	-	29	-	-	-	32	-	5	-	34	139	-	-	484
	AVERAGE	17.4	16.0	9.4	6.9	-	-	13.3	-	-	-	15.1	-	5	-	10.6	3.2	-	-	10.8

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

MISSOURI PACIFIC

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962																			
17	1963																			
16	1964		28	24																
15	1965		19	10																
14	1966			5																
13	1967		1	3												20				
12	1968															14				
11	1969															20				
10	1970															16				
9	1971															20				
8	1972				65															
7	1973				37												30			
6	1974				10												44			
5	1975				12												52			
4	1976				5												20			
3	1977				20															
2	1978																50			
1	1979																80			
0	1980				80						10						30			
	TOTAL	-	48	42	219	-	-	-	-	-	10	-	-	-	-	90	306	-	-	715
	AVERAGE	-	15.5	15.3	4.5	-	-	-	-	-	0.0	-	-	-	-	9.7	3.1	-	-	8.0

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

NORFOLK & WESTERN

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962	53																		
17	1963		15																	
16	1964		42																	
15	1965		20									78								
14	1966							30												
13	1967							30								30		35		
12	1968																	30		
11	1969																	25		
10	1970																	25		
9	1971															15				
8	1972																			
7	1973																11			
6	1974																17			
5	1975																66			
4	1976																			
3	1977																			
2	1978																50			
1	1979																			
0	1980																			
	TOTAL	53	77	-	-	-	-	60	-	-	-	78	-	-	-	45	144	115	-	572
	AVERAGE	18.0	15.9	-	-	-	-	13.5	-	-	-	15.0	-	-	-	11.7	4.2	11.7	-	12.9

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

SEABOARD COAST LINE

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962																			
17	1963	34																		
16	1964		15									}17								
15	1965																			
14	1966																			
13	1967																			
12	1968							}133										}38		
11	1969																			
10	1970																			
9	1971																			
8	1972				}60				20											
7	1973																			
6	1974																		15	
5	1975																			
4	1976																			
3	1977																			
2	1978																			
1	1979				4												27			
0	1980				13				5								9			
	TOTAL	34	15	–	77	–	–	133	25	–	–	17	–	–	–	–	36	38	15	390
	AVERAGE	17	16	–	5.9	–	–	12.0	6	–	–	15.5	–	–	–	–	0.75	11.5	6.0	10.1

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

SOUTHERN PACIFIC

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																			
25	1955																			
24	1956																			
23	1957																			
22	1958																			
21	1959																			
20	1960																			
19	1961																			
18	1962																			
17	1963	16																		
16	1964		60									2								
15	1965		57									11								
14	1966							8								78		42		
13	1967																	90		
12	1968														18	10		53		
11	1969																	132		
10	1970														8			30		
9	1971																			
8	1972																		101	
7	1973																		53	
6	1974											4					14		29	
5	1975																		60	
4	1976											1								
3	1977		1									5								
2	1978		10						19	4		4					85			
1	1979		33						30								70			
0	1980																			
	TOTAL	16	160	-	-	-	-	8	49	4	-	27	-	-	26	88	169	348	243	1138
	AVERAGE	17.0	11.3	-	-	-	-	14.0	1.4	2.0	-	9.2	-	-	11.4	13.8	1.9	11.9	6.8	9.2

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

SOUTHERN RAILWAY SYSTEM

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP38AC	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	
26	1954																				
25	1955																				
24	1956																				
23	1957																				
22	1958																				
21	1959																				
20	1960																				
19	1961																				
18	1962	57																			
17	1963	58	5																		
16	1964		67																		
15	1965												92								
14	1966			7									16								
13	1967																		53		
12	1968			1																	
11	1969			61																	
10	1970			45													16		15		
9	1971					56											13	8			
8	1972				59													31			
7	1973				45													3			
6	1974				59													11			
5	1975				9																
4	1976				30																
3	1977				30													48			
2	1978										3							26			
1	1979				25																
0	1980							6				70									
	TOTAL	115	72	114	257	56	-	6	-	-	3	70	108	-	-	-	29	119	68		1017
	AVERAGE	17.5	16.1	10.8	5.5	9.0	-	0	-	-	2.0	0	14.8	-	-	-	9.55	5.3	12.3		8.6

