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WAYSIDE ENERGY STORAGE STUDY
Volume II - Detailed Description of Analysis

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16. Abstract

Volume II summarizes an in-depth application study which was conducted to determine the practicality and viability of using large wayside flywheels to recuperate braking energy from freight trains on long downgrades.

The study examined the route structures of nine U.S. railroads and identified various wayside energy storage system (WESS) configurations. The optimum means of transferring energy from the train to the wayside was by means of a high-voltage ac catenary from either regenerative electric locomotives or modified dual-mode (diesel-electric/electric) locomotives.

The application of WESS was then analyzed for four specific routes of typical U.S. railroads. These routes and the annual returns on investment (ROI's) resulting from WESS deployment on existing railroads were as follows: Atchison, Topeka, and Santa Fe (Los Angeles to Belen), 27.1 percent; Black Mesa and Lake Powell, 17.3 percent; Conrail (Pittsburgh to Harrisburg), 22.0 percent; Union Pacific (Los Angeles to Salt Lake City) 20.2 percent.

This report occupies 4 volumes as follows: Volume I - Summary, Volume II - Detailed Description and Analysis, Volume III - Engineering Economics Analysis: Data and Results, and Volume IV - Dual-Mode Locomotive: Preliminary Design Study. Volume III is available in photocopy or microfiche from the National Technical Information Service, Springfield, VA 22161.

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PREFACE

This final report summarizes the results of the Wayside Energy Storage Study. It is submitted to the Transportation Systems Center by the AiResearch Manufacturing Company of California, a division of The Garrett Corporation, in accordance with U. S. Department of Transportation Contract No. DOT-TSC-1349. The final report comprises four volumes as follows:

Volume No.	Title
I	Summary
II	Detailed Description of Analysis
III	Engineering Economics Analysis Data and Results
IV	Dual-Mode Locomotive Design Study

The Wayside Energy Storage Study represents the joint efforts of the AiResearch Manufacturing Company of California and Bechtel Incorporated; the Bechtel staff assisted in the railroad location survey, the electrification studies, and the wayside station design.

The continued assistance and guidance of the Transportation Systems Center (TSC) Technical Monitor, Mr. John M. Clarke; the Federal Railroad Administration (FRA) Functional Coordinator, Energy/Environment, Mr. John Koper; and several members of the TSC and FRA staffs were invaluable to the success of the study.

The interest and support for the Wayside Energy Storage Study given by Mr. Peter L. Eggleton, Director General, Transport Canada Research and Development Centre, and his staff have been helpful and have shown that the concept is also applicable outside the United States. Interest in the wayside energy storage concept has also been expressed by Mr. W. Latscha, General Manager, Swiss Federal Railways.

Major contributions were made by many U.S. railroads, who contributed comprehensive information that was used to establish and maintain the necessary data base. These railroads also acted as sounding boards in the review of flywheel energy recuperation concepts developed in the study. Their comments and suggestions have been incorporated into the final recommendations of the program, with the result that the concept favored for subsequent development, demonstration, and deployment is representative of equipment that railroads would consider for future procurement. The following railroads have given substantial assistance to AiResearch in the study:

Atchison, Topeka, and Santa Fe

Black Mesa and Lake Powell

Burlington Northern

Conrail

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Denver and Rio Grande Western

Duluth, Missabe, and Iron Range

Southern

Southern Pacific

Union Pacific.

Many material and equipment suppliers were helpful in defining locomotive modifications, wayside electrification, and the flywheel stations. The suppliers contributing to the study were the following:

Edison Institute

English Electric Corporation

General Electric Industrial Sales Division

General Electric Locomotive Department

General Motors Electro-Motive Division

Lukens Steel Company

Morrison and Knudsen

Reliance Electric

Southern California Edison

Westinghouse Electric Industry Products.

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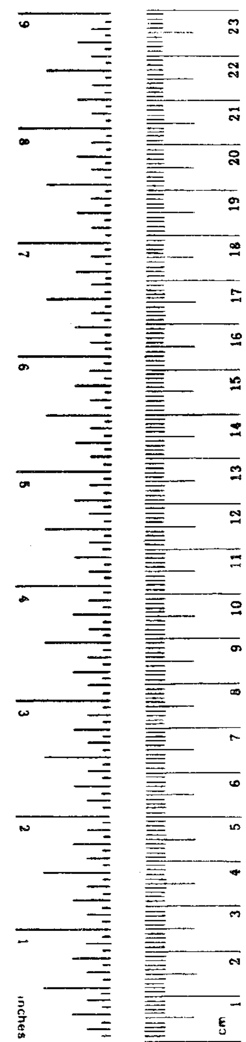
METRIC CONVERSION FACTORS

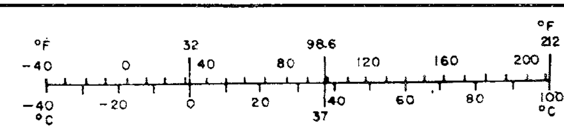
Approximate Conversions to Metric Measures

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



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	35	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



SECTION 1

INTRODUCTION

The initial intent of this Wayside Energy Storage Study was to establish the feasibility and to quantify the benefits of recuperating braking energy from freight operations. (Such energy--the annual equivalent of many million barrels of oil--is presently wasted in the daily operation of freight trains on long downgrades or during stopping); however, it was recognized at the outset that the study should concentrate on determining the best sites for deployment of wayside energy storage systems (WESS's). Therefore, criteria were established regarding grade characteristics such as elevation change, traffic density, track configuration, and length of grade. These criteria allowed a quick screening of data gathered on grades throughout the United States. The WESS study began with a series of visits to operating railroads and the Federal Railroad Administration (FRA) to obtain the needed data on actual grades.

PROGRAM OUTLINE

The WESS study was conducted by AiResearch and the program subcontractor, Bechtel, Inc.; it consisted of performing the 11 work items specified in the Statement of Work in the contract. The specific work items completed during this program are summarized below:

> Item 1, Locations--Survey the route system of U.S. railroads to identify and classify potential locations for application of wayside flywheel energy storage. The contractor shall acquire all pertinent data that is currently available, including parameters of grade, length of grade, traffic density, train speeds, train consists, and fuel consumption data. In accumulating the aforementioned data, the contractor, and/or its subcontractor, shall not conduct any survey involving more than nine (9) railroads, or other elements of the general public by questionnaire, telephone call, personal visit, or other means.

> Item 2, Systems--Derive concepts of complete systems for the applications identified by the survey (including equipment in the locomotives and at flywheel stations) for both electrified and diesel-electric railroads. System concepts for flywheel stations may also include other energy storage concepts operating in conjunction with the flywheel. Realistic operational scenarios shall be defined by the contractor. The benefits to be derived from each of the concepts, based upon the adopted scenario, shall be identified in terms of technical risks and/or deficiencies, and potential benefits. The study shall determine where a need exists for a wayside-to-train communications link to alert the ascending train of the available energy, or to inform the wayside station of train weight, length, and other pertinent data. This system study shall determine the most cost-effective design concepts along with the operational procedure to be used. The contractor shall establish limits on parameters such as train length and grade for a particular system configuration.

Item 3, Calculations--Perform calculations of power and energy requirements for proposed systems at candidate locations, and compare with fuel consumption data for existing operations. An existing train performance simulation, modified as required to model wayside storage, may be used to evaluate the performance of each system concept considered. This computer simulation model shall be capable of taking into account various operating parameters including, but not limited to, the following:

(a) Varying the rated horsepower of locomotive

(b) Varying the size of the train

(c) Varying the train schedule

(d) Topographic conditions

The simulation model may have value beyond the scope of this study. It may be employed by a railroad for a particular application to determine the proper system configuration and to measure potential benefits.

Item 4, Locomotives--Determine modifications required for diesel-electric locomotives to deliver and receive energy from the propulsion system. Consider both the direct transfer at propulsion system dc voltage level, and the onboard conversion to a different voltage level to match the ratings of the wayside collector system.

Item 5, Wayside--Derive concepts of wayside, third-rail, and/or catenary equipment to deliver and receive energy from the locomotives. Systems to be considered are to include those using the running rails as one electrical side, as well as bipolar systems consisting of two catenary wires or two opposite-side third rails. Consider the impact on existing signaling systems using the rails as one electrical side.

Item 6, Stations--Derive concepts for the flywheel stations, including alternative types of motor/generator flywheel sets, flywheel designs, number of sets for reliable service, use of standard machinery, vacuum systems, and duty cycle. Other energy storage concepts involving the flywheel also shall be considered, including batteries. The study also should consider automatic alterations to the flywheel system configuration based on approaching train data, including parameters such as weight and length.

Item 7, Controls--Determine methods for regulating the flow and storage of energy for various train configurations such as: one track with one train on the descending grade, no train ascending; ditto with ascending train; two tracks with all combinations of ascending and descending trains.

Item 8, Energy Supplement--Analyze use of utility energy to precharge the flywheels, or to supplement the flywheel energy for ascending trains. Return of energy to the utility will be taken into consideration, as will the use of flywheel sets integrated with gas turbines or other auxiliary power sources for peak-shaving at wayside substations.

Item 9, Electrified Railroads--In the design concepts of flywheel systems, consider the problem of coupling single-phase buses to substation buses. Consideration should be given to the use of flywheel sets at electrical points common to several substations, and also to the use of flywheel sets integrated with gas turbines or other auxiliary power sources for peak-shaving at wayside substations.

Item 10, Engineering Economics--Provide an engineering economy study to determine the economic viability that results from installation of a track-side flywheel energy storage system at the crucial points identified by this study. All major cost and savings increments should be considered, including those related to energy, fleet size, locomotive maintenance, and capital investment in wayside equipment and locomotive modifications. Credit should be included for equipment that would be retired, presuming it can be redeployed elsewhere in the system. Traffic density should be based upon actual schedules, and traffic growth should be based upon Department of Commerce projections. The analysis should be conducted for both diesel-electric and all-electric operation. Cost parameters to which the analysis is highly sensitive should be identified and their effect should be demonstrated by a sensitivity study.

Item 11, Development Program--Based on the results of the study covered by the preceding tasks, preliminary estimates shall be provided for a suitable follow-on program. This program shall contain recommendations concerning selected concepts, equipment requirements, test/demonstration programs, suitable test locations, and R&D requirements.

Reference to the above-listed items of the study will be made throughout the final report to show the specific efforts which have been directed toward each particular work item.

PROGRAM METHODOLOGY

A logic diagram of the methodology followed by AiResearch and Bechtel in performing the study program is shown in Figure 1-1. The initial data-gathering tasks described above, as shown at the extreme left side of Figure 1-1, were accomplished by a series of visits with the engineering and operating personnel of the following railroads:

Black Mesa and Lake Powell

Conrail

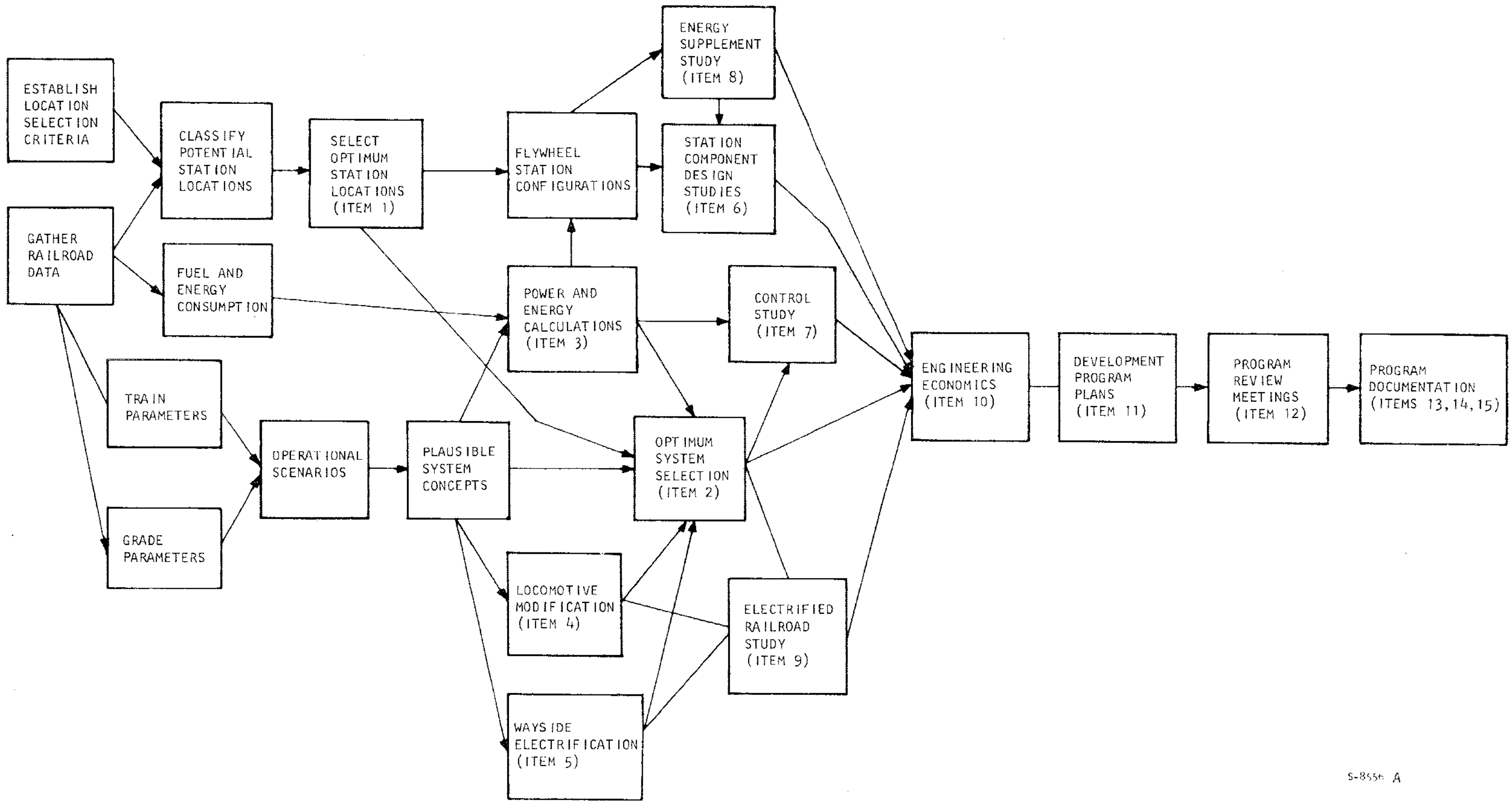


Figure 1-1. Wayside Energy Storage Study Methodology

Duluth, Missabe, and Iron Range

Southern

Southern Pacific

Union Pacific

In addition, detailed track and operational data were provided by FRA for the following railroads:

Atchison, Topeka, and Santa Fe

Burlington Northern

Denver and Rio Grande Western

This information was then used to complete the location study (item 1), and as an input to study items 2 through 5. The interaction and dependencies of these activities are shown in Figure 1-1. With the station configurations and energy requirements determined, it was then possible to complete items 6 through 8. At the same time, study of the operation of WESS as a peak-shaver on electrified railroads (item 9) was accomplished. The important engineering economic analysis (item 10) was then completed, using inputs from items 1 through 9. Finally, as shown in Figure 1-1, development plans were formulated (item 11); this task was followed by various program review and documentation activities (items 12 through 15).

TRAIN PERFORMANCE CALCULATOR

After the study was under way, a task was added to the WESS program by AiResearch as part of the power and energy calculations (item 3) to permit more accurate and complete assessment of energy savings based on actual railroad operations. During the initial work on energy calculations, it was found that the energy economics of WESS were strongly influenced by the operating timetable of the railroad. To determine the interactive effects of as many as 60 trains per day on a WESS grade, it was necessary to use a train performance calculator (TPC) with the capability of calculating energy at the WESS station for many trains at the same time. The AiResearch and Bechtel TPC programs do not have this capability, nor does the TSC program. Therefore, AiResearch decided to generate a new TPC with the required capability of simultaneously calculating the energy requirements in a complete railroad division. The new AiResearch TPC can calculate the energy requirements of up to 100 trains operating on 10 separate electrified sections. These individual train energy values can be summed by the computer to provide the energy values that would be experienced at WESS stations on the route.

As a demonstration of its versatility, the new TPC has been used to calculate the complete energy profile for a full day of operation on the Pittsburgh-Harrisburg section of Conrail, based on actual dispatcher's records. This unique TPC has been developed within the resources of the Wayside Energy Storage Study contract. In the interest of making this important tool available to TSC, FRA, and other agencies, the new TPC listing is presented later in this volume.

FORMAT OF FINAL REPORT

The sheer volume of material generated during the 1-year Wayside Energy Storage Study has necessitated publishing this report in three volumes. Volume 1 briefly describes the work conducted, the results achieved, and the conclusions reached. The main body of technical data, including the new TPC, is contained in the present volume. The extensive engineering economics analysis data and results are contained in Volume 3.

SECTION 2

SYSTEM DESIGN AND CONCEPTS

The study of the wayside energy storage system (WESS) design involved the following interacting program work items which were described in detail in Section 1:

- Item 2 System Study
- Item 4 Dual-Mode Locomotive
- Item 5 Wayside Electrification
- Item 7 Controls
- Item 8 Energy Supplement
- Item 9 Electrified Railroads

The approach used for the study and the results obtained are described in the following paragraphs.

APPROACH

The systems study first examined all the plausible energy storage means that had potential for application to WESS; next the various methods of transmitting the recuperated energy back and forth to the wayside at the grade were analyzed. Overall system configuration tradeoff studies were then conducted and optimum arrangements were selected. At this point the operational constraints indicated by meetings with railroads were applied to the system concepts and used to develop the most practical operational concepts. Then consideration was given to the electric locomotives that would be used for WESS on electrified railroads, and, finally, the dual-mode locomotive concept was developed.

PLAUSIBLE ENERGY STORAGE SYSTEMS

Prior to embarking on the detailed study of flywheel-configured WESS stations, a final comparative analysis was made to establish that no other energy storage technique should be considered. The important criteria that were used in assessing the relative merits of an energy storage device for WESS are:

- Round trip efficiency
- Deep discharge cycle life
- Energy density
- Power density
- Initial cost
- Maintenance cost

The use of these criteria in the analysis resulted in the identification and consideration of the energy storage techniques described below. Comparative data for the major characteristics of these energy storage systems are shown in Table 2-1.

Batteries

The energy density of the battery often is higher than that of the flywheel; however, the battery is clearly inferior to the flywheel in power density (charge or discharge rate capability). This low battery power density often sizes the battery. For example, for a 5 Mw-hr battery with an energy density of 14 w-hr/lb, the power density would be expected to be the lower value of 10 w/lb as shown in Table 2-2. Then the battery weight based on energy density would be 180 tons, while the weight based on power density would be 250 tons. The latter weight would then be required for the WESS application.

The deep discharge cycle life of the flywheel is its most important attribute since in WESS service the energy storage system could see as many as 40 charge-discharge cycles per day. The projected life of the flywheel at this level of service would be 55 years while that of the battery would be only 38 days.

The cost differential shown in Table 2-1 between the battery and flywheel is of negligible concern when the comparable useful lives are considered. In addition, the battery would require a high level of maintenance (changeout, watering, equalizing, etc.) compared to the flywheel, which is compatible with long, unattended operation.

The round trip efficiency of the battery (i.e., useful discharge energy divided by charge energy) is very low (60 percent) compared with that of the flywheel (i.e., useful spin-down energy divided by spin-up energy), except for very long charge-discharge cycles.

The flywheel clearly offers by far the better combination of characteristics for the WESS application as shown in Table 2-1. Consideration was also given to projected new battery types such as nickel zinc, zinc chloride, and sodium sulfur which are expected to become available within the next 10 to 15 years (ref 1).* Although these battery types promise higher energy and power densities than the lead-acid battery, their economic deep discharge cycle lives are not expected to exceed 2500.

Pumped Hydroelectric

The pumped hydroelectric system could be used for WESS, especially since mountainous terrain is involved, but investigations by AiResearch and Bechtel have shown that installation costs are about twice that for a flywheel system (although it is recognized that costs of these schemes are very much dependent on the terrain encountered). For the typical 10-Mw scheme developed later in the study, a cost of $700/kw could be expected, assuming that there were no abnormal difficulties associated with construction. Such installations make use of reversible turbine sets which, when pumping, have an efficiency of

* References are listed in Section 8.

TABLE 2-1

ALTERNATIVE STORAGE CONCEPTS

Storage Concept	Round Trip Efficiency, percent	Installed, $/kwhr	Cycle Life	Service Life
Battery	60	70	1000	2 Months
Pumped hydroelectric	76	1000	10^6	30 Years
Regeneration to utility	92	120	10^6	30 Years
Compressed air	37	N/A	10^6	30 Years
Flywheel	91.2	270	10^6	30 Years

*Site-dependent

TABLE 2-2

ENERGY STORAGE SYSTEM COMPARISON
(Based on existing technology
applied to full-size systems)

Characteristic	Present Batteries	Flywheels
Energy density, W-hr/lb	8 to 14	3 to 12
Power density, W/lb	10 to 30	100 to 200
Deep discharge, W/lb	500 to 1500	10^6
Cost, $/kwhr	100	270
Round trip efficiency	60 percent	91.2 percent

85 to 90 percent, and when acting as a turbine, have an efficiency of 90 to 95 percent. Therefore, the round trip efficiency of the pumped hydroelectric system is typically 75 percent compared with 91.2 percent for the flywheel.

Regeneration to the Utility

This technique is technically attractive, having the high round trip efficiency of 92 percent; however, economically it suffers from the disadvantage of not getting a full credit for the energy returned (usually only 60 percent for a railroad-type operation), and there would be no credit for the demand portion of the utility change (which normally accounts for 50 percent of the utility bill). Therefore, the value of the energy saved is significantly lower than for the flywheel configured system, amounting to approximately one-third of the original cost.

Compressed Air Storage

This storage system is based on gas turbine technology and consists of gas turbines compressing air in large underground storage caverns. During regeneration, the generators, running as motors, would "recharge" the air-storage caverns.

During discharge periods, the high-pressure air from underground storage caverns is released to spin the plant's turbine generators and provide the required energy to the railroad.

Potentially suitable air-storage sites include underground salt formations, depleted oil and gas wells, and played-out mines.

It is expected that this novel approach to energy storage will be of increased importance in the coming years; however, in the immediate future it is not considered suitable for WESS because of its low round trip efficiency and the improbability of finding a conveniently sized underground cavern near a WESS candidate grade.

Flywheels

The flywheel is probably the oldest energy storage technique known to man. The most common application is on the reciprocating engine where energy is stored between each power stroke of a piston to provide a near-constant output of torque from the crankshaft. The larger the flywheel, the less the variation in torque output. In the WESS application, the flywheel has most of the advantages of direct regeneration to the utility (including a high round trip efficiency of 91.2 percent) with the advantage of receiving full credit for regenerated energy. The life of the system is in excess of 10^6 deep discharge cycles, and the energy and power densities are at least competitive with those of the battery.

Large-flywheel technology is expected to make a significant advance during 1978 with the commissioning of the Tokomak flywheels, which are described in detail later in this report. Therefore the WESS flywheel will be within the state of the art.

As a result of this analysis, summarized in Table 2-1, AiResearch has determined that, within existing technology, the flywheel represents the most economic and efficient method of storing energy for reuse at a later time not exceeding 24 hr.

ENERGY TRANSMISSION CONCEPTS

A key decision in the Wayside Energy Storage Study was the determination of the most practical and cost-effective means of transmitting energy to and from freight trains on a grade. At the locomotive, during braking, this energy exists in dc electrical form and also could be used by a subsequent ascending locomotive in the same form. Thus, it appeared logical to analyze various means of electric transmission of energy to the wayside.

The basis of all the systems is that the potential energy of the descending train is converted to electrical energy and transmitted to the wayside station where it is stored in a flywheel. Subsequently, this process is reversed, and stored energy is transferred to an ascending train. All systems therefore require an electrical distribution system matched to onboard locomotive and wayside equipment.

The following arrangements were considered for transmitting electrical power to the wayside:

- Low-voltage dc through a third rail
- High-voltage dc through a catenary
- Linear induction motor
- High-voltage ac through a catenary

The technical tradeoffs involved with the various means of energy transmission are described in the following paragraphs.

Low-Voltage Dc Third Rail

The common 600- to 1000-vdc third-rail system that is used for rapid transit systems as well as for operating electric switching locomotives in electrified freight yards was the first candidate considered. In this system, power is transmitted to and from the third rail by collector shoes on each locomotive. Thus, when descending the grade, the locomotive traction motors would act as dc generators supplying power to the third rail for transmission to the wayside. At the flywheel station a converter would be used to condition this power to a suitable form to drive an electric machine that would be connected to the flywheel. The power from the descending train would thus be used to spin up the flywheel. The discharge of the flywheel to deliver power to a subsequent train climbing the grade would be the reverse of the charging sequence.

From the locomotive standpoint, the low-voltage system appears attractive since only minimal modifications would be required to an existing diesel-electric locomotive. This point is important since about 99 percent of the U.S. freight operations are accomplished by diesel-electric locomotives. There are presently only four electrified freight lines in the U.S.; these are: Conrail on the Northeast Corridor from New Haven into Washington and Harrisburg, Black Mesa and Lake Powell Railroad in northern Arizona, Muskingum Railroad in southeastern Ohio, and Texas Utility Company Railroad in Texas.

A calculation was then made of the third-rail requirements for electrification of a typical WESS grade. For this analysis it was assumed that a typical WESS site consisted of an elevation change of 1500 ft with an average grade of 1.0 percent. The length of this grade is then 23.6 miles with a wayside flywheel station assumed to be at the midpoint. A typical freight consist operating at the grade would have three 3000-hp diesel-electric locomotives (equivalent to the General Motors Electro-Motive Division (EMD) Model SD40).

If the locomotives were used to provide their full braking capability of 4000 rail hp (the higher braking capability is fully explained later in this section), this would result in the delivery of 3560 hp to the third rail from each locomotive due to the generation efficiency. The total train power into the third rail of 10,680 hp at 600 vdc would result in a current level of 13,300 amp. The transmission of this current from the extremities of the typical grade to the flywheel station with a 25-percent voltage drop would result in a two-way voltage drop of 12.7 v per mile. The third-rail resistance based on an equivalent resistance return path can then be calculated as follows:

$$\text{Third-Rail Resistance} = \frac{\text{Voltage Drop}}{\text{Current}}$$

or,

$$\text{Third-Rail Resistance} = \frac{6.35 \text{ v}}{13{,}300 \text{ amp}} = 0.48 \text{ ohm}$$

The required conductor size based on the use of soft annealed cooper is the equivalent of 539 AWG 4/0 conductors, which would have a cross section of 89.6 sq in. (a square conductor 9.5 in. on a side), which would have a weight of 911 tons per mile. Clearly, such a third-rail conductor is impractical (particularly since an equivalent return rail would be required because the running rail resistance is far too high to be a suitable return).

High-Voltage Dc Catenary

The second transmission system considered was a high-voltage dc system possibly similar to the 3-kv catenary used by the Milwaukee Road in Montana and Washington until 1974 (ref 2). This application made use of special high-voltage dc locomotives with frequent catenary feed points. The Milwaukee Road system was regenerative back to the catenary providing for the use of braking energy by other trains operating over the electrified sections.

The application of a high-voltage dc catenary system to WESS would require modification of both the present diesel-electric and electric locomotives (which operate at high ac voltages) to be compatible with dc operation. In the more important case of the diesel-electric locomotive, the conversion from high-voltage dc to low-voltage dc (and vice versa) requires a dc-to-dc voltage transformation that must be accomplished by a relatively expensive solid-state power conditioning unit. Unfortunately dc cannot be transformed in voltage as simply as ac power with a transformer. The dc-to-dc converter required for propulsion would consist of an inverter that changes the high-voltage dc to high-voltage ac power, which can be simply transformed to low-voltage ac. The resulting ac power would then be rectified and supplied to the locomotive traction motors. During braking operations, the low-voltage converter must act as a dc-to-ac inverter whose output is stepped up to be rectified for connection to the catenary.

The complexity of the converter required in which both high- and low-voltage sections must act as either an inverter or a rectifier was found to be prohibitive from a cost standpoint for serious consideration in the WESS study.

Current railroading practice has tended to draw away from high-voltage dc catenary systems in favor of high-voltage ac systems largely because of the complexity and cost of the bilateral converter.

Linear Induction Motor

A brief analysis was made of the use of a linear induction motor (LIM) for transmission of energy from train to wayside and back. This concept at first glance appears attractive since energy can be transmitted across the LIM air gap inductively without need for a catenary and pantograph. The findings were that the LIM has very low round-trip efficiency compared with catenary systems (32 percent compared with 96 percent for a catenary system--both based on the distribution system). In addition, the initial cost of installing the LIM stator magnetic structure between the running rails for a distance of 23 miles on a typical grade was found to be excessive (at least twenty times the cost of providing a catenary).

The combination of low efficiency and high cost, which is characteristic of the type of LIM required for the WESS application, resulted in dropping this concept from considerations at an early stage of the study.

High-Voltage Ac Catenary

The current practice on electrified U.S. railroads is to use a high-voltage ac catenary for electrification. Recently the preferred voltage is 25 kv, 60 Hz on older, congested routes with tighter clearances like the Northeast Corridor (this is the new electrification that will replace the present 11-kv, 25-Hz voltage and is also being proposed for the extension from Harrisburg to Pittsburgh). The electrification of Western railroads has generally been directed toward the use of 50 kv, 60 Hz as is the case with the Black Mesa and Lake Powell Railroad.

The WESS concept configured with a high-voltage ac catenary is readily compatible with the use of present electric locomotives provided these units are modified to provide regeneration back to the catenary. This modification involves the conversion of the semi-controlled rectifiers in the locomotive to fully controlled rectifiers, which can be accomplished by replacing the silicon diodes in the lower arms of the present bridges with thyristors, as shown in the schematic of Figure 2-1, and making the necessary changes in the control circuitry. The fully controlled rectifiers then would act as line commutated inverters during braking, coupling energy to the catenary. This arrangement is similar to that which has been used on the four regenerative electric locomotives built by ASEA, one of which is currently operating in Rumania. The same modification could be applied to either new or existing General Electric Model E60 electric locomotives.

Regenerative locomotives are currently in widespread use in Switzerland and the Soviet Union. Presently 52 of the order of 89 Brown Boveri Company (BBC) Model RE 6/6 electric locomotives are in service on the Swiss National Railways, providing regenerative braking for freight operations (refs 3,4). The extent of Soviet deployment of regenerative locomotives is not known since no published information is available.

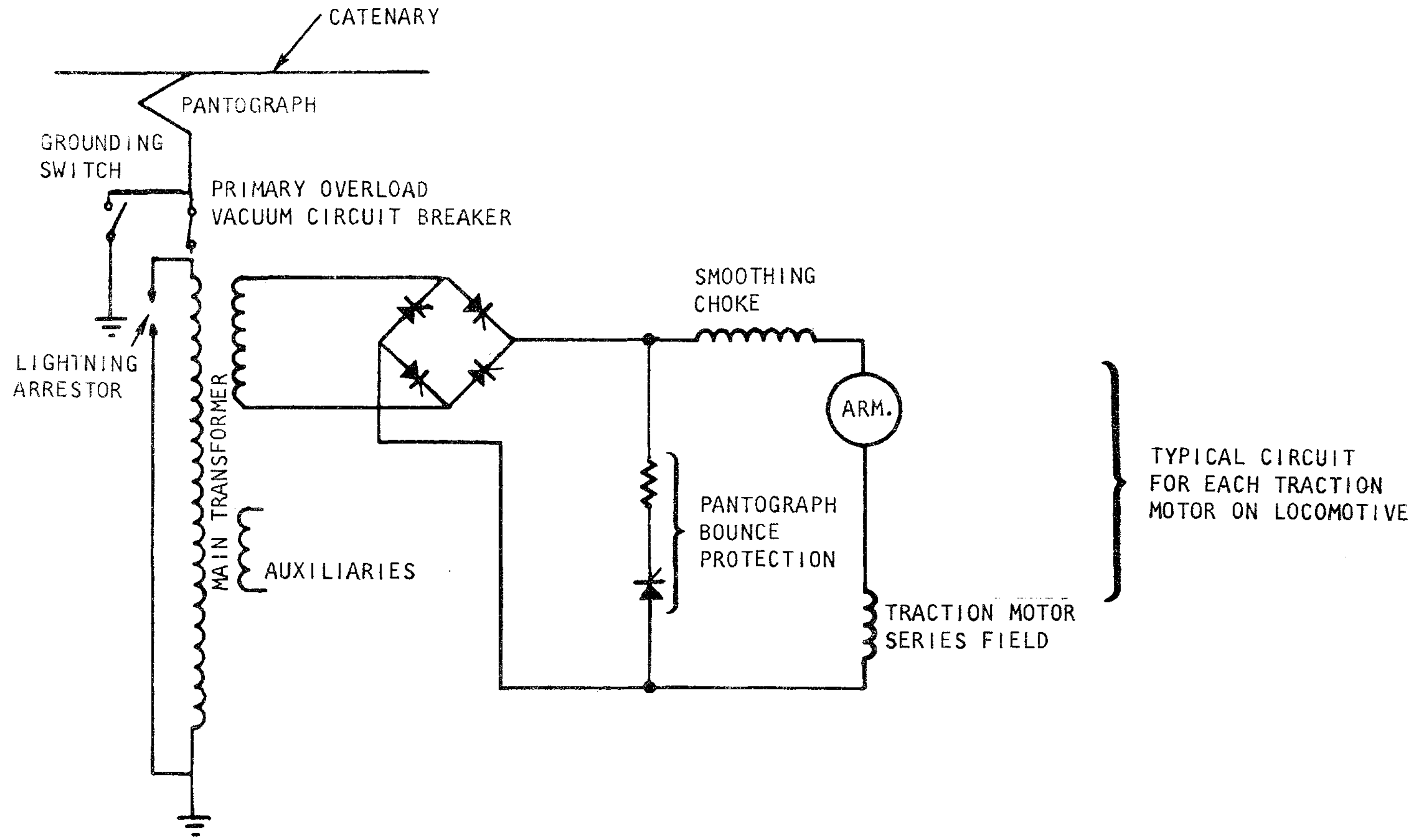


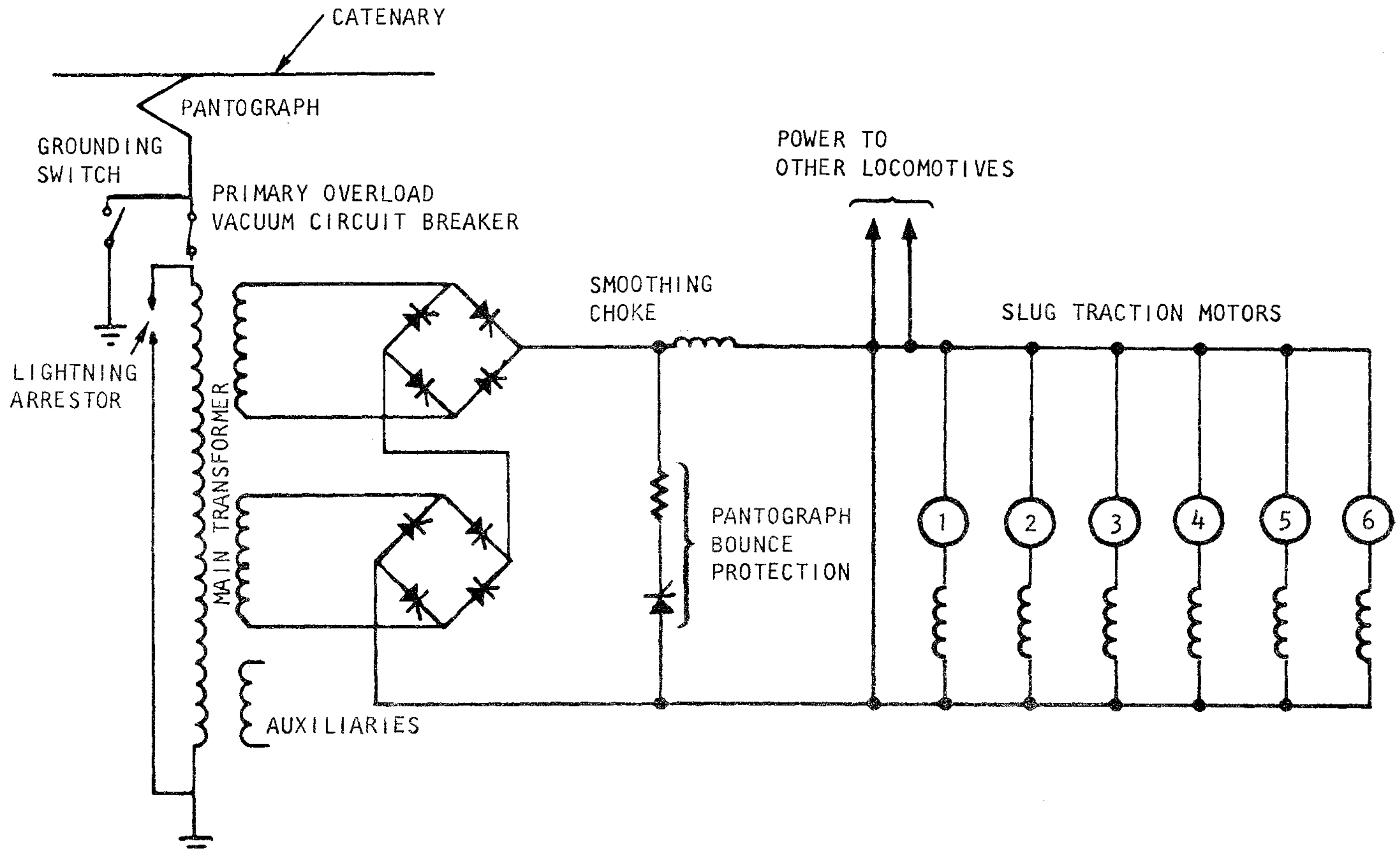
Figure 2-1. Regenerative Electric Locomotive Schematic

The regenerative electric locomotive could be directly used with WESS on presently electrified railroads. These locomotives could also be used as helpers to operate freight consists over grades with local electrification. The implications of this latter mode of operation will be discussed later in this section of the report.

The important question of making the present diesel-electric locomotive compatible with the high-voltage ac catenary was then addressed. The first approach studied was the use of slugs that would be added to the consist at its originating yard. These slugs would be fitted with a pantograph to pick up power from the high-voltage ac catenary at the grades. This power would be stepped down in voltage by a transformer and then rectified by a two-section phase delay rectifier to provide a controlled dc voltage as shown in the schematic of Figure 2-2. This controlled dc voltage would then be connected to the traction motors of the diesel locomotives in the consist and also to a set of traction motors on the slug. The freight train would operate under diesel power up to the WESS grades, at which point the diesel engines would be unloaded and run at a sufficient speed to provide auxiliary power, and the slug would be used to provide the power to all the traction motors in the consist to operate the train regeneratively over the grade. In the sections of the route between WESS grades, the slug could use power from the diesel locomotives to operate its traction motors, thereby increasing the low-speed tractive effort of the train, reducing the adhesion requirement, and possibly reducing the required diesel locomotive consist.

The idea of using slugs as helpers located only at the grades was rejected because of the difficulty of breaking the locomotive consist to place the slug between locomotives at one end of the grade, and to remove it at the other end.

The concept of using slugs was ultimately abandoned largely because of the difficulties foreseen in coupling the required high currents from the slug to the locomotives. The peak current requirement of an EMD model SD40 locomotive is 1000 amp per traction motor or 6000 amp per locomotive. Thus, if a slug were located in the middle of a consist of four locomotives it would be necessary to couple 12,000 amp through the adjacent locomotive couplings and 6000 amp through the remote locomotive couplings. The conductor size required for the connection of the slug to the diesel-electric locomotives is equivalent to 20 AWG 4/0 conductors that have a total cross-sectional area of 3.32 in.^{2} This requires two 2.0-in.-dia copper cables to be installed on all the locomotives that would be used on the WESS grade. This requirement along with the minor modifications in locomotive controls to provide for operation on the WESS grade with power supplied from the slug does not appear impossible to provide; however, the connection of the slug to the other locomotives in the consist does pose a formidable obstacle, since these connections must be capable of being made automatically as part of the coupler (the use of manual connections for this purpose has been found to be operationally unacceptable to the railroads contacted). An investigation was made into the development of an automatic connector with the necessary capability since nothing even remotely similar is presently available. The results have shown that such a development



• PROTECTION AND ISOLATION EQUIPMENT NOT SHOWN

Figure 2-2. WESS Slug Schematic

would necessarily be expensive and without a guarantee of success. The reason is that the contact resistance that must be initially achieved and then maintained under all operating conditions is so low as to be virtually unattainable. For example, a contact resistance at either connection of only one milliohm (which is the resistance of one foot of AWG 10 wire) would result in a local power dissipation at that point of 144 kw. It was on the basis of the difficulty of making these power connections that the slug concept was dropped.

The second locomotive concept that was investigated for compatibility with the high-voltage ac catenary was the dual-mode locomotive. This is a modified diesel-electric locomotive that can be operated either conventionally with the diesel engine or as a regenerative electric locomotive deriving its power from the catenary. The modifications that are described in detail later in this section consist of the addition of a pantograph, transformer, power converter, and traction motor choke. Also, the traction motors are to be rewound for separate field excitation, and the controls are to be altered.

The results of the dual-mode locomotive study showed the feasibility of this concept. The detailed findings of this investigation, which are described later, revealed that the dual-mode locomotive could meet all the requirements for WESS while providing compatibility with operation on a high-voltage ac catenary.

The WESS concept then could be deployed with regenerative electric locomotives on electrified railroads or helpers on electrified grades and as an alternative with dual-mode locomotives operating over routes where only selected grades are electrified for energy recuperation.

Thus, the first conclusion reached in the systems study (Item 2) was that the optimum system for transmission of energy from trains to the wayside is by a high-voltage ac catenary. The voltages recommended are 25 kv for railroads where clearances are limited and 50 kv for more wide-open railroads like those of the Western U.S.

The overhead line equipment was designed and costed by Bechtel. The system is designed for 70 mph with multiple-pantograph operation. The simple catenary construction is used in which the contact wire is supported from a single messenger wire by droppers. This is similar to the arrangement used on the Black Mesa and Lake Powell railroad, as shown in Figures 2-3 and 2-4.

The support structures will be wooden poles except in the Pennsylvania area where steel poles are considered more appropriate.

A study of the cost of electrification showed that the cost in 1977 dollars could vary as shown in Table 2-3 (ref 5).

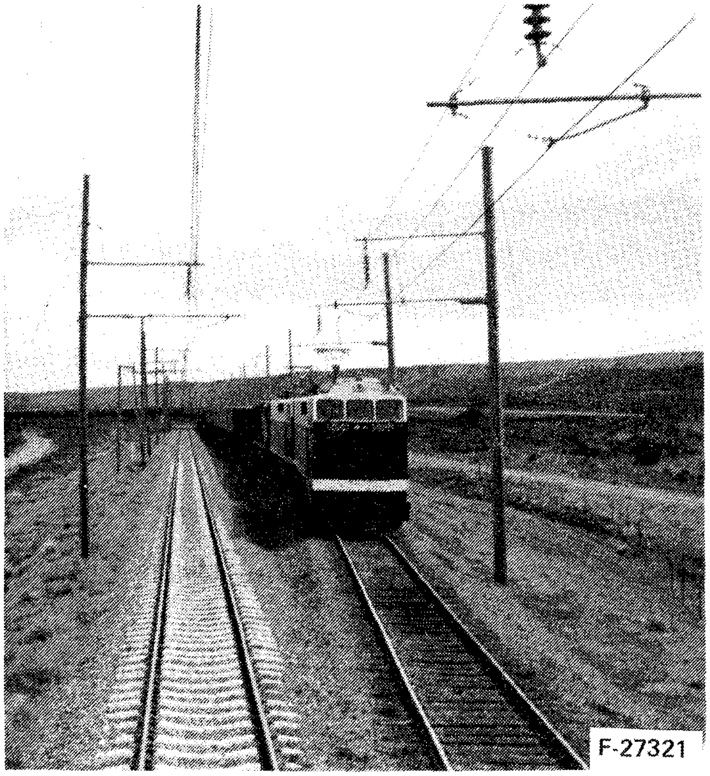


Figure 2-3. Typical Overhead Line Equipment

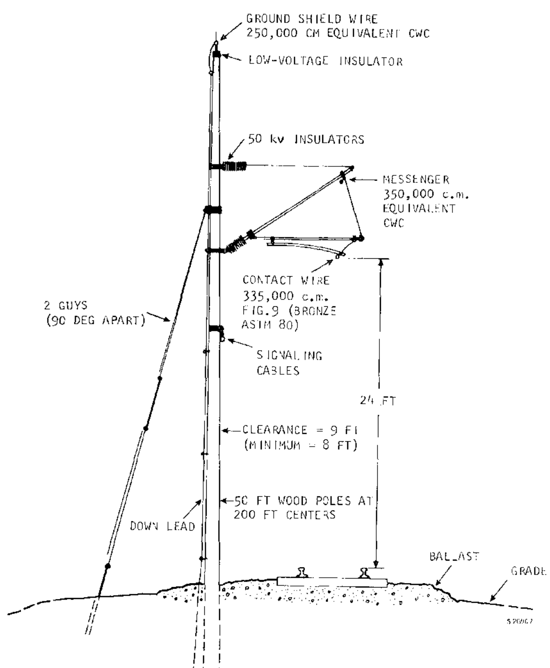


Figure 2-4. Proposed Catenary Support

TABLE 2-3

RANGE OF ELECTRIFICATION COST FROM REFERENCE 5

Estimate	Electrification Cost, 1977 Dollars	
	Single Track	Double Track
Low estimate	$125,000	$205,000
High estimate	$350,000	$495,000

The costs quoted in Table 2-3 do not include the cost of the conventional utility tie-in associated with railroad electrification. Before it was decided whether a utility tie-in was necessary, the energy supplement study (Item 8) addressed the question of the optimum source of additional energy required to move the ascending train up the hill. Clearly some form of energy supplement is necessary since the energy regenerated by the descending train is subjected to the system inefficiencies (discussed later in this section). Therefore, AiResearch considered four sources of energy supplement:

- Locomotive diesel engine (for the dual-mode locomotive)
- Gas turbine generating unit
- Diesel generator unit
- Utility tie-in

Since the prime object of the WESS program is to save oil, those sources of energy supplement directly dependent on oil products were not favored in principle; however, the economic case for each of the three latter alternatives was investigated, and the results are shown in Table 2-4.

The saving in energy cost of the utility system is compared with the diesel system and has a net present value of $0.8 million, based on the 30-year project life. The clear conclusion reached was that the utility tie-in represented the most economic and energy-efficient source of energy supplement; however, there may be isolated locations where the cost of provision of a utility tie-in exceeds the average value used in Table 2-4 by such a margin that the diesel engine alternative should be considered.

The costs of electrification used in this study (including the utility tie-in, catenary, signalling, and substation) are shown in Table 2-5.

Comparison of Tables 2-3 and 2-5 shows that the electrification costs used in this study are conservative, and this is reflected later in the study when the return on investment for electrification schemes is seen to be lower than figures normally quoted.

TABLE 2-4

EVALUATION OF ENERGY SUPPLEMENT OPTIONS

Characteristics	Utility	Diesel	Gas Turbine
Heat rate/fuel consumption	9500 Btu/kwhr	0.36 lb/bhp hr*	0.42 lb/bhp hr*
Energy efficiency at generator output terminals	36 percent	32.3 percent*	29.2 percent*
Energy efficiency at railroad metering point	34 percent	31.6 percent	28 percent
Daily energy requirement	96 Mwhr	96 Mwhr	96 Mwhr
Power source capacity	400 Mw	4 Mw	4 Mw
Fuel	Various	DF2	DF2
Supply availability	100 percent	95 percent	98 percent
Initial cost	$1,250,000**	$800,000	$1,600,000
Daily cost			
Energy cost	$1920	$3034	$3427
Power cost	$ 838	-	-
Total supply cost	$2758	$3034	$3427

*At rated output
**Based on average cost of tie-ins identified in this study.

TABLE 2-5

ELECTRIFICATION COSTS DERIVED BY BECHTEL FOR THIS STUDY

Electrification Cost/Route Mile, 1977 Dollars		
Single Track	Two Tracks	Four Tracks
238,000	400,000	500,000

SYSTEM CONFIGURATIONS

With the decision to use a high-voltage ac catenary energy transmission system for WESS, the next consideration was the definition of the entire system to be deployed at typical grades.

Two basic railroad systems were considered, those that are or will be electrified at 25 or 50 kv and those that are and will be operated by diesel-electric traction. Examples of the former that have attractive grades are the presently electrified (at 50 kv, 60 Hz) Black Mesa and Lake Powell Railroad and the Pittsburgh-to-Harrisburg route of Conrail, which is a candidate for 25-kv 60-Hz electrification. All large western railroads (like Union Pacific, Southern Pacific, Santa Fe, Burlington Northern, and Denver and Rio Grande Western) are examples of railroads that will probably continue to be operated by diesel-electric locomotives.

Locomotive Equipment

After a high-voltage ac catenary system is chosen, the locomotive equipment becomes fully defined, and the major elements are:

- Pantograph
- Transformer
- Fully controlled thyristor converter
- Smoothing choke
- Traction motors

A complete description of this equipment is given later in this report.

Flywheel Station Configuration

The choice of interface between the high-voltage ac distribution system and the flywheel is not exclusively defined by the distribution system choice. There are two basic choices for the flywheel machine:

- Dc flywheel machine
- Ac flywheel machine

Initially, a large dc machine was considered for this application, since such a machine places minimal constraints on the converter and is easy to start up. A dc machine in the 10-Mw power range, however, would necessarily operate at a much lower speed than the highly stressed flywheel, which would require reducing gears to be used between flywheel and motor. These gears reduce system efficiency and increase the maintenance requirements of the system. In addition, the dc machine imposes the requirement for brush maintenance. Also, the dc machine with its gearbox would be much larger and heavier than a comparable capacity ac machine and on this basis would adversely influence wayside station cost.