LOCOMOTIVE POPULATION DATA

EMD LOCOMOTIVES

UNION PACIFIC

AGE	YEAR BUILT	GP30	GP35	GP38	GP38-2	GP39	GP39X	GP40	GP40-2	GP40X	GP50	SD35	SD38	SD38-2	SD39	SD40	SD40-2	SD45	SD45-2	DD35	DD40X
26	1954																				
25	1955																				
24	1956																				
23	1957																				
22	1958																				
21	1959																				
20	1960																				
19	1961																				
18	1962	74																			
17	1963	74																			
16	1964		24																	6	
15	1965																			12	
14	1966							11								164					
13	1967							20													
12	1968																	50			
11	1969							20													
10	1970																				45
9	1971															80					
8	1972																79				
7	1973																72				
6	1974				40												13				
5	1975				20												17				
4	1976																30				
3	1977																74				
2	1978									6							79				
1	1979																120				
0	1980																137				
	TOTAL	148	24	-	60	-	-	51	-	6	-	-	-	-	-	244	621	50	-	18	45
	AVERAGE	17.5	16.0	-	5.7	-	-	12.4	-	2.0	-	-	-	-	-	12.3	3.1	12.0	-	15.3	10.0

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

ATCHISON TOPEKA & SANTA FE

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963																								
16	1964																								
15	1965																								
14	1966																	10							
13	1967																								
12	1968																								
11	1969													20						6		25			
10	1970	49 (1970–1971)																							
9	1971																								
8	1972																								
7	1973																							154 (1972–1975)	
6	1974																								
5	1975																								
4	1976																								
3	1977																				54 (1976–1978)				
2	1978		14																						
1	1979		26																		35				
0	1980																								
	TOTAL	49	40											20				10		6	89	25		154	
	AVERAGE	9.5	1.35											11.0				14.0		11.0	1.9	11.0		6.5	

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

BURLINGTON NORTHERN

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7	
26	1954																									
25	1955																									
24	1956																									
23	1957																									
22	1958																									
21	1959																									
20	1960																									
19	1961																									
18	1962																									
17	1963																									
16	1964			15												15										
15	1965			15												27										
14	1966					13		10								27										
13	1967					3																				
12	1968							5														8				
11	1969													11								17				
10	1970																									
9	1971																					9				
8	1972																			64						
7	1973																			34						
6	1974																			50						
5	1975																			29						
4	1976																				10					
3	1977																				35					
2	1978																				22					
1	1979																				80					
0	1980																									
	TOTAL			30		16		15						11		69				177	147	34				499
	AVERAGE			15.5		13.8		13.3						11.0		14.8				5.4	1.8	10.7				10.8

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

CHESSIE

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963			27																					
16	1964																								
15	1965																								
14	1966																								
13	1967																			13					
12	1968																								
11	1969	30																							
10	1970							}																	
9	1971							}																	
8	1972							}35																	
7	1973							}																	
6	1974							}																	
5	1975																								
4	1976																								
3	1977																								
2	1978								20																
1	1979																								
0	1980																								
	TOTAL	30	-	27	-	-	-	35	20	-	-	-	-	-	-	-	-	-	-	13	-	-	-	-	-
	AVERAGE	11.0	-	17.0	-	-	-	7.0	2.0	-	-	-	-	-	-	-	-	-	-	13.0	-	-	-	-	-

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

CHICAGO & NORTH WESTERN

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963																								
16	1964																								
15	1965																								
14	1966																								
13	1967																								
12	1968																								
11	1969																								
10	1970																								
9	1971																								
8	1972																								
7	1973																								
6	1974																								
5	1975																								
4	1976																								
3	1977																								
2	1978																								
1	1979																								
0	1980																								
	TOTAL																								
	AVERAGE																								