The use of an ac synchronous machine for WESS was found attractive since present commercial designs are available that are suitable for the application. These machines can be provided in brushless configurations and can operate at flywheel speeds, which results in minimal maintenance requirements. The converter required to operate the ac machine is relatively complicated, since it must accept a single-phase, constant-voltage, fixed-frequency input and must deliver polyphase, variable-voltage, variable-frequency power to the flywheel machine. Such a converter, however, is well within the present state of the art. On the basis of these considerations, AiResearch recommends the use of an ac synchronous flywheel machine to operate the flywheel.

The final decisions to be made in the energy transmission system reflect assurance of the compatibility of WESS with the utility and standard railroad electrification. The basic utility requirement concerns the phase unbalance due to the single-phase load demanded by the railroad. Generally phase unbalance is defined as:

$$\frac{\text{Peak single phase load}}{\text{Utility short circuit capacity}} \times 100$$

Where utility supplies are found to not be strong enough to meet this requirement, there are two courses of action open: either a second feeder or a solid-state converter can be used as described later.

Usually an electrified railroad makes use of more than one phase and therefore, by definition, the flywheel converter must have the capability of accepting more than one phase as input before reconfiguration to variable-frequency, three-phase output to the flywheel machine. The optional schemes available are shown diagrammatically in Figures 2-5 to 2-11.

Figure 2-5 shows a system that is not compatible with normal railroad electrification, since it involves the use of a variable-frequency catenary, the frequency being determined by the flywheel speed. This system was disregarded due to the difficulties in providing electrical equipment suitable for the frequency operating range. In particular the locomotive transformer would require sizing for the lower frequency, which would impose unnecessary restraints when it is considered that this system does not reduce the hardware requirements when compared to the systems considered below.

The system shown in Figure 2-6 is compatible with standard mainline electrification. The catenary has the same phase either side of the neutral section and therefore direct regeneration from one locomotive to another is possible without involving the flywheel converter. This system is compatible with the Black Mesa and Lake Powell Railroad system. The system shown in Figure 2-7 is identical to that of Figure 2-6 except that a converter is used to ensure full balance of the railroad load at the 3-phase utility tie-in.

Figure 2-8 shows the typical railroad electrification using more than one phase with unbalance at the utility. The regenerating locomotive returns energy to the flywheel converter, where it is either phase shifted and returned to a receptive locomotive or reconfigured to 3-phase variable frequency and supplied to the flywheel machine. Figure 2-9 shows the same system with the addition of a utility balance converter.

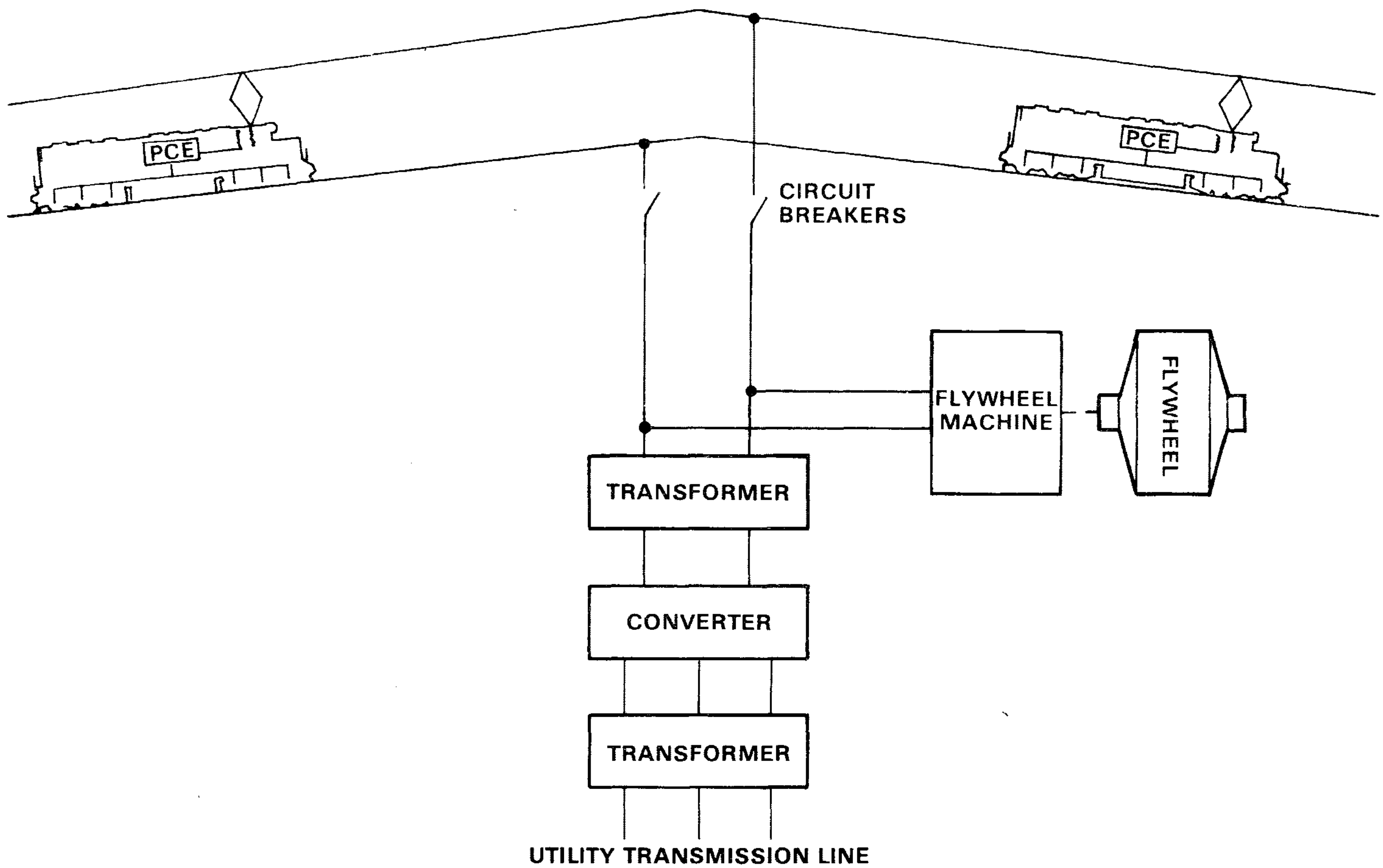


Figure 2-5. WESS High-Voltage Ac Regeneration System Option 1: Variable-Frequency Catenary

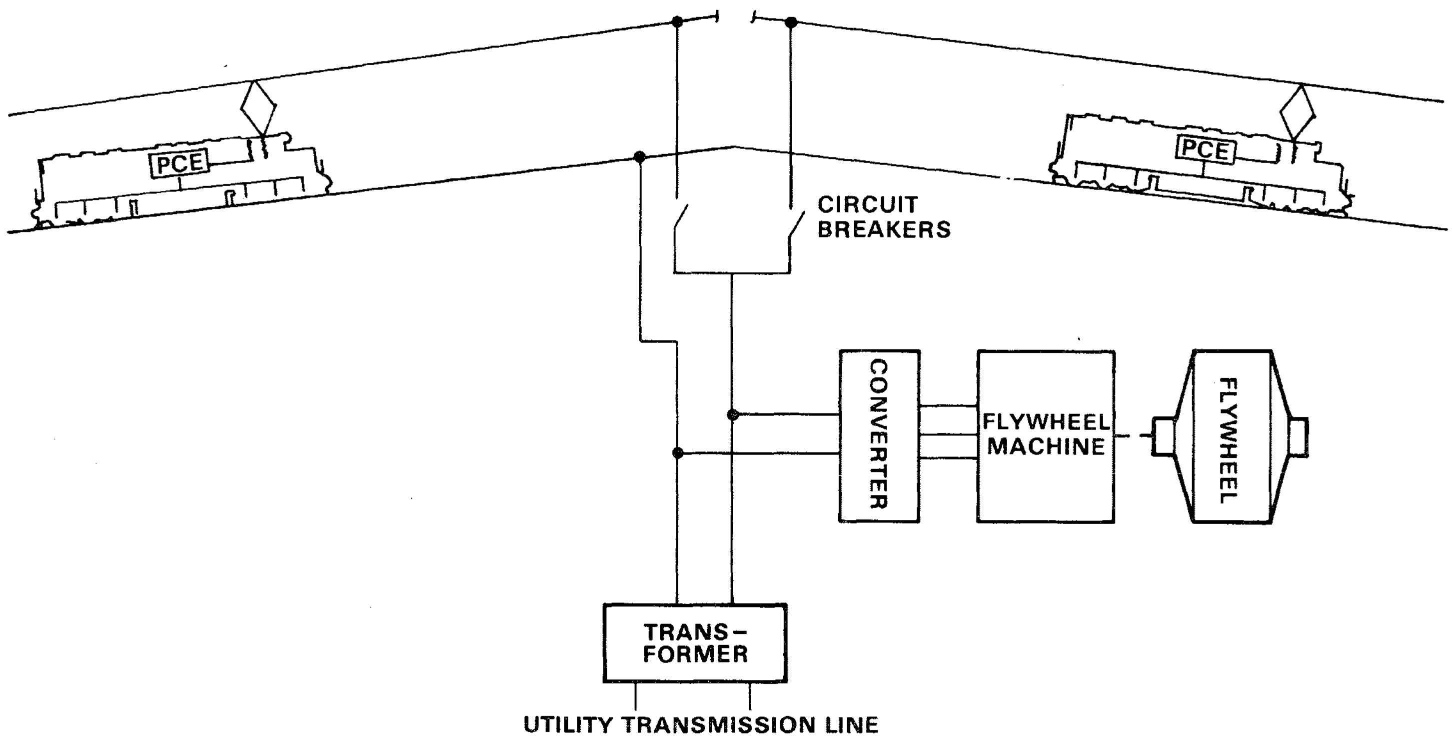


Figure 2-6. WESS High-Voltage Ac Regeneration System Option 2: Constant-Frequency, 1-Phase Catenary (Unbalance at Utility)

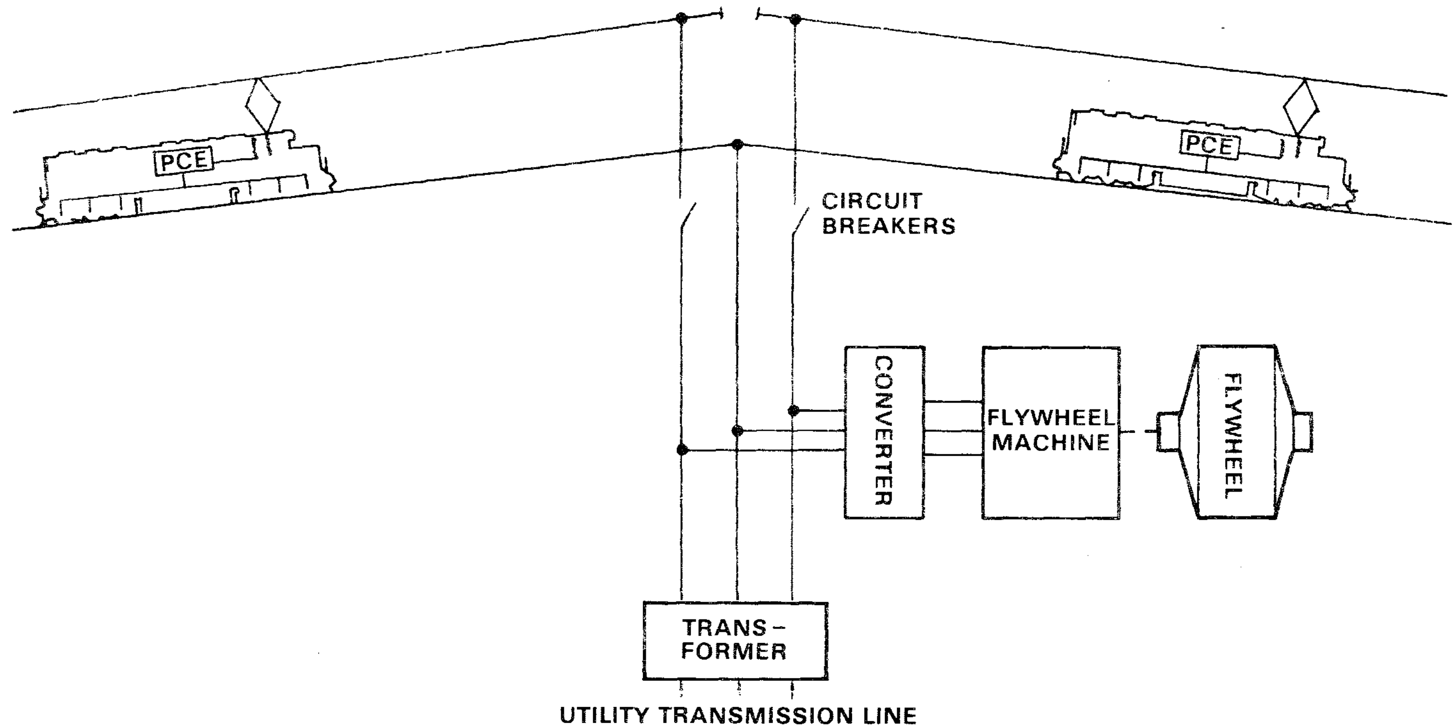


Figure 2-7. WESS High-Voltage Ac Regeneration System Option 3: Constant-Frequency, 2-Phase Catenary (Unbalance at Utility)

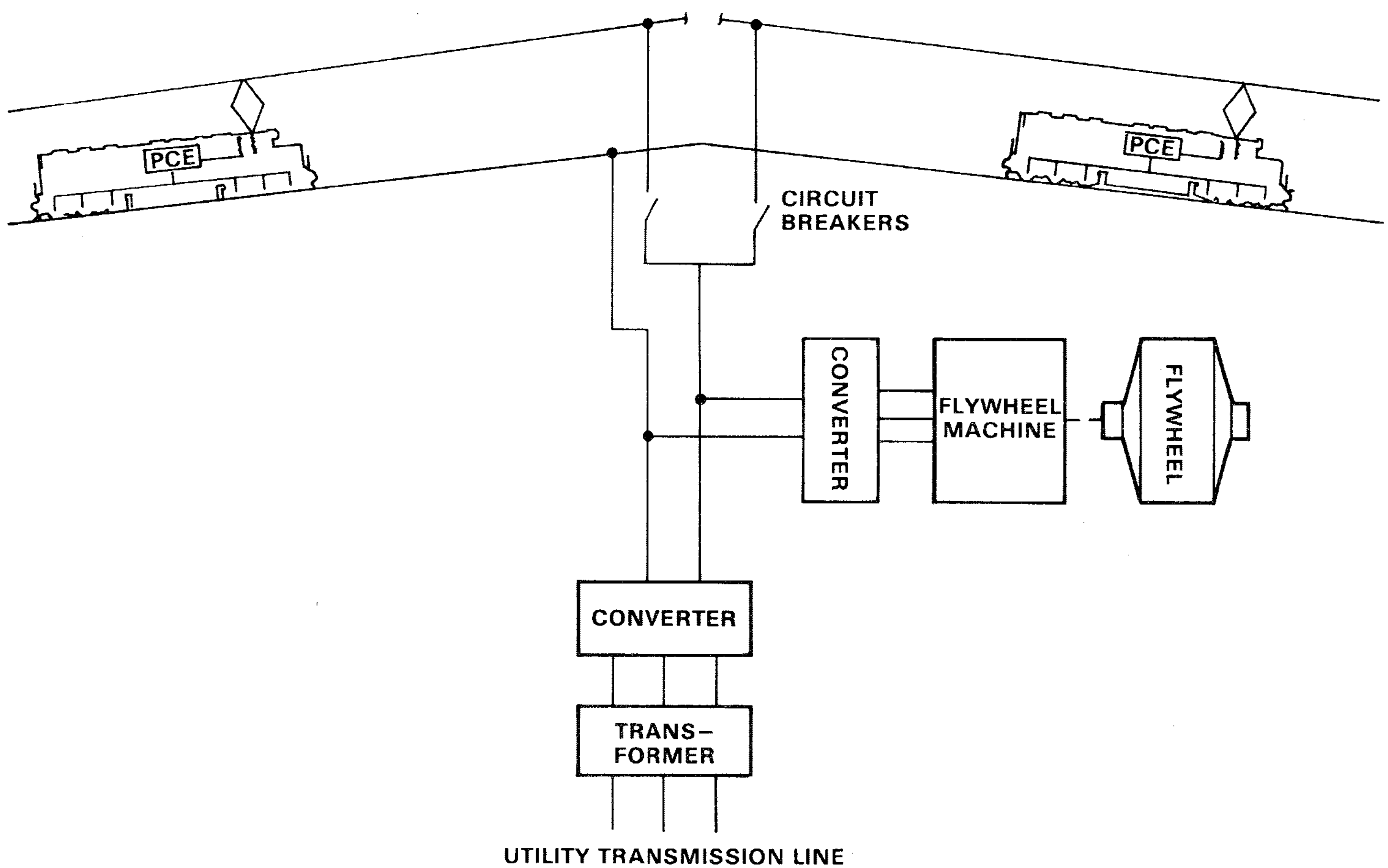


Figure 2-8. WESS High-Voltage Ac Regeneration System Option 4: Constant-Frequency, 1-Phase Catenary (Balance at Utility)

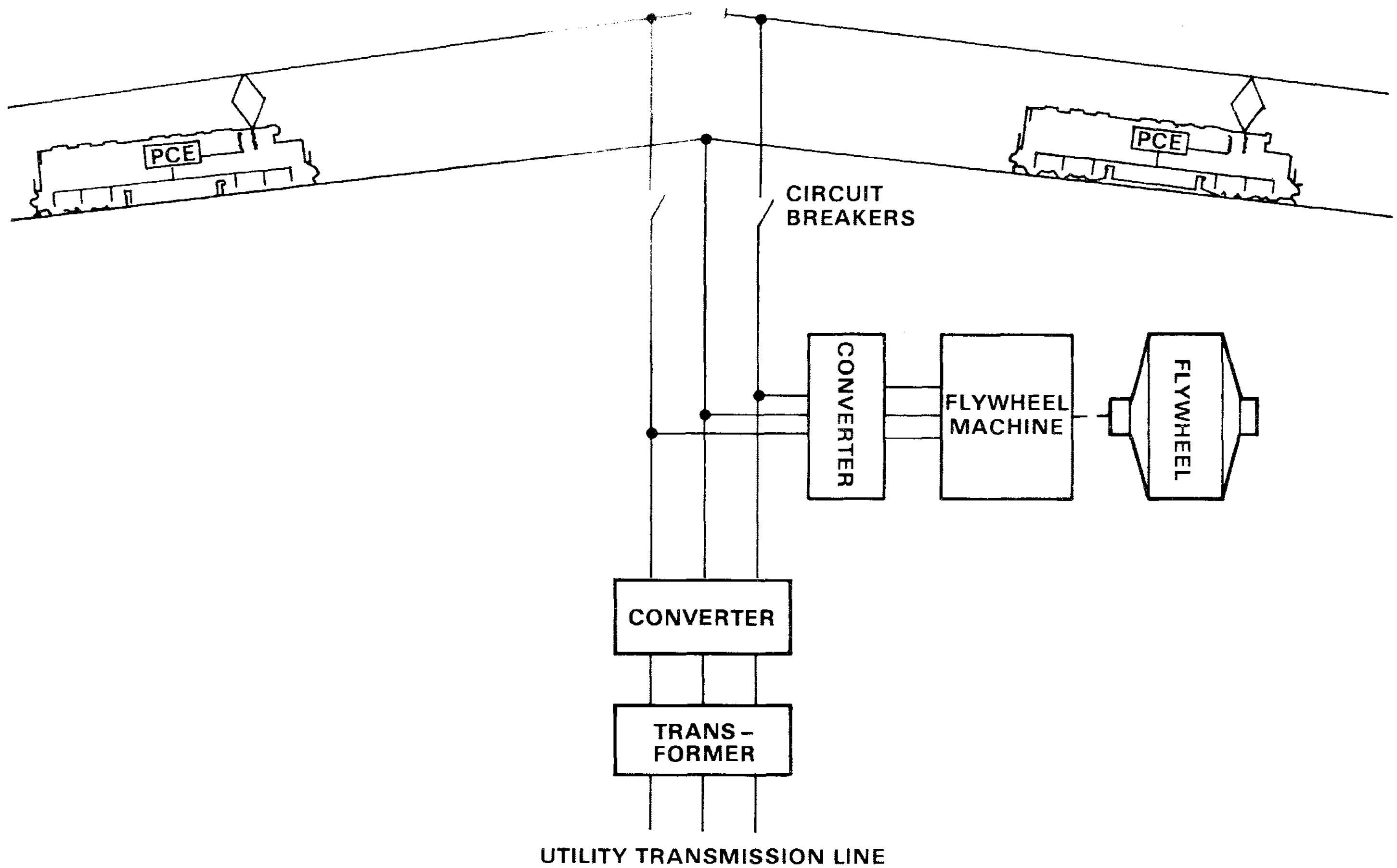


Figure 2-9. WESS High-Voltage Ac Regeneration System Option 5: Constant-Frequency, 2-Phase Catenary (Balance at Utility)

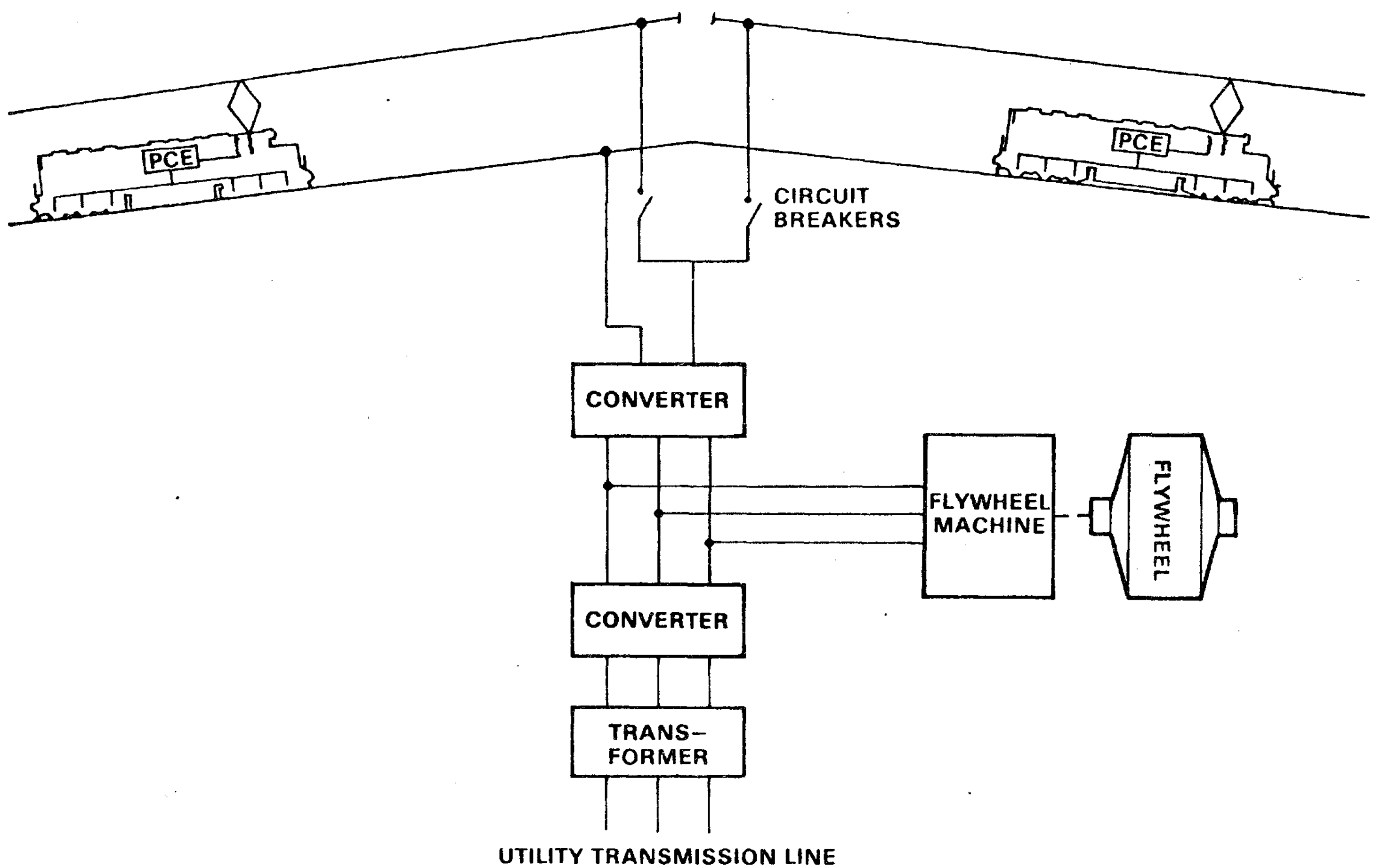


Figure 2-10. WESS High-Voltage Ac Regeneration System Option 6: Constant-Frequency, 1-Phase Catenary (Balance at Utility)

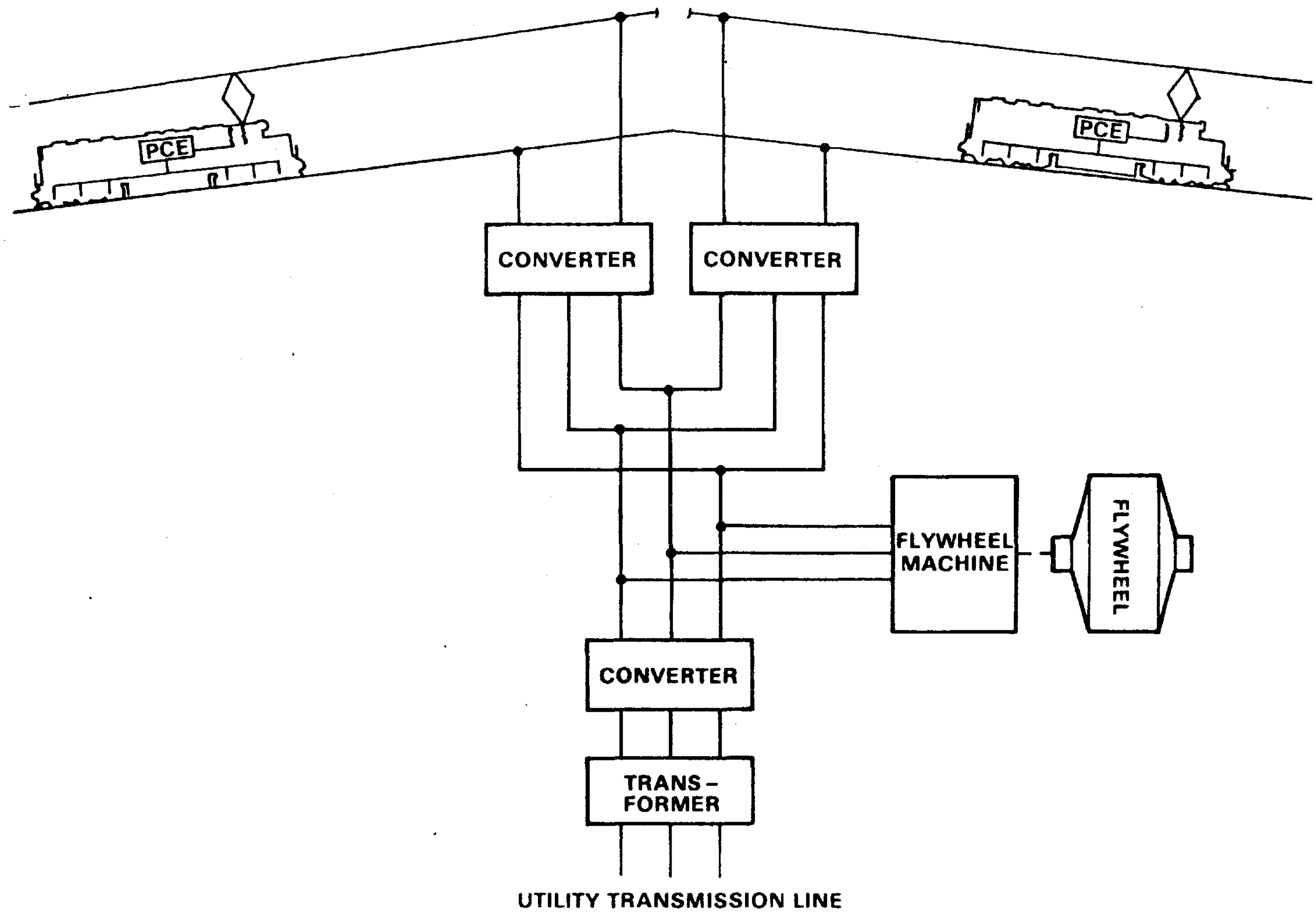


Figure 2-11. WESS High-Voltage Ac Regeneration System Option 7: Constant-Frequency, 2-Phase Catenary (Balance at Utility)

The converter logic for the above schemes requires subcyclic decision-making; that is, at each instant in time the converter must be able to decide whether energy should be returned to the catenary, the flywheel machine, or the utility. This represents an expensive addition to the converter and, to minimize costs, a method of avoiding the subcyclic decision process was considered.

The systems avoiding subcyclic decisions for one- and two-phase catenaries are shown in Figures 2-10 and 2-11. Essentially the flywheel machine is allowed to absorb the energy of each half-cycle so that, if conditions change during the half-cycle, the converter is not required to redirect the energy during that period. Therefore subcyclic decisions are not required. To achieve this, however, an additional converter is required for the normal railroad two-phase catenary, and therefore the cost of converter equipment is higher than for the subcyclic decision converter.

Therefore, the basic decision was to use the system shown in Figure 2-7. The transformer coupling the utility to WESS is a three-phase to two-phase connection designed by Gibbs & Hill (Figure 2-12) that has been demonstrated in service at the Cos Cob substation of the Northeast Corridor. This transformer connection has been shown to be superior in operation to the familiar Scott-connected tee arrangement commonly used for three-phase to two-phase transformation.

SYSTEM EFFICIENCY

A critical characteristic of the WESS system is its efficiency. After the optimum system shown in Figure 2-7 was defined, the overall system efficiency was determined as described below.

The system comprises three discrete subsystems:

- Locomotive
- Distribution
- Flywheel station

Each subsystem may be considered separately.

Locomotive

The mechanical energy available at the wheel of a braking locomotive passes first through the traction motor assembly (comprising gears and a traction motor), where electrical and mechanical losses result in an energy loss that is speed- and load-dependent. Figure 2-13 shows the efficiency curve for the D77 traction motor as published by EMD. It can be seen that typically the efficiency of the motor assembly is 90 percent.

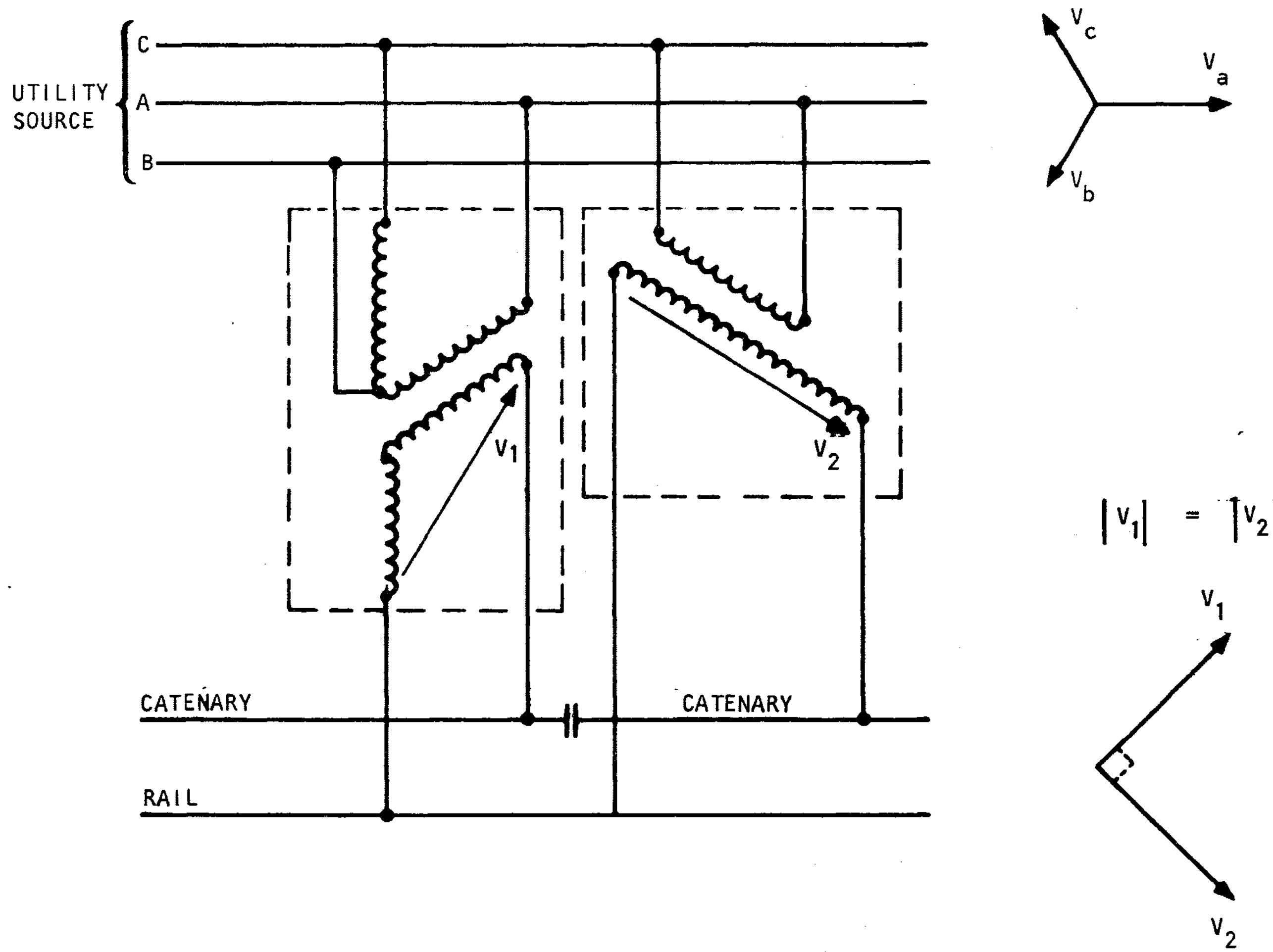


Figure 2-12. Gibbs and Hill Three-Phase/Two-Phase Transformer Connection

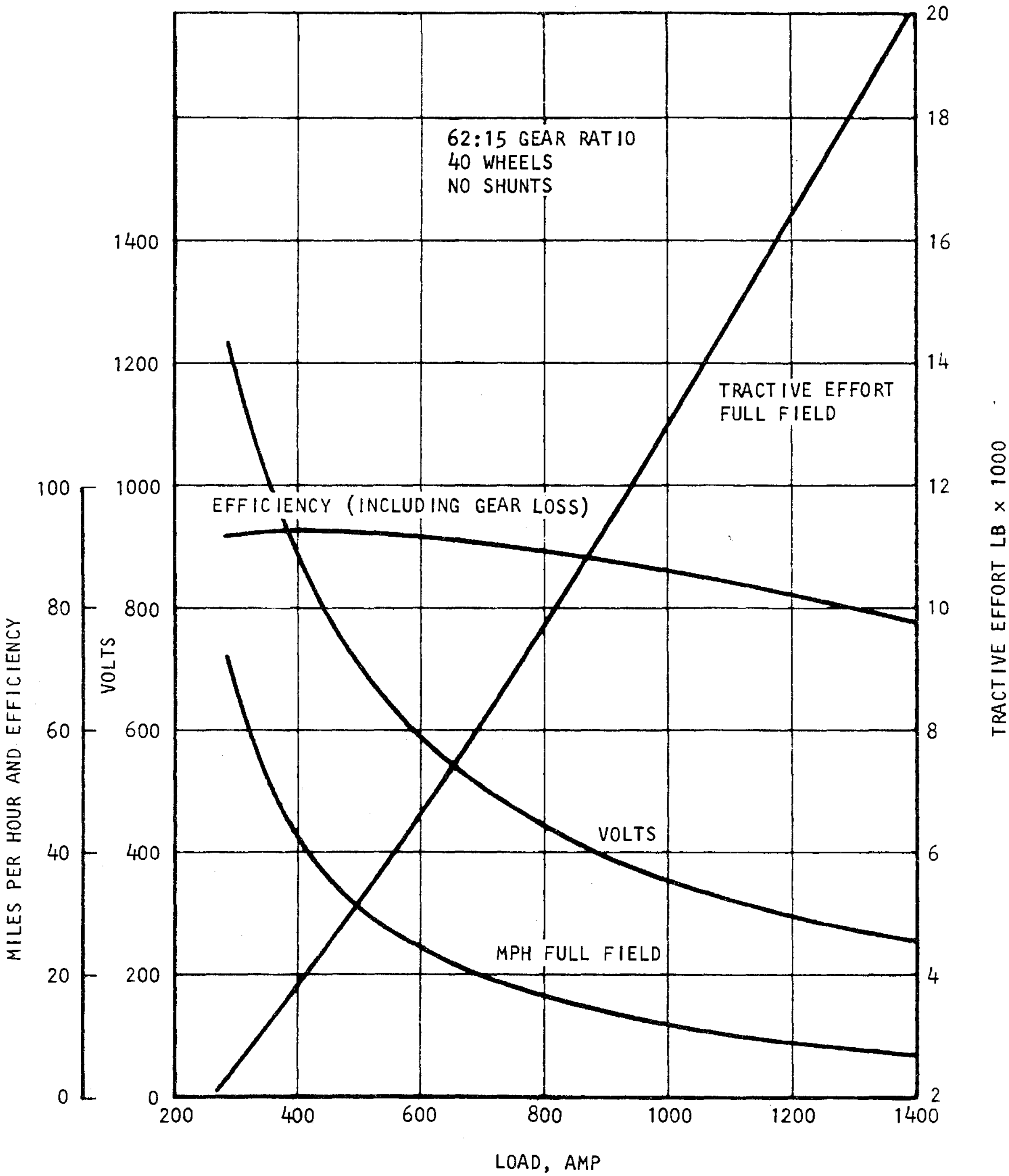


Figure 2-13. D77 Traction Motor Characteristics for 3000-hp SD40 Locomotive

The energy, now in electrical form, passes from the traction motor to the converter, where a forward voltage drop of 1.5 v per device occurs. This results in a converter efficiency of 98 percent. Losses in the locomotive transformer during step-up in voltage to 25 or 50 kv are load dependent but may be assumed typically to result in an efficiency of 96 percent. Therefore, the overall efficiency of the locomotive regeneration system is 84.6 percent. Similarly 84.6 percent of the energy derived from the pantograph during propulsion is delivered to the locomotive wheels as useful energy.

Distribution System

From the locomotive pantograph to the flywheel station energy losses are dependent on load and distance from the feeder point. Typically an efficiency of 96 percent is reasonable.

Flywheel Station System

Electrical energy from the distribution system received at the flywheel station is reconfigured from 25-/50-kv, single-phase, 60-Hz supply to 25-/50-kv, three phase, variable-frequency (flywheel speed dependent) supply. The losses in the converter are load dependent. Losses in the flywheel machine are load and speed dependent. On a typical duty cycle the efficiency at the flywheel converter and machine is estimated to be 96 percent.

The losses in the flywheel (bearing and air friction, ancillaries, etc.) amount to 1.5 percent per hr at full speed and 0.5 at half speed. Therefore the efficiency used in this study (99 percent) represents a conservative estimate.

The system efficiency diagram is shown in Figure 2-14. Consideration of the overall system shows system efficiency at 60 percent. That is, 60 percent of the energy available at the wheel of the descending train is available for reuse at the wheel of a subsequent ascending train.

The typical figures for efficiency derived here were not used in the detailed calculations made later in the study.

OPERATIONAL CONSTRAINTS

During the study AiResearch had many discussions with railroads, from which a number of operational constraints appeared. These constraints are addressed below.

Adhesion

A great deal of research has been undertaken by various organizations around the world in an attempt to understand railroad adhesion and its characteristics. The deployment of WESS demands that, whichever option is adopted, a fully controlled thyristor bridge circuit is used to control the traction motors. This enables the question of the assumed adhesion level to be re-examined and designs to be optimized.

The advent of the thyristor has enabled traction engineers to assume tractive effort/axle load ratios that would not have been considered a few years before. A steep tractive effort/speed curve was an advantage when an axle slipped. If the curve was steep enough, spontaneous recovery of adhesion resulted.

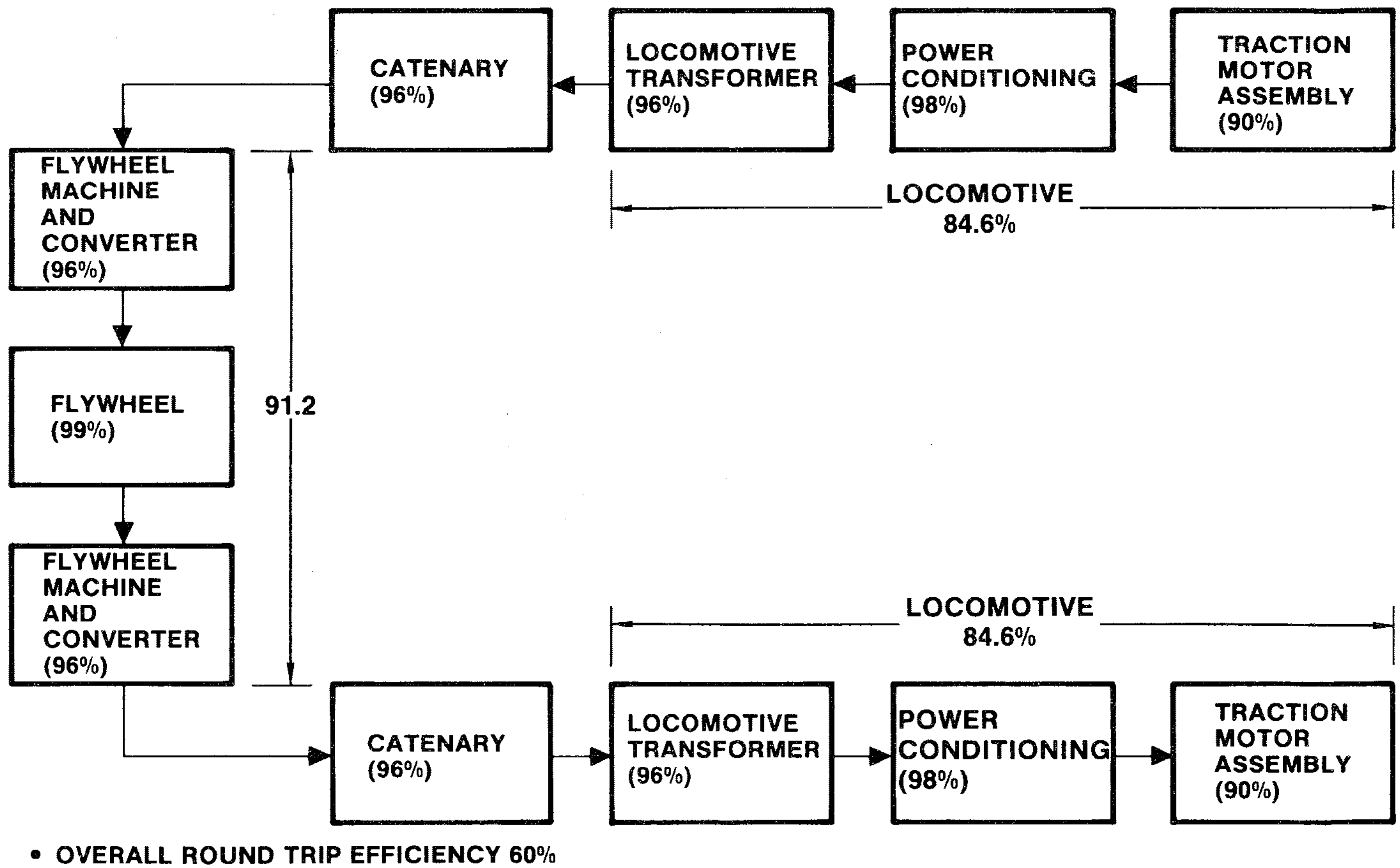


Figure 2-14. WESS Storage System Efficiency

The use of thyristors (either in the main power circuit or in field control, or both) facilitates individual motor control, which eliminates the difficulty in ensuring equal distribution of current values between sets of motors. Then when slipping does occur, the action taken is limited only to the motor affected and does not entail a general reduction of current in the other motors with consequent loss of tractive effort.

To operate at the practical limit of adhesion it must be possible to vary the firing angle of the thyristors rapidly and frequently. Unlike mechanical systems involving moving contacts, variation of the firing angle involves no wear and does not in any way affect the life of the thyristor. This fact has fundamental implications as regards the ideal system of regulation for making optiumum use of existing adhesion.

With individual supply to the motors, no constraints are encountered other than those related to the difference in wheel diameter permitted by the user railroad. This is not a major problem since, with the thyristor, each motor can be operated at the limit of adhesion.

The thyristor, with good slip correction and current regulation, makes it possible to dispense with all the ingenious mechanical and electrical devices designed to offset weight transfer (which is a product of the tractive effort and coupler height and can never be eliminated altogether). Once speed builds up, it should be realized that axle loads vary quite appreciably anyway. Consequently, all the devices intended to improve weight distribution under quasi-static conditions have little real effect during conditions of normal running. The benefit of individual axle control, as applied to a typical U.S. locomotive, is analyzed later in this report.

It is generally stated that the adhesion of an electric locomotive is greater than that of a diesel; this is incorrect. If the electric transmission were to be treated similarly in the two types of locomotive, the same results would be obtained in terms of the use of adhesion. In any case it must not be said that a type of locomotive has "an adhesion of X percent." No locomotive can "produce" adhesion: all that can and should be expected is that the locomotive makes optimum use of the adhesion existing between wheel and rail. If there is six percent adhesion available between rail and wheel, no locomotive can extract more.

The only way to raise the adhesion coefficient in particularly unfavorable conditions is by putting down sand, or perhaps cleaning the rail with a chemical. Sanding is very efficient, and can be combined with the anti-slip function. The extremely sophisticated automatic devices now available are able to decide for themselves when to introduce foreign matter, whether sand or something else.

It is considered, therefore that, in view of the foregoing an adhesion level of 22 percent may be assumed for separately excited, thyristor-controlled motors, using creep prediction techniques for both dual-mode (electric/diesel) and electric locomotives.

Head-End Brake Limitation

Because the dynamic brake concentrates the braking force and braking power at the head end of the train, there are practical limits concerning the amount of braking that can be achieved with the dynamic brake alone. The ideal situation for WESS is to have the locomotive units do all the braking; however, the division of the braking work done by the cars and the locomotive units equipped with regenerative brake is important in order to obtain the best train operation in any particular situation. In practical terms, it has been found that from 200,000 to 240,000 lb of retarding force concentrated at the locomotives is the most that should be used when going through turnouts, into and out of passing tracks, and on sharp curves (ref 6). A large consist of modern diesel engine units has the capability of producing considerably more than 240,000 lb of retarding force with the dynamic brake. Caution must be exercised in the amount of dynamic brake that is to be used not only for grade braking operations, but also for assisting the slowdowns and stops.

The limit as to the number of axles and motors in dynamic braking for reliably safe operation depends upon:

(a) Type of equipment. Units with pin type couplers and no alignment control features must have bolster stops applied to allow operation in consists with units capable of high dynamic braking effort. The bolster stops limit bolster-to-truck-frame lateral clearance to 1/2 in. on each side, thereby limiting lateral rail forces when units are subjected to buff loads.

(b) Particular track profile conditions.

(c) Engineer's skill.

(d) The practical limit for dynamic brake is often stated as "no more than 24 motorized axles may be operated in dynamic brake from the lead locomotive of the consist".

Calculations of power and energy regenerated during braking must take into account this limitation. When necessary the required brake force could be achieved by adding helper locomotives part way down the train or using the air brake to supplement the dynamic brake.

It is proposed that the brake force developed by any group of locomotives modified for WESS operation will be automatically limited to 240,000 lb to enable braking effort to be developed by a remote group of locomotives as required. In the calculation of power and energy for this study, the head-end braking force was limited to 210,000 lb.

Axle Load Limitation

While it is recognized that axle loads should be kept to a minimum to reduce track and truck maintenance, it has been considered reasonable to assume the current maximum axle loads when calculating usable tractive effort. The maximum static axle load assumed for performance calculations was 68,300 lbf.

Dedicated Locomotives

Railroad operations depend on flexibility: the ability to be able to send any locomotive anywhere at any time. It is recognized that most railroads prefer to keep certain locomotives operating within specific divisions but these are not necessarily dedicated locomotives since they have the ability to go anywhere at any time as required. Therefore, any scenario developed for WESS that requires modifications to existing locomotives or the introduction of new locomotives, with neither able to operate outside a small specific route, would probably have difficulty in gaining acceptance by the railroads. The key to the problem is probably found in the size of the route to which locomotives must be restricted in relation to the amount of through traffic.

As a general rule it has been assumed in this study that a diesel-locomotive fleet may, under normal conditions, be restricted to operate between two nominated classification yards. When a service disruption occurs the dedicated fleet may be used anywhere on the system, and standard locomotives are able to use the routes where WESS is deployed (without, of course, the benefit of WESS).

Electric locomotives, of course, are constrained to operate in electrified areas only.