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

CHICAGO MILWAUKEE ST PAUL & PACIFIC

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963																								
16	1964																								
15	1965																								
14	1966																								
13	1967																								
12	1968																								
11	1969																								
10	1970																								
9	1971																								
8	1972																								
7	1973																								
6	1974																								
5	1975																								
4	1976																								
3	1977																								
2	1978																								
1	1979																								
0	1980																								
	TOTAL	5	-	11	-	12	-	6		-	-	-	-	-	-	-	-	-	-	8	-	3	-	4	-
	AVERAGE	6.7	-	14.7	-	13.9	-	13.0		-	-	-	-	-	-	-	-	-	-	5.4	-	12.0	-	7.8	-

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

CONRAIL

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963																								
16	1964																								
15	1965																								
14	1966																								
13	1967																								
12	1968																								
11	1969																								
10	1970																								
9	1971																								
8	1972																								
7	1973																								
6	1974																								
5	1975																								
4	1976																								
3	1977																								
2	1978																								
1	1979																								
0	1980																								
	TOTAL	99	141	161		2		56		79		4		19		20		15		10	10	39		13	
	AVERAGE	6.2	1.1	15.3		13.6		12.3		10.8		3.3		9.1		14.3		13.2		12.7	2.1	11.4		7.3	

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

LOUISVILLE & NASHVILLE

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963			13												3									
16	1964			14												2									
15	1965															18									
14	1966					3		2								5									
13	1967							4																	
12	1968																								
11	1969																			15					
10	1970	10																		10					
9	1971																			20					
8	1972																			29					
7	1973	43																							
6	1974	20																							
5	1975	24																							
4	1976																								
3	1977		15																						
2	1978																								
1	1979																				36				
0	1980																								
	TOTAL	97	15	27	-	3	-	6	-	-	-	-	-	-	-	28	-	-	-	77	36	-	-	-	-
	AVERAGE	12.8	3.0	16.4	-	14.0	-	13.3	-	-	-	-	-	-	-	15.1	-	-	-	92	1.0	-	-	-	-

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

MISSOURI PACIFIC

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963																								
16	1964																								
15	1965																								
14	1966																								
13	1967																								
12	1968																			6					
11	1969																			4					
10	1970																			4					
9	1971																			5					
8	1972																			5					
7	1973	7																		6					
6	1974	11																							
5	1975	5																							
4	1976	5																							
3	1977	10																							
2	1978		30																						
1	1979		20																						
0	1980		20																						
	TOTAL	38	70																	35					
	AVERAGE	5.0	1.1																	8.9					

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

NORFOLK & WESTERN

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7	
26	1954																									
25	1955																									
24	1956																									
23	1957																									
22	1958																									
21	1959																									
20	1960																									
19	1961																									
18	1962																									
17	1963																									
16	1964																									
15	1965																									
14	1966																									
13	1967																									
12	1968																									
11	1969																									
10	1970							4																		
9	1971																									
8	1972																									
7	1973																									
6	1974																			3						
5	1975																									
4	1976																									
3	1977																									
2	1978																				35					
1	1979																				45					
0	1980																									
TOTAL		-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	3	80	-	-	-	-	87
AVERAGE		-	-	-	-	-	-	10.0	-	-	-	-	-	-	-	-	-	-	-	6.0	1.4	-	-	-	-	5.8

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

SEABOARD COAST LINE

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963																								
16	1964															17									
15	1965																	3							
14	1966																			4					
13	1967							19																	
12	1968									28															
11	1969																								
10	1970																								
9	1971											106												7	
8	1972																								
7	1973																								
6	1974																								
5	1975																								
4	1976																								
3	1977																								
2	1978		30																						
1	1979		10																		16				
0	1980																								
	TOTAL	-	40	-	-	-	-	19		28	-	106	-	-	-	16	-	3	-	4	16	-	-	7	-
	AVERAGE	-	1.75	-	-	-	-	13.0		12.0	-	9.0	-	-	-	16.0	-	15.0	-	14.0	1.0	-	-	9.0	-

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

SOUTHERN PACIFIC

AGE	YEAR BUILT	U23B	B23-7	U25B	B25-7	U28B	B28-7	U30B	B30-7	U33B	B33-7	U36B	B36-7	U23C	C23-7	U25C	C25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	C36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963																								
16	1964																								
15	1965																								
14	1966																								
13	1967																								
12	1968																			30					
11	1969																			7		45			
10	1970																					40			
9	1971																					24			
8	1972																					53			
7	1973																					18			
6	1974																					11			
5	1975			1																		14			
4	1976			1																					
3	1977																								
2	1978								23																
1	1979								60																
0	1980																								
	TOTAL			2					83											37		205			
	AVERAGE			4.5					1.3											11.8		8.8			

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

SOUTHERN RAILWAY

AGE	YEAR BUILT	U23B	B23-7	U25B	U28B	U30B	B30-7	U33B	B33-7	U36B	U23C	U25C	U28C	U30C	C30-7	U33C	C30-7	U33C	U36C
26	1954																		
25	1955																		
24	1956																		
23	1957																		
22	1958																		
21	1959																		
20	1960																		
19	1961																		
18	1962																		
17	1963																		
16	1964																		
15	1965																		
14	1966																		
13	1967													5					
12	1968																		
11	1969																		
10	1970															5			
9	1971																		
8	1972	8														5			
7	1973	31																	
6	1974	3																	
5	1975	11																	
4	1976																		
3	1977																		
2	1978		10																
1	1979		10																
0	1980																		
	TOTAL	53	20	-	-	-	-	-	-	-	-	-	-	5	-	10	-	-	-
	AVERAGE	6.7	1.5	-	-	-	-	-	-	-	-	-	-	13.0	-	9.0	-	-	-

LOCOMOTIVE POPULATION DATA

GE LOCOMOTIVES

UNION PACIFIC

AGE	YEAR BUILT	U23B	B23-7	U25B	U25-7	U28B	U28-7	U30B	B30-7	U33B	U33-7	U36B	U36-7	U23C	U23-7	U25C	U25-7	U28C	C28-7	U30C	C30-7	U33C	C30-7	U36C	U36-7
26	1954																								
25	1955																								
24	1956																								
23	1957																								
22	1958																								
21	1959																								
20	1960																								
19	1961																								
18	1962																								
17	1963																								
16	1964																								
15	1965																								
14	1966					20												6							
13	1967																								
12	1968																								
11	1969																								
10	1970																								
9	1971																								
8	1972																			20					
7	1973																			40					
6	1974																			34					
5	1975																			15					
4	1976																			40					
3	1977																				15				
2	1978																				15				
1	1979																				30				
0	1980																				40				
	TOTAL					20												6		149	100				
	AVERAGE					14.0												14.0		5.9	1.1				

APPENDIX B

SOUTHERN CALIFORNIA EDISON
RATE SCHEDULE

SOUTHERN CALIFORNIA EDISON COMPANY
2244 Walnut Grove Avenue
Rosemead, California 91770

Revised Cal. P.U.C. Sheet No. 5225-E

Cancelling Revised Cal. P.U.C. Sheet No. 5147-E

Schedule No. TOU-8

GENERAL SERVICE — LARGE

APPLICABILITY

Applicable to general service, including lighting and power.

This schedule is applicable for all customers of record on *April 10, 1979*, the date of the decision in Application No. 57653, served on Schedule No. A-8 and thereafter to all customers whose monthly maximum demand exceeds 1,000 kW for any three months during the preceding 12 months. Any customer whose monthly maximum demand has fallen below 900 kW for 12 consecutive months may elect to take service on any other applicable schedule.

TERRITORY

Within the entire territory served, excluding Santa Catalina Island.

RATES

	Per Meter Per Month
Customer Charge:	$1,075.00
Demand Charge (to be added to Customer Charge):	
All kW of on-peak billing demand, per kW	$ 5.05
Plus all kW of mid-peak billing demand, per kW	0.65
Plus all kW of off-peak billing demand, per kW	No Charge
Energy Charge (to be added to Demand Charge):	
All on-peak kWh, per kWh	0.530¢
Plus all mid-peak kWh, per kWh	0.380¢
Plus all off-peak kWh, per kWh	0.230¢

Minimum Charge:

The monthly minimum charge shall be the sum of the monthly Customer and Demand Charges. The monthly Demand Charge shall be not less than the charge for 25% of the maximum on-peak demand established during the preceding 11 months.