Examples of routes that are assumed to accept dedicated fleets are:

Harrisburg-Pittsburgh	Conrail
Los Angeles-Salt Lake City	Union Pacific
Salt Lake City-Omaha	Union Pacific
Los Angeles-Belen	Santa Fe
Colton-El Paso	Southern Pacific
Sacramento-Ogden	Southern Pacific

Signals and Communications

At the present time most railroads use dc track circuits for wayside signaling, and 60-Hz carrier systems are used for in-cab signaling. Data are transmitted between signal locations by overhead open-wire lines running along the right-of-way. Communications are handled by microwave data link and/or open-wire overhead lines where relatively long distances are encountered. These and other types of signaling and communications systems are vulnerable to interference brought about by electrification catenary systems, and each one must be considered with appropriate corrective modifications to be compatible for electrification. The electromagnetic and electrostatic fields developed by a catenary system can, and usually do, induce currents and voltages in signaling and communications systems closely associated with railroad operations that are adverse to operations. The source and effects must be considered and appropriate action taken to keep these effects within tolerable limits.

The electrification analysis undertaken by Bechtel included consideration of the modification of the existing signalling systems on the specific routes in question. The AT&SF and UP routes are presently signalled with dc track circuits and therefore require replacing with 100-Hz or 92-2/3-Hz circuits to achieve compatibility with electrification at 60 Hz. The track circuit lengths will be reduced to about 1 mile, which is about the maximum length for satisfactory operation of track circuits under electrified sections, to keep the induced voltage to acceptable levels.

Electrification

It has been established (ref 7) that most of the grades suitable for WESS are on routes that are considered possible candidates for future electrification (Figure 2-15 shows those major U.S. routes). This is hardly surprising since both WESS and electrification require a high traffic flow to be cost effective. This reinforces the case for constraining the WESS system to be compatible with the mainline electrification systems proposed for use in the U.S. and other interested countries.

All of the major railroads contacted have performed electrification studies on routes that were later identified as WESS routes (that is, routes with many WESS candidate grades). The economics of such a major capital investment, however, have not yet been shown to be attractive enough to justify the funding level required. As will later be demonstrated, the inclusion of WESS in an electrification program significantly enhances the economics of railroad electrification.

Operating Scenarios

Within the total system design, three operating scenarios have been identified. It is essential that the interface between the new and existing systems result in the minimum disturbance to either system. The operating scenarios are:

(a) Dual-Mode Locomotive--Under normal operations the routes under consideration are assumed to be operated by dual-mode locomotives, which are standard diesel locomotives retrofitted with pantograph, transformer, and thyristor converter to enable the locomotive to operate either as an electric locomotive when on a WESS grade, or as a diesel locomotive when not "under the wire." The changeover from electric to diesel operation will be accomplished automatically upon reaching the end of the electrified section or when the flywheel is nonreceptive. The power rating of these locomotives remains unchanged in the diesel (primary) mode at 2600 rail horsepower (rhp); however, in the electric (secondary) mode, it is increased to the traction motor limit of 4000 rhp. Due to this increased power rating of the locomotive when connected to the catenary, the number of locomotives required to operate a given route is reduced, and therefore so is the number of locomotives to be modified.

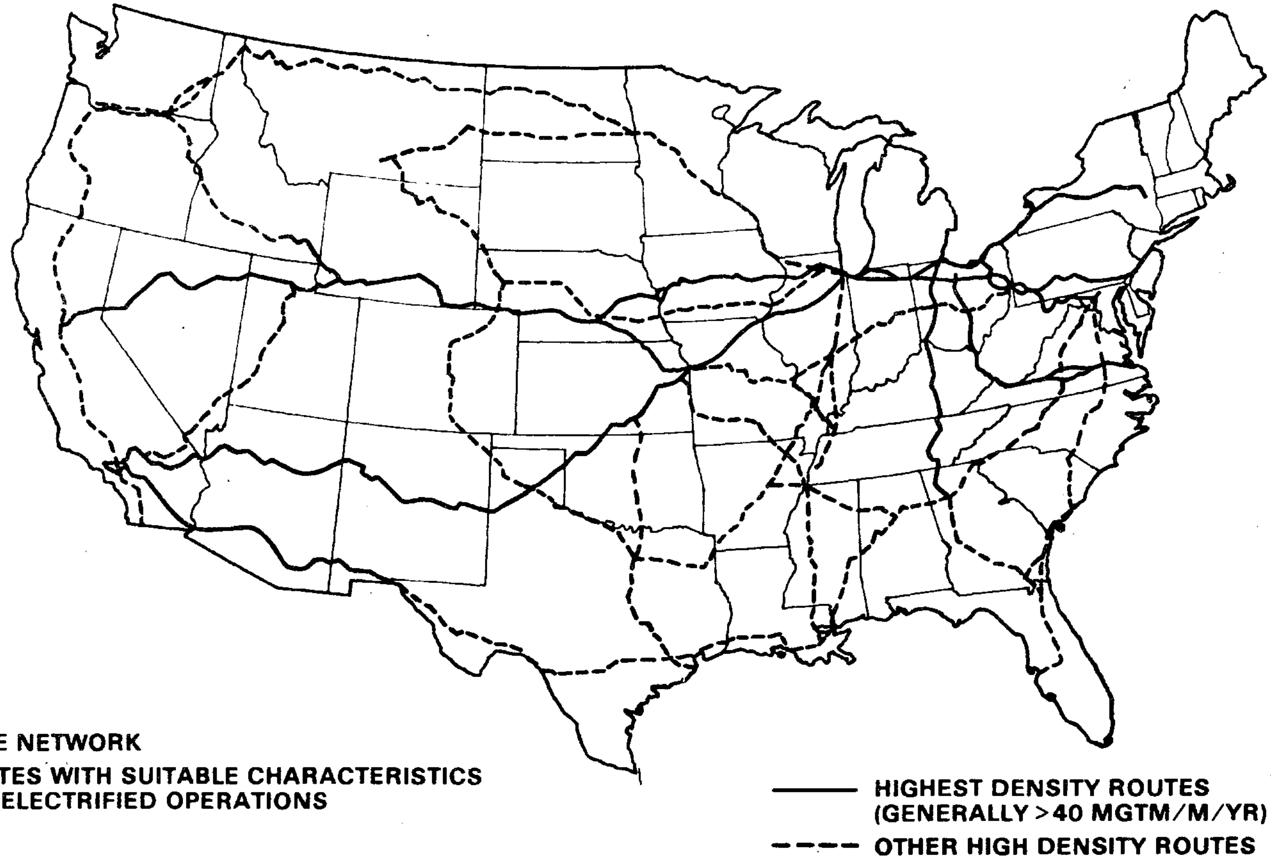


Figure 2-15. Proposed National Electrified Network

An important spin-off from this scenario is that it allows an evolutionary concept of electrification. That is, a railroad operating dual-mode locomotives could electrify only the grades on its chosen route at a substantial return on investment (ROI). Then, the sections in between the major grades gradually could be electrified. This electrification concept allows the railroads to gain electric operation experience before committing themselves to very large investments.

(b) Electric Helper--When ascending/descending a WESS grade, the motive power comprises diesel locomotives with the addition of up to two electric locomotives. The latter are designed for high tractive effort and limited-speed, high-power, 50/25-kvac, 60-Hz operation. At the extremities of the WESS sections, the electric locomotives are detached to await the next train in the opposite direction. The number of diesel locomotives in use is less than that normally used because in most railroading operations the ruling grade determines the number of locomotives required. When WESS is deployed, the gradient duty is eased by the use of electric locomotives with high tractive effort. This scenario is labor-intensive, and allowance was made for having the electric locomotive crewed for 72 man-hours per day to take account of travelling time to and from the possibly remote location of the WESS grade.

(c) All Electric--The entire railroad operation was assumed to be electrified, and diesel power is used only for yard switching and spur lines. WESS would not impose any particular procedure on the railroad method of operation other than the input of data to the wayside energy storage system communications (WESSCOM), if such a system is provided (see below).

The three scenarios described above are summarized in Table 2-6. Each of these operating methods involves a change in the economics, cost, and procedures and must be evaluated in detail for each grade under consideration. It will also be clear that the true cost of adoption cannot be considered on a grade-by-grade basis since locomotive fleet sizes depend on traffic flows between classification yards.

Operational Procedure

The scenarios defined in Table 2-6 may, as far as operational procedure is concerned, be divided into the two types as described below.

1. Through Working of Motive Power

This applies to scenarios 1 and 3. In all cases there is no action required by the engineer on arrival at the WESS site. Where necessary the pantograph will be automatically raised using track magnets. When voltage has been established at the transformer secondary, the control equipment will cut off the power from the diesel engine and and reduce the engine to a speed at which it is able to supply auxiliary loads. The traction and auxiliary power will be supplied from the transformer. This state will continue until the flywheel is fully charged,

TABLE 2-6

SUMMARY OF WESS SCENARIOS

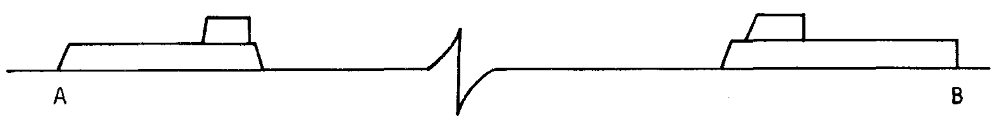
	Scenario	Whole Route Electrified	New Vehicles Required	New/ Modified Vehicles Usable on Other Routes	Additional Operating Labor Required	Diesel Locomotives Saved	Special Stops Required
1	Dual-Mode	No	No	Yes	No	Yes	No
2	Electric Helper	No	Yes	No	Yes	Yes	Yes
3	Electric Railroad	Yes	Yes	No	No	Yes	No

at which time power will be supplied from the utility. As a regenerating locomotive enters the section, direct energy transfer may take place. On arrival at the end of the WESS-equipped section, the pantograph will be automatically lowered in a sequence initiated by a track magnet and diesel power will be restored.

In the case of the electrified railroad, the engineer will follow normal rules and methods of operation and will have no visible indication of whether the train is regenerating to the flywheel, to another train, or to the utility; and similarly he will have no indication of the source of the power. It is proposed that a light should be provided to indicate to the engineer when rheostatic brake is in operation.

2. <u>Change of Motive Power at a Grade</u>

This applies only to scenario 2. Consider a typical single-track layout:



The track would be electrified from A to B, including the sidings, which are those sidings nearest to the extremities of the grade. The train with the electric locomotive leading departs from A and the electric locomotive performs its duty as an interface with the distribution system. On arrival at the signal at B the train halts, and the electric locomotive is uncoupled and draws forward onto the siding where it either couples immediately to a waiting train or waits for an A-bound train to arrive. It is expected that a crew of two would be permanently occupying the electric locomotive. The train from A is now cleared to carry on its journey. When the A-bound train arrives, the electric locomotive is coupled and then departs, and on arrival at A the uncoupling procedure is repeated. To handle two consecutive trains in the same direction, a storage siding is required to store the spare electric locomotive. The principle of operation for a double-track line is the same.

On routes where a number of grades exist but which are so far apart that the track in between has not been electrified, the procedure adopted would be as follows.

The train departs A as above but at the approach to the end of the electrified section, the pantograph is automatically lowered by track magnets and the diesel engines take over completely, supplying the train power requirements. On arrival at the next electrified section of track, the pantograph is automatically raised, and the electric locomotive again interfaces with the distribution system.

At the final electrified section the electric locomotive uncouples as described above.

Communication System

A wayside energy storage system communications (WESSCOM) link is essential in situations where there is no utility tie-in to the system. The benefits of such a system are not so clear-cut when a utility tie-in is available and WESSCOM could only be used to optimize peak shaving. The benefit of WESSCOM would then be the difference between a best guess at the required average demand and the computer-predicted average demand.

A utility tie-in is not essential to the railroad/WESS operation in scenarios 1 and 2. The cost of provision of such a tie-in was considered against the anticipated benefits in the study. In cases where it is decided against having the utility tie-in, it is imperative that the flywheel is not taken below its minimum design speed by an excessive energy demand from an ascending train. This could be achieved by opening the protection circuit breakers in the feeder station without recourse to a train/wayside communication system, but the resulting loss in power and delay before diesel power was available would be unacceptable. Furthermore, it is necessary to keep the system available at all times to accept regenerated energy, which would not be the case if the feeder station circuit breakers were used to protect the flywheel from underspeed. It has been concluded that a communication system is a necessity at installations without a utility tie-in.

Where a utility tie-in is available, such as in scenario 3, the WESSCOM system has to be evaluated against the quality of human judgment. In a complex railroad operation where trains do not run to fixed timetables, it is most probable that minimization of the peak demand could only be handled by a computer.

Such a system is commercially available from the Reliance Electric Company based on the Automate 31ML Programmable Controller. A flow diagram for the system is shown in Figure 2-16.

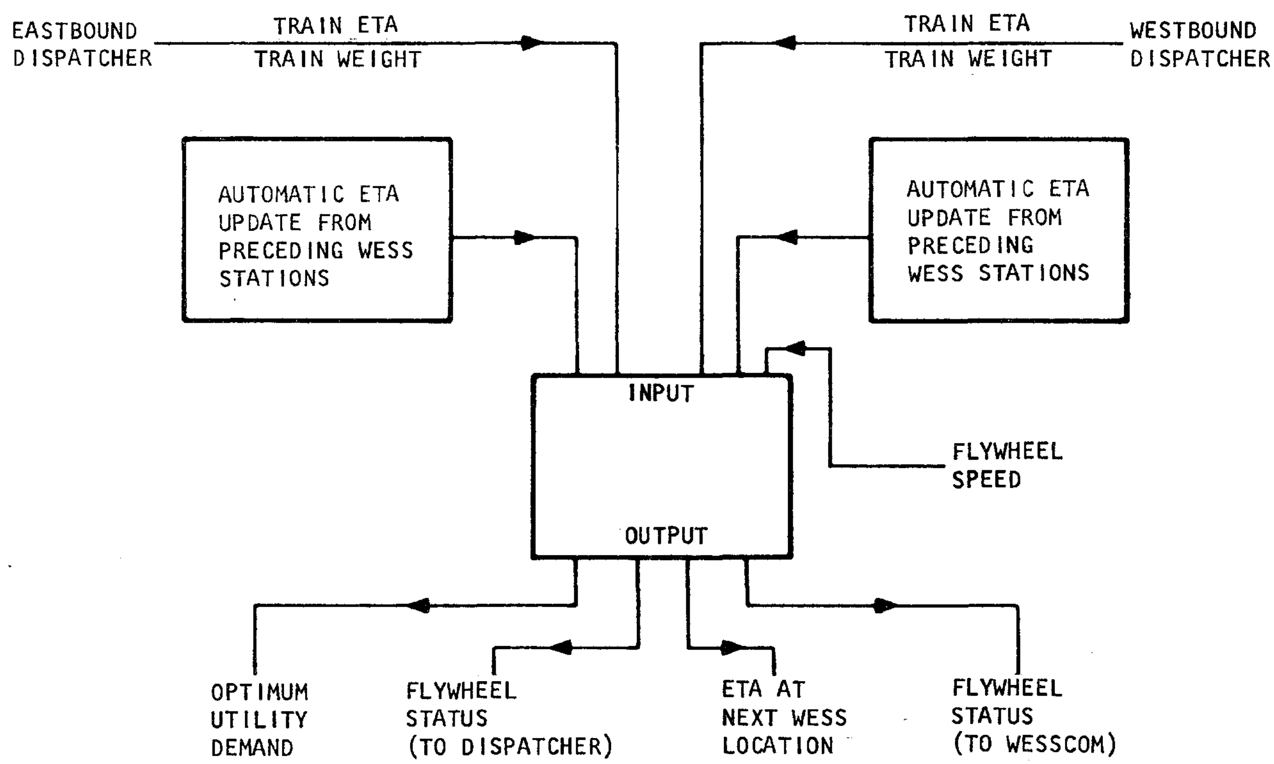


Figure 2-16. WESSCOM Flow Diagram

The microprocessor, located at each flywheel station will be programmed to accept the following inputs:

- Estimated train arrival time (ETA)
- Train weight
- Train direction
- Train identification code

Time of arrival would initially be inputted by the dispatcher, but to provide for unforeseen delays en route, provision will be made in the system for automatic and manual update of the arrival time at subsequent WESS stations as each station is encountered. Train weight, direction, and identification code would be entered by the dispatcher at the commencement of the journey.

With the above inputs the microprocessor will be able to compute the optimum demand from the utility tie-in to ensure that the flywheel is at the necessary speed for energy to be provided to an ascending train without incurring an unnecessarily high demand peak. If the flywheel is predicted to be at too high a speed to accept all the energy available from a descending train, then one of two actions will be taken. If the utility is receptive, energy could be returned to the utility (even if no credit is received). The second option is to accept that the locomotive resistor brake and/or air brake will be required for at least part of the descent.

The first option is preferred but is dependent on utility receptivity. If the utility is not receptive, a signal will be transmitted to the regenerating locomotives as the flywheel approaches full speed. This will enable the engineer to reduce electrical braking and apply (or increase) air braking.

Wayside flywheel assembly fault indication will be provided as an output from the microprocessor and will include the following:

<u>Vibration</u>--Accelerometers will be used to sense vibration levels and give a warning of impending failure.

<u>Oil Characteristics</u>--Oil pressure and temperature.

<u>Oil Pump Status</u>--Main or back-up pump running.

<u>Vacuum</u>--Within specified limits.

Based on the actual time the train leaves the WESS site, the revised estimated time of arrival at the next site will be calculated based on the train weight (since the microprocessor has been programmed with the route data) and transmitted to the succeeding WESS stations. The cost of this system would be $6000 per site and approximately $20,000 for the initial programming.

<u>Summary of Impact on Railroad Operations</u>

The deployment of WESS on an operating railroad is expected to have a minimal effect on existing railroad operations with the exception of the electric helper scenario. The operation of either electric or dual-mode locomotives over WESS grades can be accomplished with essentially no change in operating procedures. The system has been structured to minimize crew training required and to leave train handling techniques unaltered.

For the diesel-electric railroad that is converted to dual-mode, probably the greatest impact will be in the provision of maintenance facilities, although this will be minimal. There are three impact areas surrounding the maintenance function:

- Retraining--As with the introduction of any new equipment, maintenance personnel will require training in fault-finding techniques and general maintenance requirements.

- Spares holding--Due to the reduction in fleet size (described later in this report), the level of diesel spares will be reduced but this will be offset by the spare equipment required for the electric traction mode.

- Maintenance Equipment--Existing lifting equipment will be suitable for the electric traction equipment. A transformer oil test facility, however, will be required at each major maintenance facility.

A common practice nowadays is the running through of locomotives from one railroad to another. The concept of the dual-mode locomotive or a newly electrified railroad would reduce the financial incentive to continue this procedure. Therefore, additional work will be required at the classification yards at the extremities of the WESS and/or fully electrified route to change motive power that previously would have worked through to the train's final destination.

MOTIVE POWER

In this study all calculations and design studies have assumed only continuous ratings. Advantage is not taken of short-term ratings that could distort the findings of the study.

Dual-Mode Locomotives

The system concept of a high-voltage ac catenary was shown to be highly compatible with a dual-mode locomotive. The background, description, and cost of modification of an existing diesel-electric locomotive to a dual-mode configguration is described in this section. The locomotives selected for the modification that will be described are the General Motors Electro-Motive Division (EMD) models SD40 or SD40-2, which are the present workhorses of U.S. freight railroad operations. These modifications have been reviewed with the technical staff of EMD. Similar modifications can be made with other locomotives such as the GE model C-30.

The concept of dual-mode traction equipment is not new since the problem of interfacing electrified and nonelectrified railroads has existed since the first electric railway started operation. Normally the problem is one of economic viability, and the operator is forced to accept the operating restrictions of dedicated motive power units. Advancing technology has enabled higher power/weight and power/volume ratios to be developed that have resulted in the increased viability of the dual-mode locomotive and multiple unit.

Usually it is accepted that when on the "secondary mode," operation will be at a reduced performance. This will not be the case for the converted diesel locomotives. It is intended to operate up to the known limit of the traction motors when on electric (secondary) mode, rather than be limited by the prime mover as is the case for the diesel (primary) mode.

The dual-mode locomotive design is such that the motive power will be derived from either the diesel engine or the catenary, never both together, thus avoiding causing distress to the alternator by the introduction of harmonics.

To establish which existing diesel locomotives should be considered for modification it was first necessary to determine the population of road locomotives in the U.S. This is shown in Table 2-7.

It can be seen that by far the most popular road locomotive is the SD40 (and SD40-2, which does not differ significantly as far as this study is concerned from the basic model). Therefore the major effort in this study was concentrated on the SD40 locomotive, although cursory checks of the DD-40-X, SD45, and SD38 showed that those locomotives were also candidates for the modification.

1. <u>Modification Principles</u>

The basic principle of this modification is to use the existing equipment, modified as necessary, and to provide the minimum of new equipment compatible with satisfactory operation.

To commence the feasibility study it was first necessary to determine the equipment required to achieve the secondary mode. A simplified schematic is shown in Figure 2-17. Current is taken from the catenary via the pantograph through a high-voltage circuit breaker incorporating a grounding switch to a transformer (protected by a lightning arrestor). The low-voltage output from the transformer is conditioned in a thyristor converter (phase delay rectifier) to give irregular pulses of variable-voltage dc. A smoothing choke is required to reduce the ripple to a level acceptable to the traction motors.

Therefore the equipment to be accommodated on the existing locomotive comprises:

- Roof equipment

  Pantograph

  Circuit breaker

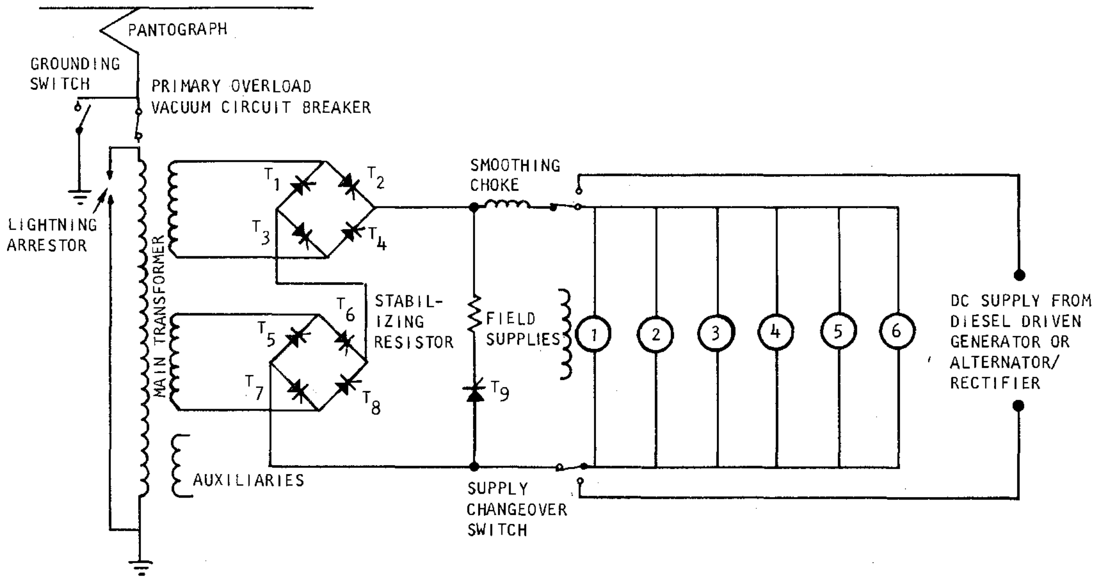
  Grounding switch

  Lightning arrester

TABLE 2-7

U.S. ROAD LOCOMOTIVE POPULATION (1974)

Railroad	DD-40-X	SD45	SD40 & SD40-2	EMD 2500- to 3000-hp Range	Other Locomotives
Atchison, Topeka, & Santa Fe	-	254	48	188	87
Burlington Northern	-	220	147	45	319
Baltimore & Ohio	-	-	234	65	0
Chesapeake & Ohio	-		133	51	79
Chicago & NW	-	61	53	39	41
Chicago, Milwaukee & St. Paul	-	15	134	11	41
Seaboard	-	45	155	61	198
Illinois Central Gulf	-	-	122	45	22
MKT	-	-	61	-	0
Missouri Pacific	-	-	115	24	25
Norfolk & Western	-	134	116	156	176
Conrail	-	135	383	187	450
St. Louis - San Francisco	-	-	49	33	44
SOO	-	-	43	10	10
Southern Pacific	-	426	89	182	530
Union Pacific	47	50	244	34	132
Western Pacific			43	19	20
Total	47	1340	2169	1150	2174



• EXISTING PROTECTION AND ISOLATION EQUIPMENT NOT SHOWN

Figure 2-17. Secondary Mode Simplified Schematic

- Body-mounted equipment

  Transformer

  Converter

  Smoothing choke

2. <u>Locomotive Performance</u>

Before equipment sizes could be determined, it was necessary to establish the performance required from the locomotive. Currently the SD40 locomotive is limited in the power it can produce by its prime mover, the diesel engine, to 2600 rail horsepower. The tractive effort of the SD40 is limited by its traction motor (under the conditions considered), which has a continuous rating of 1050 amp. The power available for traction (that is the rail horsepower) is derived from Figure 2-18 as follows:

Engine output		3100 shaft horsepower (shp)
Auxiliaries	40 hp (ref 8)	
Alternator loss (4 percent)	122 hp	

Rectifier loss (2 percent)	59 hp	
Traction motor assembly loss (10 percent)	288 hp	
Power available to rail		2590 rail horsepower (rhp)

The published rating of the EMD D77 traction motor (the motor used in all the EMD road locomotives) is approximately 720 shp (input), giving a total traction motor power capability of 4000 rhp. For this study it was considered appropriate to take advantage of the surplus traction motor capability and rate the locomotive in the secondary mode at 4000 rhp.