Daily time periods will be based on Pacific Standard Time and are defined as follows:

On-peak: 12:00 noon to 6:00 p.m. summer weekdays except holidays
5:00 p.m. to 10:00 p.m. winter weekdays except holidays

Mid-peak: 8:00 a.m. to 12:00 noon and 6:00 p.m. to 10:00 p.m. summer weekdays except holidays
8:00 a.m. to 5:00 p.m. winter weekdays except holidays

Off-peak: All other hours.

Off-peak holidays are New Year's Day, Washington's Birthday, Memorial Day, Independence Day, Labor Day, Veterans Day, Thanksgiving Day, and Christmas.

For initial implementation of this schedule by the Company, winter shall consist of the billing periods for the six regularly scheduled monthly billings beginning with the first regularly scheduled billing ending after November 14, 1977. Thereafter, regularly scheduled monthly billings shall include six summer billing periods followed by six winter billing periods. In no event will winter include scheduled billing periods ending after May 31 of any year.

(Continued)

(To be inserted by utility)
Advice Letter No. 493-E

Decision No. 90146, 90475

Issued by
Edward A. Myers, Jr.
Name

Vice President
Title

(To be inserted by Cal. P.U.C.)
Date Filed June 22, 1979

Effective July 22, 1979

Resolution No.

Schedule No. TOU-8

GENERAL SERVICE — LARGE

(Continued)

SPECIAL CONDITIONS

1. **Voltage:** Service will be supplied at one standard voltage.

2. **Maximum Demand:** Maximum demands shall be established for the daily on-peak, mid-peak, and off-peak periods. The maximum demand for each period shall be the measured maximum average kilowatt input indicated or recorded by instruments to be supplied by the Company, during any 15-minute metered interval, but not less than the diversified resistance welder load computed in accordance with the section designated Welder Service in Rule No. 2. Where the demand is intermittent or subject to violent fluctuations, a 5-minute interval may be used.

3. **Billing Demand:** Separate billing demands for the on-peak, mid-peak, and off-peak daily time periods shall be established for each monthly billing period. The billing demand for each daily time period shall be the maximum demand for that daily time period occurring during the respective monthly billing period.

4. **Voltage Discount:** The charges before adjustments will be reduced by 3% for service delivered and metered at voltages of from 2 kV to 10 kV; by 4% for service delivered and metered at voltages of from 11 kV to 50kV; and by 5% for service delivered and metered at voltages over 50 kV; except that when only one transformation from a transmission voltage level is involved, a customer normally entitled to a 3% discount will be entitled to a 4% discount.

5. **Power Factor Adjustment:** The charges will be adjusted each month for reactive demand. The charges will be increased by 20 cents per kilovar of maximum reactive demand imposed on the Company in excess of 20% of the maximum number of kilowatts.

The maximum reactive demand shall be the highest measured maximum average kilovar demand indicated or recorded by metering to be supplied by the Company during any 15-minute metered interval in the month. The kilovars shall be determined to the nearest unit. A device will be installed on each kilovar meter to prevent reverse operation of the meter.

6. **Temporary Discontinuance of Service:** Where the use of energy is seasonal or intermittent, no adjustments will be made for a temporary discontinuance of service. Any customer prior to resuming service within twelve months after such service was discontinued will be required to pay all charges which would have been billed if service had not been discontinued.

7. **Contracts:** An initial three-year facilities contract may be required where applicant requires new or added serving capacity exceeding 2,000 kVA.

8. **Energy Cost Adjustment:** The rates above are subject to adjustment as provided for in Part G of the Preliminary Statement. The applicable energy cost adjustment billing factors and fuel collection balance adjustment billing factor set forth therein will be applied to all kWh billed under this schedule.

9. **Tax Change Adjustment:** The rates above are subject to adjustment as provided for in Part I of the Preliminary Statement. The applicable tax change adjustment billing factors set forth therein will be applied to kWh billed under this schedule.

10. **Conservation Load Management Adjustment:** The rates above are subject to adjustment as provided for in Part J of the Preliminary Statement. The applicable conservation load management adjustment billing factors set forth therein will be applied to kWh billed under this schedule.

(To be inserted by utility)	Issued by	(To be inserted by Cal. P.U.C.)
Advice Letter No. 493-E	Edward A. Myers, Jr. (Name)	Date Filed June 22, 1979
Decision No. 90146, 90475		Effective July 22, 1979
	Vice President (Title)	Resolution No.

APPENDIX C

WEIGHT AND BALANCE CALCULATIONS

APPENDIX C

WEIGHT AND BALANCE CALCULATIONS

BASE LOCOMOTIVE WEIGHT

The first task in the assessment of the weight and balance of the DML is to determine the weight of the base locomotive, which, in itself, is not straightforward and must be carefully studied. Reference 13 gives the total approximate loaded weight on the rail as 368,000 lb and states that the locomotive shown in Figure C-1 is defined to be balanced so that each axle supports 61,333 lb.

Locomotive Options

There are many optional items of equipment available that increase the locomotive weight. These are shown in Table C-1; this table also shows that the fully loaded weight of a SD40-2 with the common options is 383,501 lb.

Locomotive Balance

Calculations of locomotive balance for each DML option are shown in Tables C-2 through C-5 as follows:

Table C-2	50 kv regenerative
Table C-3	50 kv nonregenerative
Table C-4	25 kv regenerative
Table C-5	25 kv nonregenerative