The D77 traction motor, having been modified to improve heat dissipation by fitting aluminum conductors, has a continuous current rating of 1050 amp. From Figure 2-13 it will be seen that the tractive effort available at that current is 13,780 lb. Therefore the secondary mode characteristic is defined and is shown in Figure 2-19, where it is compared with the existing or primary mode performance.

3. Secondary Mode Equipment

After the desired power rating was established, the next task was to establish whether the equipment could be located satisfactorily on the locomotive.

a. Roof Equipment

It is proposed that the roof equipment consisting of a pantograph mounted on standoff insulators, vacuum circuit breaker, grounding switch, lightning arrestor, and high-tension cable through bushing will be mounted on an extended cab roof. A typical layout of roof equipment for an electric locomotive is shown in Figure 2-20. The cab roof will need to be strengthened to afford protection to the crew in the event of a mishap involving the forcing down of the pantograph toward the cab area.

b. Body Equipment

There are two potential space envelopes available in the SD40 locomotive in which the body-mounted equipment (transformer, thyristor converter, and smoothing choke) may be mounted. Those spaces are in the short front hood (Figure 2-21) and the compressor compartment (Figure 2-22).

To avoid dilution of the main effort of the study by making detailed design studies of the various required components, a survey of equipment ratings and physical sizes was conducted. The following information sources were used:

(a) General Electric E42C--Currently being delivered to the Taiwan Railway Administration (TRA)

(b) General Motors JM4C--Locomotive designed but never built

(c) GEC Traction 87101--Thyristor locomotive built in 1974 for British Rail

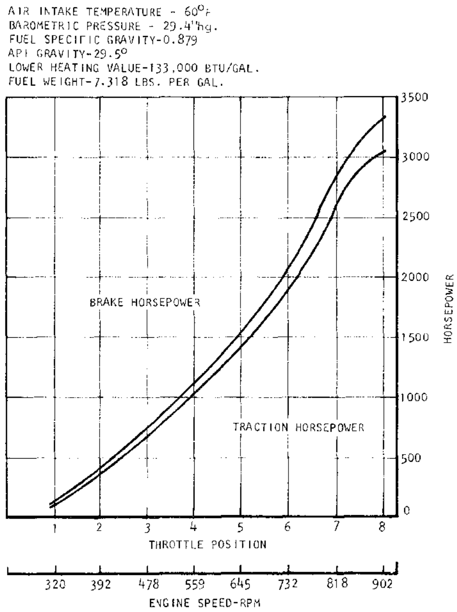


Figure 2-18. Performance of 16-645E3 Engine on SD40-2 Diesel Locomotive (Ref 4)

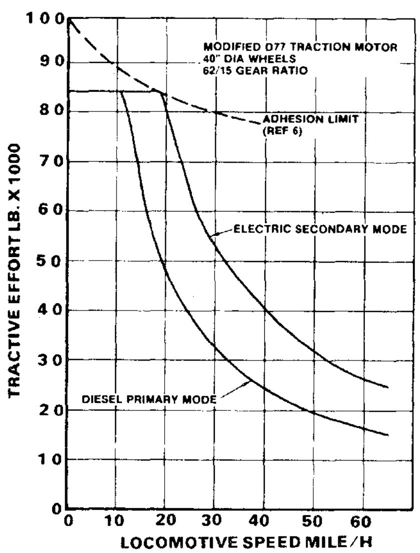


Figure 2-19. Proposed Locomotive Characteristics for WESS Dual-Mode Locomotive, Based on Continuous Ratings

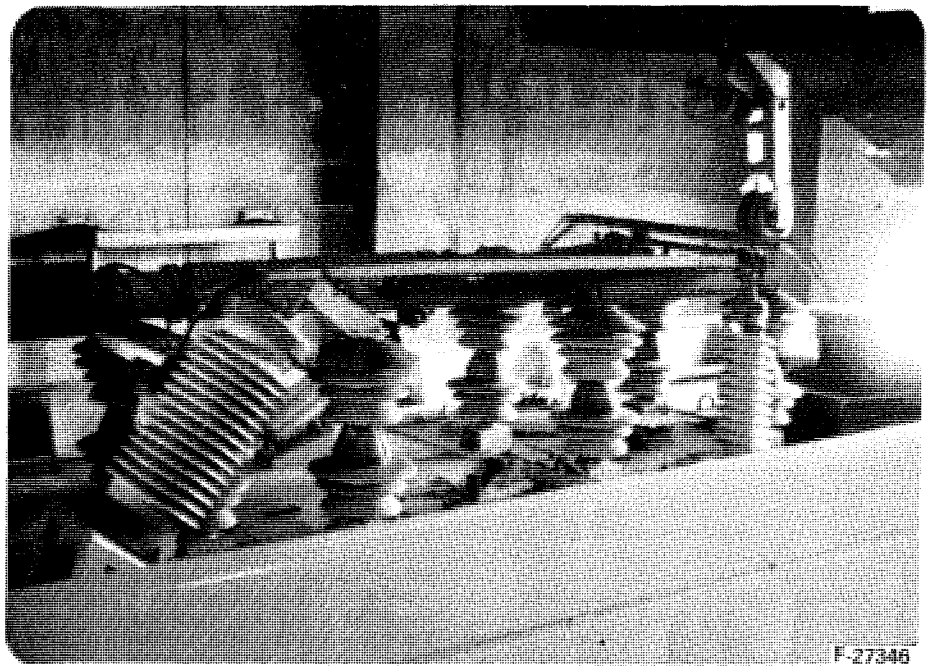


Figure 2-20. Electric Locomotive Roof Equipment

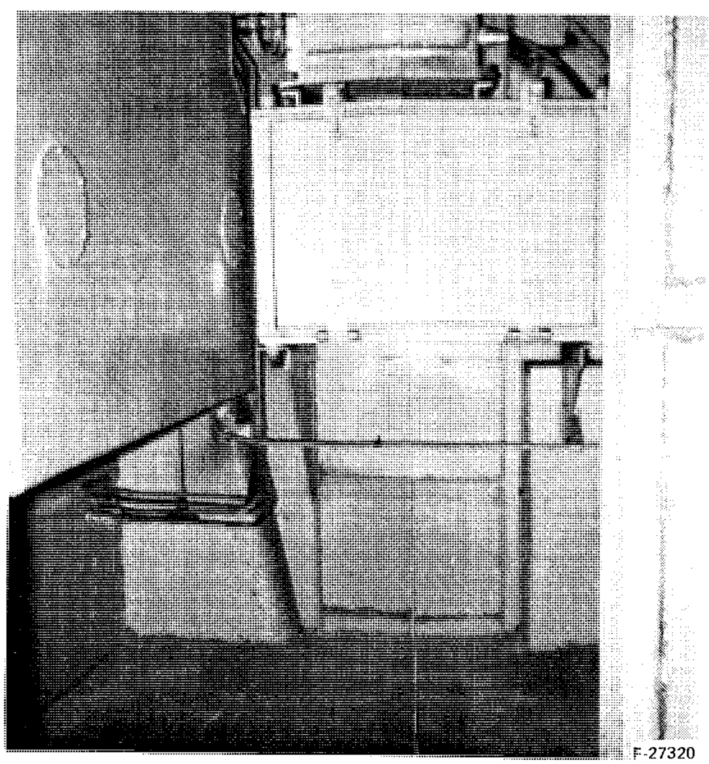


Figure 2-21. SD40 Short Hood Compartment

Figure 2-22. SD40 Compressor Compartment

(d) GEC Traction (TRA-BB)--Delivery to TRA completed in 1978

(e) British Rail Class 88--Design now available with prototype locomotive scheduled for 1980

Transformer sizes are shown in Table 2-8.

TABLE 2-8

TYPICAL TRACTION TRANSFORMER SIZES

	General Electric 42C	General Motors JM4C	GEC Traction 87101	GEC Traction (TRA - BB)	BR Class 88
Power rating	4000 rhp	4000 rhp	6561 rhp	3000 rhp	5550 rhp
Input voltage	25 kv	25 kv	25 kv	25 kv	25 kv
Catenary frequency	60 Hz	50 Hz	50 Hz	60 Hz	50 Hz
Height	58 in.	54 in.	75 in.	64 in.	43 in.
Width	48 in.	48 in.	43 in.	36 in.	60 in.
Length	64 in.	108 in.	75 in.	56 in.	74 in.
Volume	116 cu ft	195 cu ft	140 cu ft	75 cu ft	110 cu ft
No. of secondaries	6 + 2	6 + 2	4 + 2	4 + 2	4 + 2

The number of secondaries in Table 2-8 refers to the number of traction and auxiliary windings. Therefore 6 + 2 refers to 6 traction secondaries and 2 auxiliary secondaries.

The space available in the short hood section is 54 (H) by 48 (L) by 72 in. (W). The data gathered showed that this space would not be sufficient; however, it is possible to extend the length of the short hood an additional 12 in. to accommodate the transformer without causing an obstruction (see Figure 2-23).

The inspection of Table 2-8 was made against the background that certain fundamental relations exist between the kva ratings of transformers and their physical size and performance; for example, larger transformers are inherently more efficient than smaller units. To simplify the problem of deriving the relations, the following assumptions were made:

Constant physical proportions

Constant current density in the copper

Constant flux density in the iron

Figure 2-23. Short Hood of SD40 Locomotive

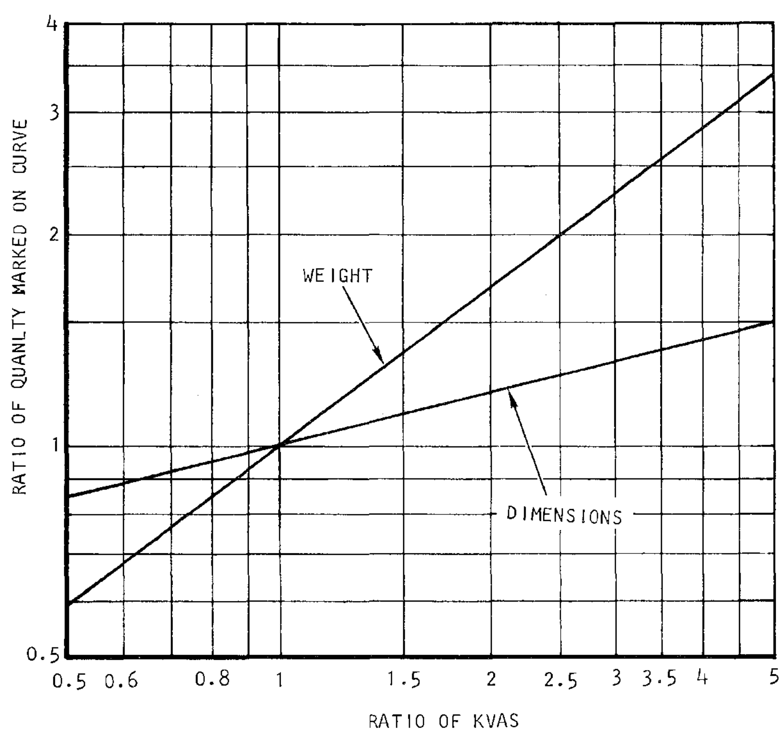


Figure 2-24. Size and Performance Relations to Rating of Transformers

Because in practical designs these factors are only approximately constant over a limited range, actual transformers follow these relations only approximately. Where the difference in kva rating is not too great, the relations are sufficiently accurate for estimating purposes. These relationships are shown graphically in Figure 2-24. Furthermore the transformer decreases in volume approximately in proportion to the frequencies at which it is designed to operate, within the 50- to 60-Hz variation under consideration.

Consideration of Table 2-8 and Figure 2-24 led to the conclusion that the dual-mode locomotive transformer could be housed in a volume 54 (H) by 60 (L) by 60 in. (W) giving a total volume of 112 cu ft. This conclusion was reinforced when, as described later in this section, the decision was made to have two secondary traction windings and one secondary auxiliary winding on the transformer.

The thyristor converter size was based on the General Electric E60C locomotive, since this is the only locomotive for which size information was readily available. The E60C converter has a total volume of 56 (H) by 12 (W) by 48 in. (L) to give 12.5 cu ft. AiResearch determined that in the compressor compartment of the SD40 a space 48 (H) by 72 (W) by 12 in. (L) (giving a volume of 24 cu ft) was available.

The sizes of smoothing chokes currently in use are given in Table 2-9.

TABLE 2-9

TYPICAL SMOOTHING CHOKE SIZES

	General Electric E42C	General Motors JM4C
Power rating	400 hp	4000 hp
Input voltage	25 kv	25 kv
Catenary frequency	60 Hz	50 Hz
Height	32 in.	34 in.
Width	32 in.	48 in.
Length	102 in.	108 in.
Volume	60 cu ft	102 cu ft

AiResearch determined that in the compressor compartment of the SD40, a space 48 (H) by 72 (W) by 46 in. (L) (giving a volume of 92 cu ft) was available.

It should be remembered when comparing sizes of equipment for a given power rating that the generous width of the U.S. gage does not normally impose serious constraints on equipment size, and therefore it is probable that equipment sizes may be reduced further from those given for the dual-mode locomotive following a concerted design effort.

4. Power Circuit

A simplified power schematic was shown in Figure 2-17. The dual-mode locomotive has a full regenerative capability in the secondary mode, which necessitates the use of a fully controlled thyristor converter bridge (see Figure 2-1), whereas a nonregenerative thyristor-controlled locomotive requires a half-controlled bridge. The usual fully controlled bridge configuration suffers from the distinct disadvantage of having to operate at a very poor power factor due to the fact that there is no freewheeling path to ensure device commutation. The AiResearch circuit overcomes this inherent disadvantage by continuously gating thyristors T3, T4, T7, and T8 of Figure 2-17 when operating in the propulsion mode and therefore providing the necessary freewheeling path.

The simple transformer/converter arrangement chosen enables the volume occupied by those components to be minimized. Full control of each individual axle is maintained by the use of separately excited traction motors.

In the braking mode, it is essential to have a continuous path for the braking current; however, the pantograph does not maintain continuous contact with the catenary. Pantograph bounce occurs even at the relatively low speeds under consideration (maximum 70 mph). It is also necessary to have an instantaneously available alternate path for the braking current in the event of the wayside flywheel reaching maximum speed and no longer being receptive. These requirements are achieved by use of the stabilizing resistor circuit shown in the schematic of Figure 2-17. In the event of pantograph bounce or nonreceptivity, thyristor T9 is gated and energy is dissipated in the existing dynamic brake resistor. Since the traction motors are separately excited, field control eliminates the need for the extended range dynamic brake feature. During pantograph bounce, the T9 thyristor may be gated for up to an hour. This blending feature is an extension of the Garrett chopper circuit (see Figure 2-25) technology developed and proved for use on transit cars.

5. Traction Motors

Because all motors are controlled by a single thyristor converter, this configuration does not provide the flexibility desirable in the event of a fault developing or wheel spin unless a separately excited motor configuration is adopted. The decision to adopt the separately excited motor configuration was a tradeoff based on the need to minimize the transformer size. While separately excited motors have advantages over the series field machine, there are serious risk areas that must be addressed and accommodated in the circuit design and analysis.

The series field machine is inherently self-protecting in the event of a flashover. The field provides inductance in the faulty motor leg to limit the rate of rise of current while the protection equipment is operating. The

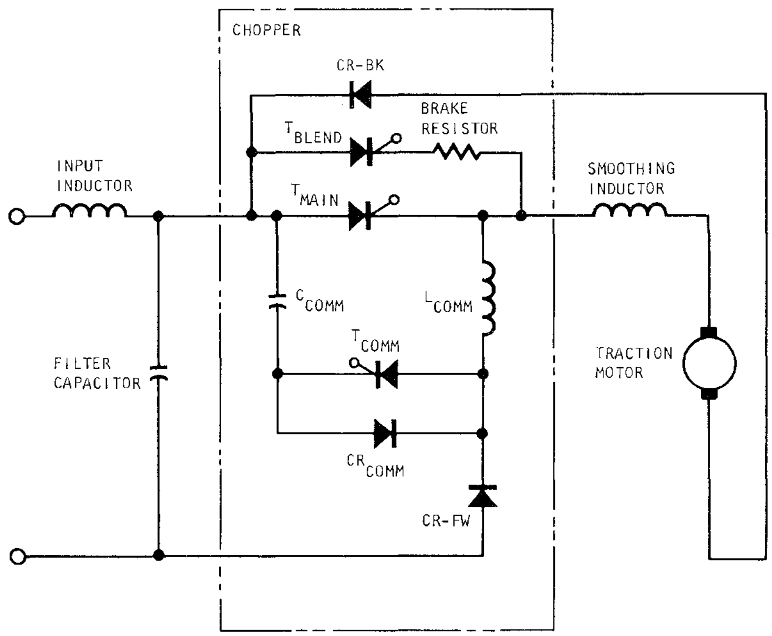


Figure 25. Simplified Schematic of Chopper, Brake Mode

separately excited machine has no such inherent protection but an analysis of the circuit design shows that in a flashover condition in electric brake (which is the most likely case), the current build-up will result in an increase in the braking effort, and eventually wheel slide. At this point the machine acts as a constant current generator and the fault current is limited at a high, but not massive, value. At flashover detection, all traction motor fields are forced down so that within 100 msec, the fault current is cleared. Once the motor isolation contactors have operated on the affected motor, the fields can be immediately reestablished on the other motors and propulsion or braking effort is restored on five out of six motors.

The series field machine is the simplest machine configuration available, relying on the applied voltage to overcome the armature back emf and supply current that is used to provide magnetic flux and torque. There are two mechanisms by which the field strength can deviate from the designed value for a given armature current:

(a) Field winding shorted

(b) Field weakening fault (contactor welded)

For the separately excited machine, it is still possible to have the field winding short as in the case of the series machine but the possibility of the field control malfunctioning is increased by shear component count of the power supplies required to control the fields.

A decision as to whether to use separately excited or series field machines can only be made following an in-depth analysis of the dual mode locomotive

6. Weight Transfer Compensation

If individual axle control is provided, this will enable the tractive effort applied at each axle to be matched to the dynamic axle load. Typical weight transfer characteristics of a C-C locomotive are shown in Figure 2-26.

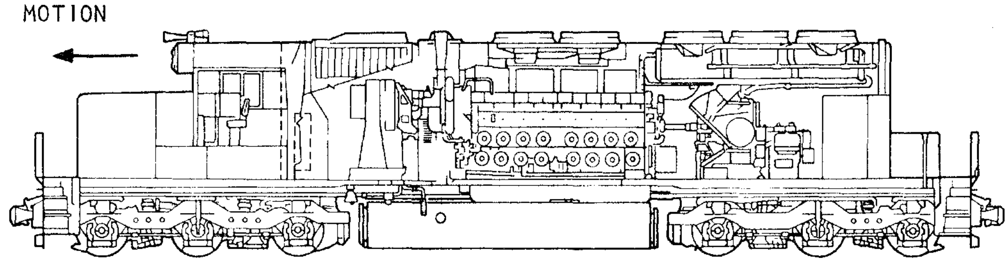


Figure 2-26. Typical Weight Transfer Characteristics of a C-C Locomotive

Currently all railroads contacted (with the exception of Conrail) dispatch their locomotives on the basis of 20-percent adhesion (see para. 4, "Railroad Dispatching Policy", at the end of this section). The adhesion value used is defined as

$$\frac{\text{Locomotive gross weight}}{\text{Number of axles}}$$

No account is taken of the reduction in axle load due to truck dynamics.

Considering a locomotive of total weight W with the weight transfer characteristics shown in Figure 2-26, which has a tractive effort of T per axle operating at the 20-percent adhesion level defined above:

$$\text{Effective } \mu \text{ max} = \frac{T}{0.86 \frac{W}{6}}$$

where μ max = coefficient of friction at lightest axle.

Therefore, without increasing the maximum effective adhesion level, the tractive effort for the dual mode locomotive becomes

$$\sum_{\text{axle 1}}^{\text{axle 6}} \frac{T}{0.86 \frac{W}{6}} \text{ X dynamic axle load}$$

$$= \frac{T}{0.86 \frac{W}{6}} \left[0.92 \frac{W}{6} + 0.94 \frac{W}{6} + 1.14 \frac{W}{6} + 0.86 \frac{W}{6} + 1.06 \frac{W}{6} + 1.08 \frac{W}{6} \right]$$

$$= \frac{6T}{0.86} = 6.977T$$

Therefore, increase in available tractive effort per locomotive

$= 6.977T - 6T$

$= \underline{0.977T}$

Therefore, for the SD40 based dual-mode locomotive with separately excited motors, the tractive effort available for the same adhesion level may be increased by 16 percent compared with the standard locomotive.

7. Locomotive Reliability

The circuit configuration used for the electric mode is not that which would normally be chosen for a road locomotive, since if a fault occurs on the converter, power will be lost to all motors. Normal practice is to provide at least two independent power circuits so that in the event of a fault a minimum of 50 percent power is maintained; however, since in the event of an electric mode failure the diesel engine is available to provide power (albeit reduced), this tradeoff against equipment size is considered satisfactory.

8. Dual-Mode Conversion Cost

A statement of work has been prepared for the modification of the SD40 and SD40-2 locomotives to dual mode, and is attached as Appendix A. Based on this statement of work a cost estimate has been prepared and is attached as Appendix B. This shows that the total cost for a railroad to carry out the modification would be $211,000.

Electric Locomotives

The electric locomotive considered for use in the WESS study was a regenerative version of the GE Model E60, which is the only recently designed electric locomotive in regular service in the U.S., as shown in Figure 2-27. The

Figure 2-27. General Electric E60C Locomotive in Service at Black Mesa and Lake Powell

essential change to the E60 locomotive for the WESS application is the substitution of thyristors for the diodes in the lower arms of the six individual semiconverters that power the six traction motors. This change permits the converter to operate as a line-commutated inverter during electric braking operation, thereby coupling power back into the ac catenary.

The cost of regenerative electric locomotives similar to the modified GE E60 has been obtained from two sources. The first is the A. D. Little projection of $180 per rail horsepower in 1976, which should be escalated to $191 per rail horsepower with 10 percent added for modification to provide regenerative capability for 1977. This results in an estimated cost of $1,071,000 for a 5100-rhp locomotive. The second source used for the cost of an E60 is based on the most recent purchase of these locomotives. In 1976, Black Mesa and Lake Powell Railroad purchased three E60 units for $750,000 each. With adjustment for inflation, today's cost should be about $795,000. The cost of modifying new E60 locomotives as described above was reviewed with the GE Locomotive Department. The estimated cost for this modification is 10 percent of new cost, resulting in a regenerative locomotive cost of $875,000.

In keeping with the conservative approach used by AiResearch in the WESS economic analysis, the higher cost of $1,071,000 suggested by A. D. Little was used for regenerative electric locomotives.

No change is proposed to the locomotive performance in the propulsion or resistor braking modes. The proposed regenerative braking characteristic is shown in Figure 2-28, where the limitation on the existing braking effort imposed by the resistor grids is removed.

Locomotive Fleet Size

Before the benefit of a reduction in fleet size could be quantified, it was first necessary to establish the size of the existing locomotive fleet required to operate a particular route with a known traffic level. Initially an attempt was made to get the information from the cooperating railroads, but it was found that the determination of this information would take more resources than the railroads were able to commit. Therefore to establish fleet size it was necessary to resort to statistical data. The Federal Railroad Administration provided the following statistics for locomotive use in U.S. (ref 5):

	Min.	Max.	Average
Electric locomotives/1,000 MGTM*/year	1.94	4.22	3.6
Diesel locomotives/1,000 MGTM/year	2.80	9.90	6.8

The routes to be considered later in this report are representative of the most efficient railroad operations in the U.S. and, therefore, it would be expected that the locomotive utilization would be above the average; that is, in the case of the diesel locomotive where, for the U.S. on the average, 680 locomotives are required to move 10^5 MGTM/year, the more efficient routes probably require only 400 to 450 locomotives for the same freight movement. Since the basis for this projection could not be quantified, however, the average locomotive use figures of 6.8 (diesel) and 3.6 (electric) have been used in this study, thereby presenting a conservative approach to the economics study.

After the fleet size for the existing railroad was established, it was possible to determine the number of locomotives required for the modified railroad.