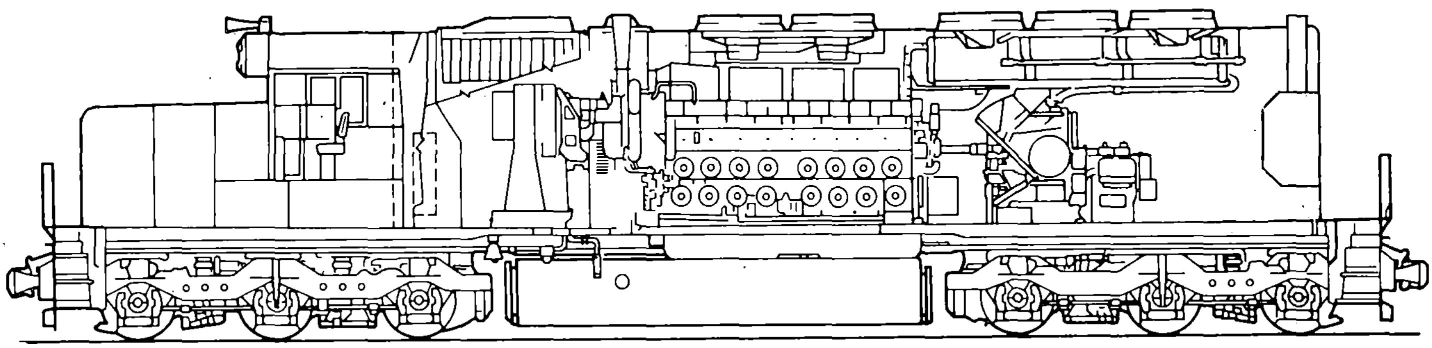


Figure C-1. Basic SD40-2 Locomotive

S-45635

TABLE C-1

ANALYSIS OF SD40-2 WEIGHT

Item Description	Source/Remarks	Weight, lb
Basic locomotive	EMD Specification 8087, March 1978	368,000
Air System Options		
Engineer alertness system	Vapor alertor, black box, relays, speaker	10
Overspeed limit		20
Compatibility with 6BL schedule	F1 selector valve	30
Air flow indicator	Garrett estimate	Negligible
Automatic drain valves	} mutually exclusive	30
Timed blow down	Not included }	
6 cylinder compressor	Not included	
Sanding options		
Pneumatic trainline control	2 pneumatic relay valves piping length of unit	120
MU control options		
Break-in-two protection	A-1 relay valve	25
Auto timed sanding	Reservoir	15
Breakaway support posts		-
Dynamic brake		
Grids (3)	EMD SD-40-2 locomotive service manual	1,155
Blowers (2)	EMD SD-40-2 locomotive service manual	1,520
Contactors (6)	EMD SD-40-2 locomotive service manual	210
Miscellaneous equipment	Garrett estimate	200
Electrical system options		
Automatic ground play reset	Black box, wiring	5
Quick access tm covers	Net zero	0
Traction motor lockout	Motorized rev switch	10
18-kw auxiliary generator	Trade-off net	0
Manual power reduction	Potentiometer	Negligible
Push-to-test control lights	Button, wires	1
Engine system options		
Increased capacity oil pan	Not required on DML	0
Engine turning jack		30
Fuel oil preheater		30
Bolted-on engine stubshaft		10
Immersion heater	Not included	
Low engine idle speed	Garrett estimate	Negligible
Engine purge control system		70
Truck options		
Clasp brake arrangement		600
Provision for wheel truing		0
Huck fasteners		0
Floating tm bellows		0
Lateral shock absorbers		50
Gearcase inspection covers		0

TABLE C-1 (Continued)

Item Description	Source/Remarks	Weight, lb
Cab options		
Third cab seat		35
Water cooler/refrigerator		80
Electric cab heat		0
Air conditioning	Not included	0
Benelex flooring		40
Awnings/wind deflectors	Garrett estimate	40
Fixed corner windows	Garrett estimate	Negligible
Polycarbonate side glazing	Garrett estimate	Negligible
Radio		
Typical radio equipment		60
Carbody options		
Reinforced nose		600
Anticlimber		300
Snow plows	One end only	750
NC390 draft gear		200
Type F coupler	Not included (negligible)	0
Signal light/roof top beacon		10
Toilet		35
Lifting eyes in end sheets	Negligible	0
Low level cooling air intake	Not included	
Fuel tank options		
4000-gal tank	EMD, SD-40-2 locomotive service manual	3,390
Additional 800-gal fuel	6.4 lb/gal	5,120
Automatic fill adaptors		
100-gal retention tank	Not required on DML	0
Styling and painting options		
Permanent front end ID plates	Garrett estimate	Negligible
ACI labels	Garrett estimate	Negligible
Polyurethane paint	Garrett estimate	Negligible
Scotchlite	Garrett estimate	Negligible
	LOCOMOTIVE WEIGHT WITH OPTIONS	383,501

TABLE C-2

LOCOMOTIVE BALANCE FOR 50-kv REGENERATIVE

CALCULATION: 50 kv regenerative

Moments about front bolster

Convention: +ive moment CW, -ive moment CCW, +ive force down

	Weight, lb	Location, in.	Moment
	4,035	-25	-100,875
	275	45	12,375
	1,265	59	74,635
	15,650	98	1,533,700
	-2,300	117	-269,100
	144	123	17,712
	-4,700	143	-672,100
	579	146	84,534
	-800	180	-144,000
	2,000	180	360,000
	-12,050	260	3,133,000
	500	260	130,000
	-760	275	-209,000
	700	275	192,500
	-760	330	-250,800
	700	330	231,000
	4,000	370	1,480,000
	400	392	156,800
	415	415	172,225
	-2,577	498	-1,283,346
	790	498	393,420
	$-R_B$	520	$-520R_B$
	4,300	546	2,347,800
	2,500	616	1,540,000
TOTAL	14,306	TOTAL	2,664,480

$\therefore R_{rear} \times 522 = 2,664,480$
$\therefore R_{rear} = 5,104$ lb
$\therefore R_{front} = 14,306 - 5,104 = 9202$ lb

TABLE C-3

LOCOMOTIVE BALANCE FOR 50-kv NONREGENERATIVE

CALCULATION: 50 kv nonregenerative

Moments about front bolster

Convention: +ive moment CW, -ive moment CCW, +ive force down

	Weight, lb	Location, in.	Moment
	4,035	-25	-100,875
	1,265	59	74,635
	15,650	98	1,533,700
	-2,300	117	-269,100
	144	123	17,712
	-4,700	143	-672,100
	579	146	84,534
	-800	180	-144,000
	2,000	180	360,000
	-12,050	260	3,133,000
	500	260	130,000
	-760	275	-209,000
	700	275	192,500
	-760	330	-250,800
	700	330	231,000
	4,000	370	1,480,000
	400	392	156,800
	415	415	172,225
	-2,577	498	-1,283,346
	790	498	393,420
	$-R_B$	520	$-520R_B$
	4,100	546	2,238,600
	2,500	616	1,540,000
TOTAL	14,106	TOTAL	2,555,280