1. Dual-Mode Locomotive Railroad

Consider a typical 4600 trailing ton train required to travel at 60 mph on level track with diesel power and to negotiate a 2.2 percent grade at 20 mph under electric power. This will be compared with a conventional SD40 performing the same duty using only diesel power. Since the SD40 is ballasted to the maximum permissible axle load (total locomotive weight 205 ton) it is assumed that the dual-mode version weighs the same as the standard locomotive.

From Figure 2-29 it can be seen that it requires three locomotives to achieve 60 mph on level track.

To ascend a 2.2 percent grade at 20 mph requires either six SD40 locomotives as shown in Figure 2-30 or four dual-mode locomotives as shown in Figure 2-30.

*MGTM: millions of gross ton miles

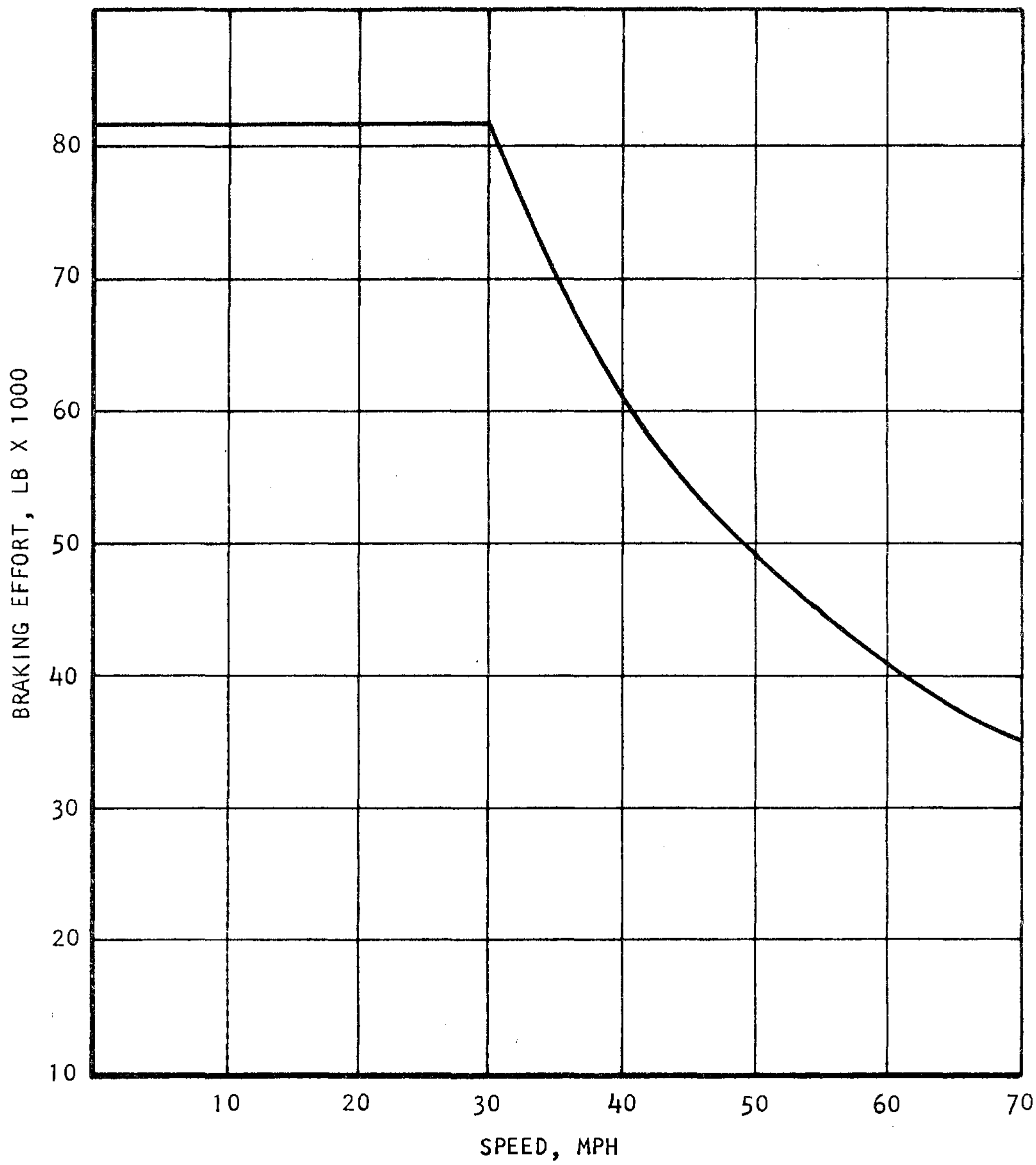


Figure 2-28. Proposed E60C Regenerative Brake Characteristic

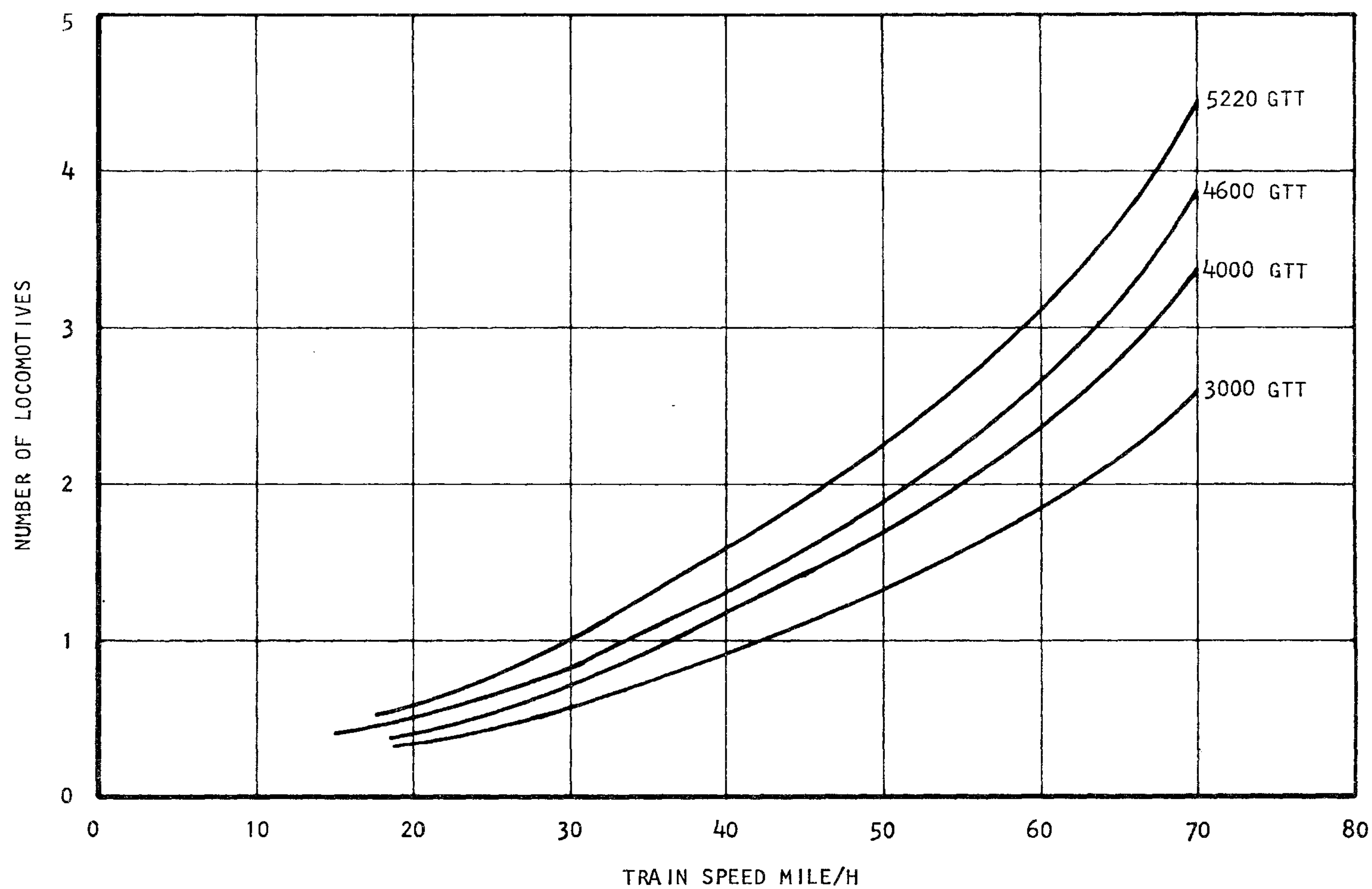


Figure 2-29. Number of SD40 Locomotives Required to Achieve Speed on Level Track

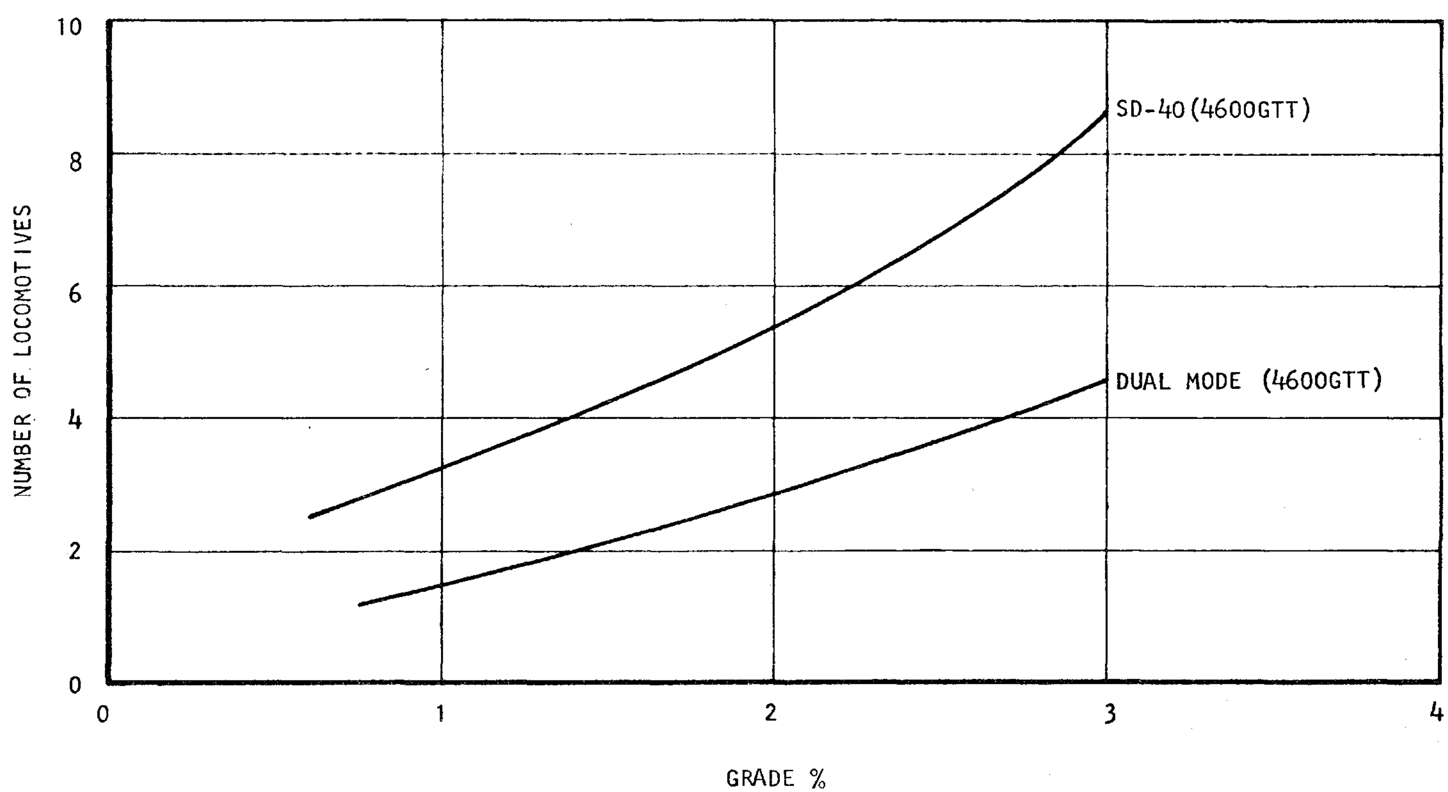


Figure 2-30. Number of SD40 Locomotives Required to Climb a Grade at 20 mph

Thus, the benefit of using a dual-mode locomotive is considerable. It must be recognized that a utility tie-in is necessary to take advantage of this saving since if the electrical capability could not be guaranteed, the diesel capability would still be required.

2. Electric Helper Railroad

The number of locomotives saved in the case of the electric locomotive hauling the diesel locomotives and consist up the grade is reduced since the electric locomotive has to haul the dead weight of the diesel locomotives (as the diesels do not contribute to the train tractive effort, thus saving the maximum amount of diesel fuel).

3. Electric Railroad

The introduction of WESS to the electric railroad does not impact the fleet size.

4. Railroad Dispatching Policy

The savings in locomotives referred to above in the dual-mode and electric helper cases are directly dependent on the railroad dispatching policy. In the example, it was assumed that the consist was required to achieve a speed of 20 mph on the ruling grade and 60 mph on level track. When the criteria had been established for determining the number of locomotives required for a given train, some of the cooperating railroads supplied the information shown in Table 2-10.

TABLE 2-10

RAILROAD DISPATCHING POLICY

Railroad	Minimum Speed on Ruling Grade, mph			Adhesion Level, percent
	Drag	Medium-Speed Service	High-Speed Service	
AT&SF	12.5	17.5	20	20
Conrail	11	11	20	18
Southern	11	20	25	20
Union Pacific	15	20	25	20

The saving in locomotives was computed for each railroad based on their dispatching policy. The crucial factor is the tractive effort available at the minimum speed required on the ruling grades.

If all the grades are electrified and therefore negotiated in the electric mode, then the governing criterion for the number of locomotives becomes the minimum speed required on level track. Therefore, there is a minimum number of grades that may be electrified on each route and still allow the full locomotive saving to be legitimately claimed. This point is reached where, in the diesel mode, the number of locomotives required to negotiate the remaining nonelectrified ruling grade is less than or equal to the number of locomotives required on level track.

A similar argument applies to the electric helper scenarios.

For the purpose of this study it was assumed that for the dual-mode locomotive scenario, the locomotive fleet could be reduced by the ratio of tractive efforts available in the primary and secondary modes at the minimum speed required for a medium-speed train to ascend the ruling grade. For example, in the case of AT&SF where the minimum speed on the ruling grade for a medium-speed train is 17.5 mph (from Table 2-10), the tractive effort in the primary mode at 17.5 mph is 45,000 lb and in the secondary mode is 83,000 lb. Therefore the fleet may be reduced in size from N locomotives to 0.54 N. Since the value of N used in the study is conservative, the remaining locomotives requiring modification will also be conservative; however, since railroads can and do take advantage of short-term ratings of electrical equipment, the full credit in terms of locomotives saved is not allowed in the study. This adds yet another conservative element to the study.

SECTION 3

WESS APPLICATION TO INDIVIDUAL GRADES

LOCATION STUDY (ITEM 1)

Methodology

A search for favorable locations within the U.S. where railroad energy storage installations would be both feasible and beneficial was conducted at an early stage of the study. AiResearch was constrained by the contract statement of work not to involve more than "...nine railroad companies or other elements of the general public".

The methodology used to conduct the location study (Figure 3-1) comprises five distinct phases:

(a) Preliminary calculations

(b) Data acquisition

(c) Identification of prime candidate grades

(d) Individual grade ranking

(e) Identification of WESS routes

Preliminary Calculations

Before approaching railroads, it was necessary to understand the scale of the systems under consideration and to decide the necessary magnitude of the variables. Such variables as change in elevation, length of grade, weight, and number of trains had to be allotted minimum values in order to be able to define to the railroads the information required. It became clear that there was no minimum value for each variable because a high traffic level could, for instance, counteract a small elevation change (as was later seen to be the case on the Harrisburg-Pittsburgh route); however, system costs and savings are dependent on the scenario adopted and it was necessary from the outset to assume what was later to be termed the "electric helper" scenario in order to get the preliminary calculations under way.

Consider the general case where a train of weight W ton is descending a grade of length (L) miles with a change in elevation of h feet. It is assumed for this preliminary calculation only that the train arrives at the grade at the descent speed (v) mph/hr, which is taken to be constant. Neglecting the effect of curvature (which is generally of second-order importance) and aerodynamic drag (which is negligible at the typical ascent and descent speeds being considered), train resistance may be expressed as a constant $\frac{Wr}{2000}$, where r is the specific rolling resistance in lb/ton.

The above may be represented diagrammatically, as shown in Figure 3-2.

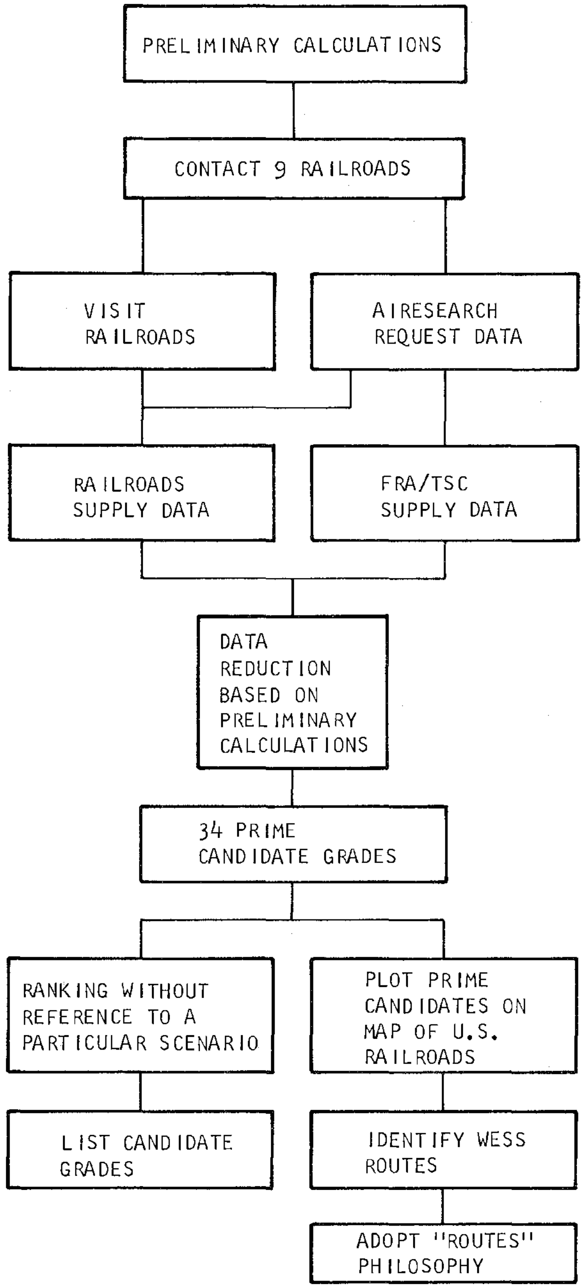


Figure 3-1. Location Study Methodology

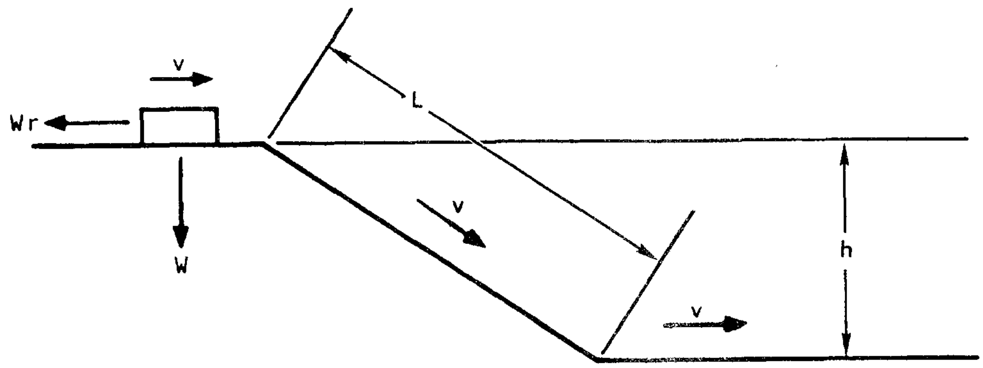


Figure 3-2. Diagrammatic Representation for Energy Calculations

Then, change in potential energy = Wh ft-lb

$$= 3.77 \times 10^{-7} \text{ kwhr}$$

Energy consumed by train resistance = WrL ft-lb

$$= 9.94 \times 10^{-7} \text{ kwhr}$$

∴ Energy available at the wheel of the descending train

= change in potential energy - energy consumed by train resistance

$$= (3.77 \times 10^{-7}\ Wh - 9.94 \times 10^{-7}\ WrL) \text{ kwhr}$$

$$= 3.77\ W(h - 2.64\ rL)10^{-7} \text{ kwhr}$$

Assuming that the train resistance has the constant value of 3.8 lb/ton,

Energy saving at the wheel of the descending train = $3.77\ W(h - 10L)10^{-7}$

From Figure 3-3, it will be seen that the overall round trip efficiency of the WESS system is 60 percent. Therefore, energy saving at the wheel of the ascending train

$$= 0.60 \times 3.77\ W(h - 10L)\ 10^{-7} \text{ kwhr}$$

$$= 2.22\ W(h - 10L)10^{-7} \text{ kwhr}$$

Annual energy saving = (energy saved/ascending train) x number of trains/year

$$= 2.22\ W(h - 10L)10^{-7} \times \frac{T}{G} \text{ kwhr}$$

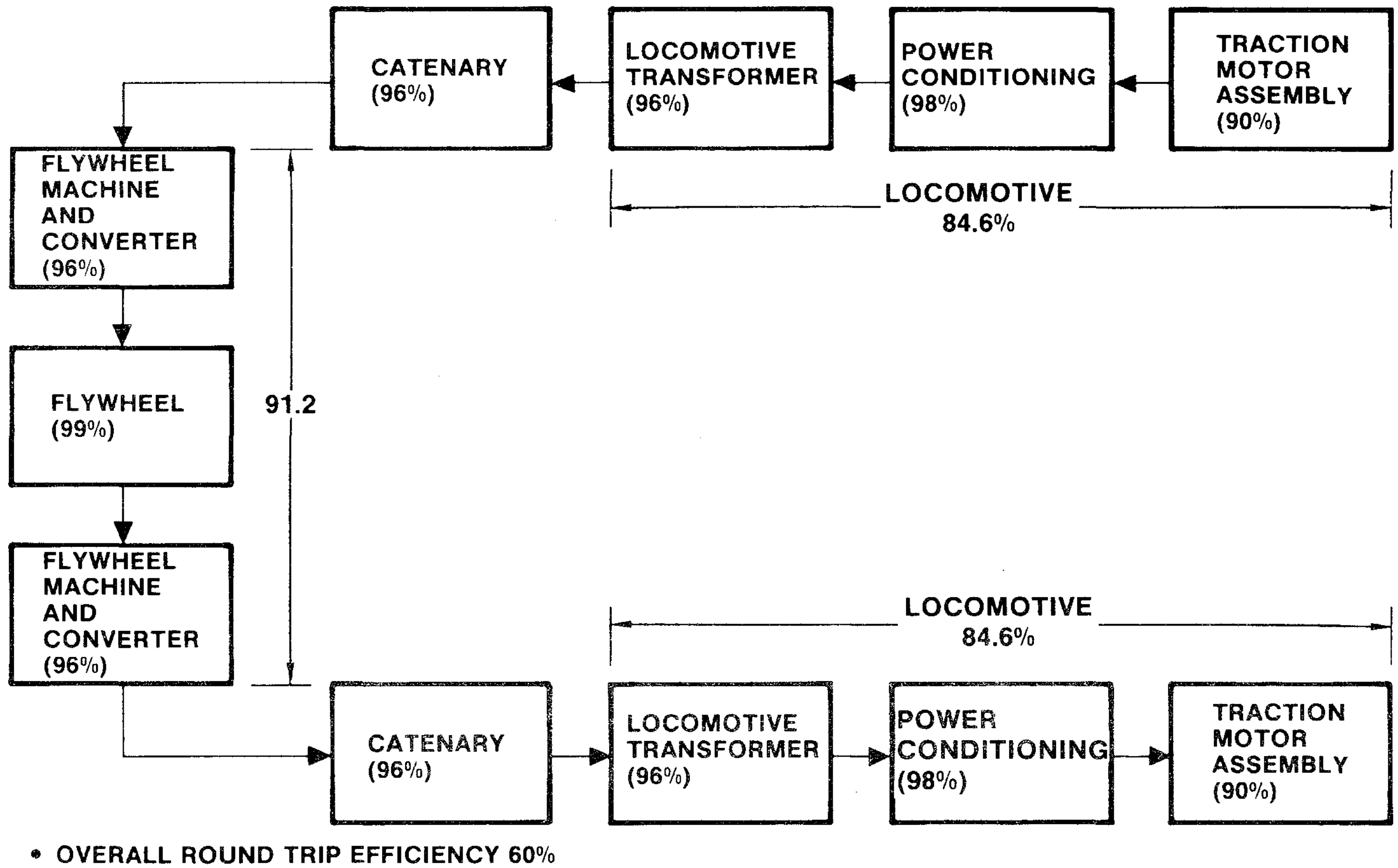


Figure 3-3. WESS Efficiency with High-Voltage Ac Catenary

where T = annual traffic density in the direction under consideration (gross trailing tons)

G = average gross trailing ton/train

Assuming an energy content/gal of diesel fuel at 52 hphr (38.8 kwhr) and from Figure 3-4, a diesel locomotive efficiency of 25.2 percent

$$\text{Energy saving} = \frac{2.22\ WT}{0.252 \times 38.8\ G} (h - 10L)10^{-7} \text{ gal of fuel}$$

Assuming a 30-year life and discounting at 10 percent, the net present value (NPV) of this annual saving

= (discount factor x fuel cost/gallon x energy saving) dollars

$$= 9.427 \times 0.38 \times 0.227 \frac{WT}{G} (h - 10L)10^{-7} \text{ dollars}$$

$$NPV = \left[0.813 \frac{WT}{G} (h - 10L)10^{-13}\right] \$ \text{ million}$$

The initial investment required to realize the annual saving consists of the following three major elements:

Electrification--The cost of electrification is approximately proportional to the track length (L miles) and number of tracks n. An electrification cost of $0.15 million was assumed at this stage of the study. More accurate figures were used in the engineering economics analysis later in the study.