$\therefore R_{rear} \times 522 = 2,664,480$
$\therefore R_{rear} = 4,895$ lb
$\therefore R_{front} = 14,106 - 5,104 = 9,210$ lb

TABLE C-4

LOCOMOTIVE BALANCE FOR 25-kv REGENERATIVE

CALCULATION: 25-kv regenerative

Moments about front bolster

Convention: +ive moment CW, -ive moment CCW, +ive force down

	Weight, lb	Location, in.	Moment
	4,035	-25	-100,875
	275	45	12,375
	692	59	40,828
	12,560	98	1,230,880
	-2,300	117	-269,100
	144	123	17,712
	-4,700	143	-672,100
	495	146	72,270
	-800	180	-144,000
	2,000	180	360,000
	-12,050	260	3,133,000
	500	260	130,000
	-760	275	-209,000
	700	275	192,500
	-760	330	-250,800
	700	330	231,000
	4,000	370	1,480,000
	400	392	156,800
	415	415	172,225
	-2,577	498	-1,283,346
	790	498	393,420
	$-R_B$	520	$-520R_B$
	4,300	546	2,347,800
	2,500	616	1,540,000
TOTAL	10,559	TOTAL	2,315,589

$\therefore R_{rear} \times 522 = 2,315,589$

$\therefore R_{rear} = 4,435$ lb

$\therefore R_{front} = 10,559 - 4,435 = 6,124$ lb

TABLE C-5

LOCOMOTIVE BALANCE FOR 25-kv NONREGENERATIVE

CALCULATION: 25-kv nonregenerative

Moments about front bolster

Convention: +ive moment CW, -ive moment CCW, +ive force down

	Weight, lb	Location, in.	Moment
	4,035	-25	-100,875
	275	45	12,345
	692	59	40,828
	12,560	98	1,230,880
	-2,300	117	-269,100
	144	123	17,712
	-4,700	143	-672,100
	495	146	72,270
	-800	180	-144,000
	2,000	180	360,000
	-12,050	260	3,133,000
	500	260	130,000
	-760	275	-209,000
	700	275	192,500
	-760	330	-250,800
	700	330	231,000
	4,000	370	1,480,000
	400	392	156,800
	415	415	172,225
	-2,577	498	-1,283,346
	790	498	393,420
	$-R_B$	520	$-520R_B$
	4,100	546	2,338,600
	2,500	616	1,540,000
TOTAL	10,359	TOTAL	2,305,589

$\therefore R_{rear} \times 522 = 2,305,589$

$\therefore R_{rear} = 4,416$ lb

$\therefore R_{front} = 10,359 - 4,416 = 5,942$ lb

The resulting total bolster loads are summarized in Table C-6, together with the end-to-end variation. The maximum variation is well within the normally permitted 5,000-lb difference, and is therefore considered to be satisfactory. If it is found necessary to adjust the bolster loads during the detailed design, this would be most efficiently achieved by adjustment of equipment locations, such as moving the main converter assembly and smoothing inductor further to the rear of the locomotive. At this stage, it is concluded that balancing ballast is not required on any version of the DML.

TABLE C-6

DML BOLSTER LOADS

Option	Bolster Load, lb		
	Front	Rear	Difference
50-kv regenerative	143,752	139,654	4,098
50-kv nonregenerative	143,760	139,445	4,315
25-kv regenerative	140,674	138,985	1,689
25-kv nonregenerative	140,492	138,996	1,526

ADHESIVE BALLAST

The minimum locomotive weight is well within the mechanical capability of the locomotive design, and it may be considered desirable to add ballast for adhesion purposes. This would be at the option of each railroad. Adhesive ballast could be located under the diesel engine in the location often used for this purpose in conventional locomotives. The maximum weight of the DML should not exceed 416,000 lb.

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