Slugs--For the purpose of this preliminary analysis, it was assumed that the cost of motive power modifications and provision of slugs would be offset by the savings in locomotives previously referenced in Section 2 of this volume.

Flywheel--The flywheel was initially estimated to cost $0.33 million/Mwhr, a more detailed analysis not being available at this stage.

Initial Investment (IIN) is then

$$0.15\ n\ L + 1.0 \times \frac{nL}{10} + \frac{2.22}{\eta} W \frac{(h - 10L)}{10^3} 10^{-7} \times 0.330$$

where η = system efficiency from wheel to flywheel = 0.77 from Figure 3-3.

$$\therefore IIN = \$ \left[0.15 \frac{nL}{2} + 0.951\ W(h - 10L)\ 10^{-10}\right] M$$

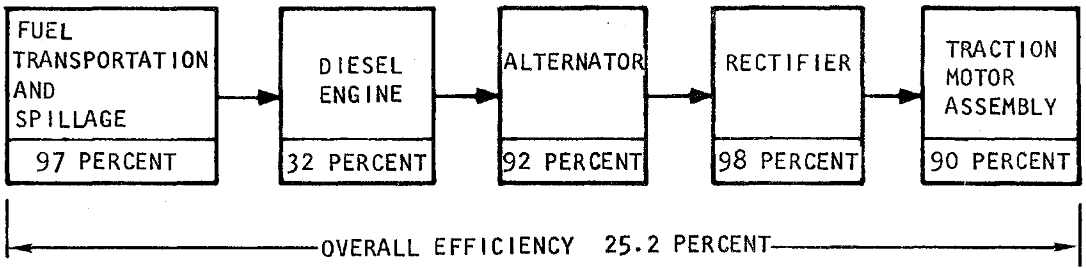


Figure 3-4. Diesel Locomotive Efficiency

Although it was derived in a crude manner, having made many assumptions that at the time could not be validated, there now existed a simple method of assessing the relative merit of the grades being considered. AiResearch took the view for this initial approach that if the NPV of the annual savings at least equalled the initial investment, then the grade was worth investigating further. This was particularly true since it was known that the motive power costs were overestimated.

$$\therefore \text{ for candidacy } \Delta NPV = IIN$$

$$\therefore 0.813 \frac{WT}{G} (h - 10L)\ 10^{-13} = 0.15\ nL + 0.951\ W\ (h - 10L)\ 10^{-10}$$

Assuming an average train size of 4600 gross trailing tons with an associated train weight of 5010 tons and dividing both sides of the above equation by L, we have

$$0.813 \times 5010 \times \frac{2000}{4600} \times T \left(\frac{h}{L} - 10\right) 10^{-13}$$

$$= \quad 0.15n + 0.951 \times 5010 \times 2000 \left(\frac{h}{L} - 10\right) 10^{-10}$$

$$1764\ T(52.8p - 10)10^{-13} = 0.15n + 0.953\ (52.8p - 10) \times 10^{-3}$$

where p = grade in percent, e.g., 1.4

$$\therefore \; T = \frac{0.15n + 0.953\,(52.8p - 10) \times 10^{-3}}{1764\,(52.8p - 10)\,10^{-13}}$$ for economic viability at the preliminary stage

where T = traffic density (gross trailing ton/year)

n = number of tracks

p = grade in percent

Then the solution to this equation shows typically the traffic density required for viable WESS installations on various track configurations and grade combinations. The solutions are shown in the curve of Figure 3-5.

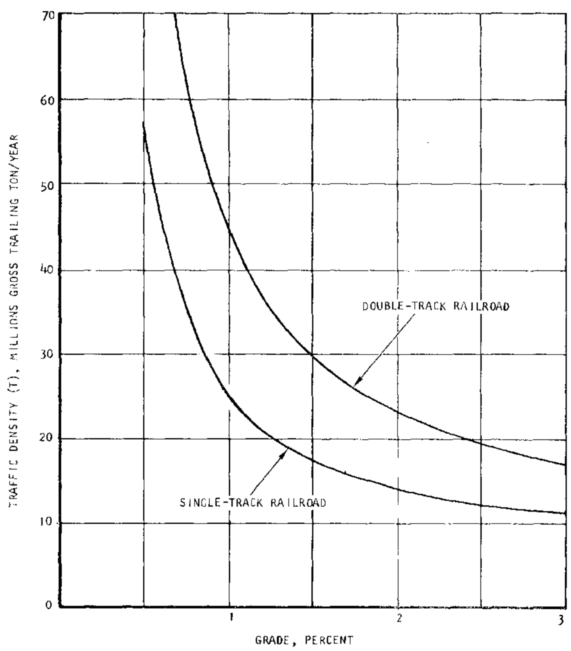


Figure 3-5. Relationship Between Traffic Density and Grade for Initial WESS Candidacy

Clearly, a finite amount of energy must be recovered to make the system viable and to place practical constraints on this theoretical approach. Initially, AiResearch regarded 600 kwhr as the minimum amount of energy that should be available at the wheel of the ascending train for deployment of a WESS. Therefore, from equation 1:

$$\text{Energy saved} = 2.22\ W(h - 10L)\ 10^{-7} = 600\ \text{kwhr}$$

$$\therefore \quad 2.22\ Wh\left(L - \frac{10}{52.8p}\right)10^{-7} = 600$$

if W = 5010 ton as before

$$2.22 \times 5010 \times 2000 \times h \left(1 - \frac{10}{52.8p}\right) 10^{-7} = 600$$

$$\therefore h = \frac{270}{\left(1 - \frac{10}{52.8p}\right)}$$ for realistic energy savings at this preliminary stage.

where h = elevation change (ft)

p = grade (percent)

The solution to this equation is shown in the curve of Figure 3-6.

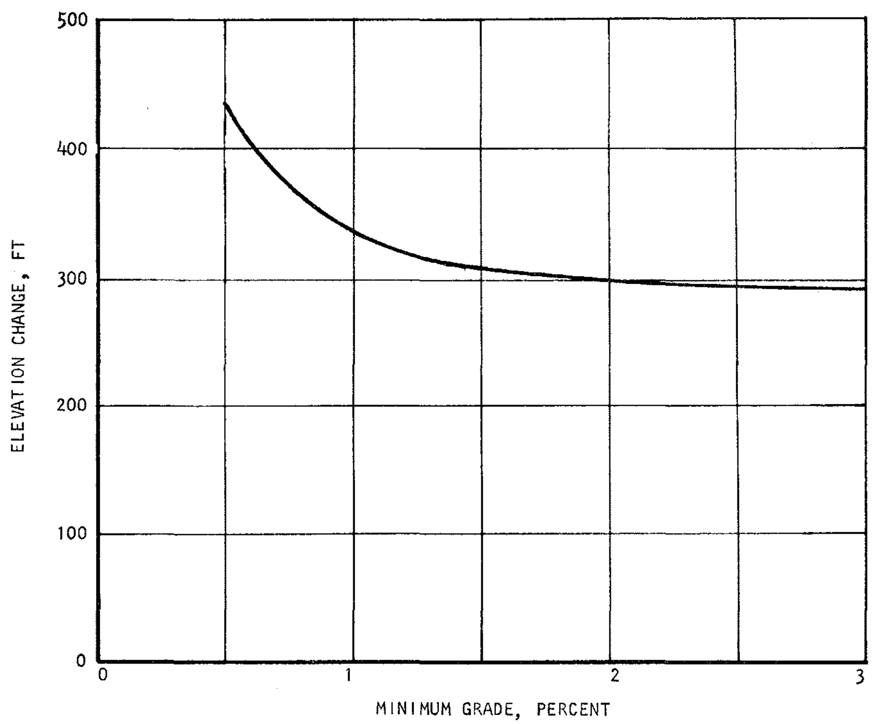


Figure 3-6. Relationship Between Elevation Change and Grade for Minimum Specified Energy Saving

The simplified approaches used above were solely for the purpose of identification of individual grades and were not used in the study for any other purpose. Calculations of energy savings were made using the AiResearch TPC, specially developed for the purpose, which treats all the variables in a technically correct manner.

Based on these preliminary data, AiResearch established that, in general, elevation changes in excess of 300 ft at a rate of 1.5 percent, with an annual traffic density at 20 x 10^6 ton would be of specific interest with regard to the application of WESS.

Data Acquisition

At the request of AiResearch, six railroads were approached by TSC. The following six railroads were approached by TSC:

Southern Pacific Transportation Company (SP)

Union Pacific Railroad (UP)

Southern Railway (SR)

Consolidated Rail Corporation (Conrail)

Atchison, Topeka, and Santa Fe Railway Company (AT&SF)

Burlington Northern (BN)

In their responses, AT&SF and BN declined to participate because of the heavy workload of their engineering staffs; however, a series of meetings was arranged with the other railroads. An informal approach was made to Duluth, Missabe, and Iron Range Railroad with the railroad agreeing to participate. The final meeting in the series took place on August 11, 1977.

Each grade was allotted a grade index number (GIN) from initial information on traffic density and grades. The preliminary calculations were used as a primary screening process to reduce the number of grades to be considered to manageable proportions as follows:

SP - 4 grades

UP - 9 grades

SR - 1 grade

DMIR - 1 grade

Conrail - 1 grade

The data collected for the prime candidate grades are shown in Appendix C. For each grade, a location map identifies the grade in relation to the nearest state or international borders. The grade data are shown on a separate sheet and include:

- Track profile (distance and elevation)
- Track configuration
- Annual traffic level (tonnage includes locomotives and was escalated from 1976 data--SP data 1977)
- Speed limits

The location study, as originally structured, was intended to cover approximately 50 percent of the major routes in the United States (see map of Figure 3-7) with approximately 80 percent of the Western Railroads covered. This was because these railroads consume 50 percent of the fuel used for rail traction. Clearly, the inability of BN and AT&SF to participate was a serious blow to the proposed comprehensive coverage.

Information was also obtained from the Denver & Rio Grande Western Railroad, Black Mesa and Lake Powell Railroad, and Transport Canada. The primary screening process then was applied to the U.S. grades identified during this indirect approach to the railroads and further primary candidate grades were identified as follows:

AT&SF - 10 grades

BN - 4 grades

D&RGW - 2 grades

BMLP - 2 grades

The data collected for these further prime candidate grades are included in Appendix C. It should be noted here that AT&SF subsequently agreed to cooperate in this study and have provided much valuable information.

Ranking Individual Grades

Having established the existence of 34 prime candidate grades on U.S. railroads, it was necessary to rank these grades in order of merit as directed by the contract statement of work. To meet this requirement, AiResearch presented a list of the 10 most attractive grades, based on the best information available at the time. This was done to remove the dependence on a particular operating scenario. Ignoring the motive power costs, it is shown that the costs and benefits of operating a particular grade are related as follows:

Cost of electrification is proportional to length of grade (L) and number of tracks (n).

Flywheel costs, and therefore capacity, are proportional to elevation change (h).

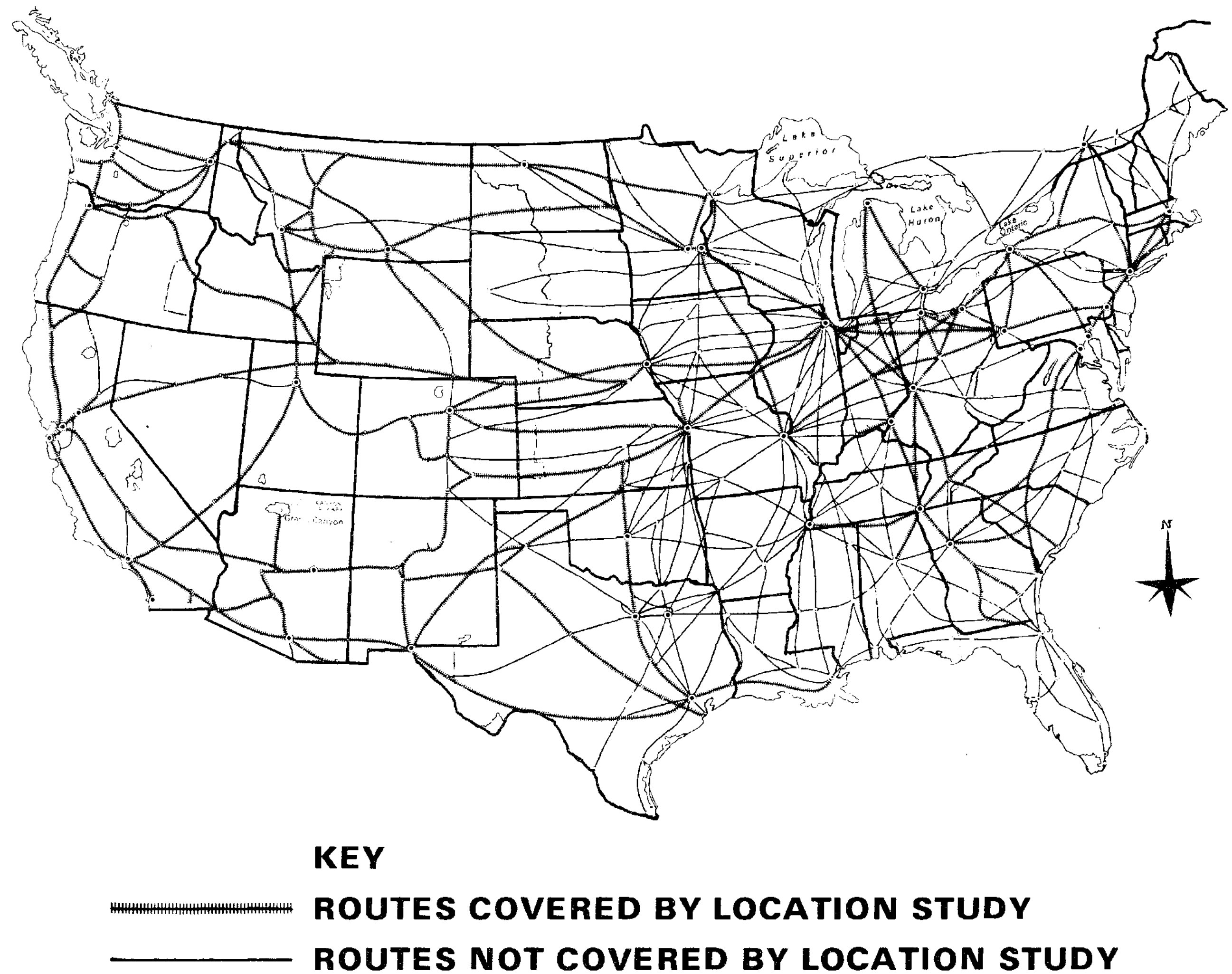


Figure 3-7. Routes Covered by Location Study

Energy savings are proportional to elevation change (h) and traffic density (T).

Therefore, the benefit-to-cost ratio of WESS grades may be expressed as being proportional to

$$\frac{Th}{nL + h}$$

Using this method, the benefit/cost ratio was derived for each grade and a list of the primary candidate grades with their ranking factor is shown in Table 3-1. It will be seen that the most attractive trades identified by this method were between Cheyenne and Laramie on the UP mainline, and between Harrisburg and Pittsburgh on the Conrail line.

The two grades on BMLP could not be evaluated in this manner since it is already electrified; also, the low cost of energy to that railroad further distorts the ranking; however, subjectively it appeared that with the combination of large elevation change and electrification already existing, these grades must be extremely attractive.

Identification of Wess Routes

The 34 prime candidate grades were displayed on a map of U.S. railroads, Figure 3-8, and were compared with a possible U.S. electrified network. It was noted that, with the exception of three grades, the prime candidate grades are located on routes considered to have electrification potential. This is hardly surprising since both WESS and electrification require a high traffic density to be economically viable.

The routes with WESS potential (i.e., routes with many WESS prime candidate grades between major classification yards) were identified and classified by characteristics such as high speed medium traffic, medium speed high traffic, etc. The ten routes are:

Los Angeles-Belen (AT&SF)

Los Angeles-Salt Lake City (UP)

Pocatello-Council Bluffs (UP)

Pocatello-Portland (UP)

Sacramento-Ogden (SP)

Sacramento-Portland (SP)

Los Angeles-El Paso (SP)

Denver-Salt Lake City (D&RGW)

TABLE 3-1

WESS PRIME CANDIDATE GRADES

Grade Index No.	Railroad	Identification	Ranking Factor
035	Union Pacific	Baker - Weatherby	32.4
036	Union Pacific	Union Junction - Powder River	69.7
037	Union Pacific	La Grande - Duncan	32.88
056	Union Pacific	Cheyenne - Laramie	112.75
061	Union Pacific	Echo - Wahsatch	57.5
063	Union Pacific	Orr - Milepost 40	43.8
088	Union Pacific	Elgin - Crestline	27.8
089	Union Pacific	Borax - Las Vegas	27.12
090	Union Pacific	Kelso - Nipton	27.46
121	Southern	Braswell Mountain	37.4
145	DM& IR	Duluth	33.8
175	Southern Pacific	Cascades (South)	41.2
176	Southern Pacific	Cascades (North)	39.7
183	Southern Pacific	Sierras (Roseville - Sparks)	41.6
195	Southern Pacific	Colton - Indio	58.0
202	Denver & Rio Grande Western	Helper - Springville	34.1
206	Denver & Rio Grande Western	Denver - Granby	30.6
220	Burlington Northern	Wenatchie - Skykomish	*
222	Burlington Northern	Easton - Auburn	*
226	Burlington Northern	Garrison - Missoula	*
227	Burlington Northern	De Smet - Dixon	*
230	Consolidated Rail Corp.	Harrisburg - Pittsburgh	10.8
240	Atchison Topeka & Santa Fe	San Bernardino - Victorville	69.5
242	Atchison Topeka & Santa Fe	Needles - Goffs	50.7
243	Atchison Topeka & Santa Fe	Flagstaff - Canyon Diablo	50.3
244	Atchison Topeka & Santa Fe	Bellemont - Flagstaff	50.2
246	Atchison Topeka & Santa Fe	Eagle Nest - Williams Junction	55.8
247	Atchison Topeka & Santa Fe	Hackberry - Pica	56.1
248	Atchison Topeka & Santa Fe	Topock - Kingman	56.3
251	Atchison Topeka & Santa Fe	Gallup - Belen	54.3
252	Atchison Topeka & Santa Fe	Belen - Silio	29.1
255	Atchison Topeka & Santa Fe	Vaughn - Fort Sumner	56.9
261(a)	Black Mesa & Lake Powell	Page - Milepost 31	+
(b)	Black Mesa & Lake Powell	Milepost 44 - Kayenta	

*Traffic data not available

+The ranking technique cannot be applied to BM & LP since the railroad is electrified and this distorts the rankings. This is because the simplistic approach adopted is only valid when comparing similar (in this case diesel) railroads.

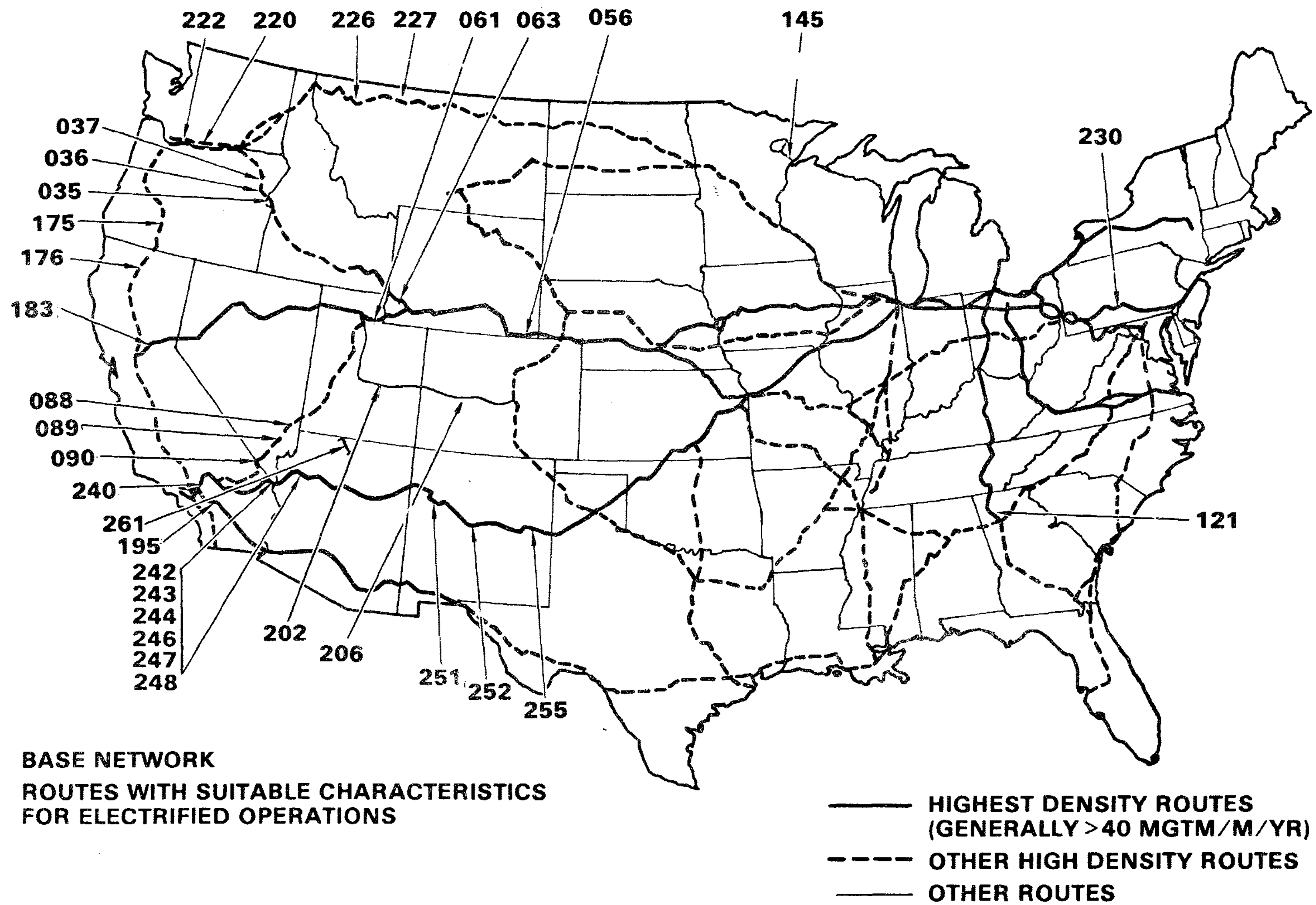


Figure 3-8. WESS and the National Electrified Network

Harrisburg-Pittsburgh (Conrail)

Page-Kayenta (BM & LP)

These routes are shown in Figure 3-9.

The routes operated by railroads who had indicated they did not wish to be involved in the study were deleted and four representative routes then were chosen for detailed analysis. The routes chosen were:

- Los Angeles - Belen--This route is part of the major Santa Fe artery between Chicago and Los Angeles and currently has a traffic density of approximately 50 x 10^6 GTT/year. The traffic is virtually all operated as high-speed manifest with typically a 2.6 hp/ton power/weight ratio.

  This route is classified in this report as a high-speed, high-traffic route.

- Los Angeles - Salt Lake City--Although this route is not associated with the high traffic routes of Union Pacific it is UP's only link between the Pacific Northwest, the Great Plains, and Los Angeles. It currently has a traffic density of approximately 39 x 10^6 GTT/year. The traffic consists of a mixture of high-speed manifest (4 hp/ton), medium speed (2.5 hp/ton), and drag (1.2 hp/ton).

  Harrisburg - Pittsburgh--This route is Conrail's major link to the East Coast from the heavy industry of Pennsylvania and currently has a traffic density of approximately 112 x 10^6 GTT/year. A large proportion of the traffic consists of heavy coal and ore unit trains.

  Black Mesa and Lake Powell--This coal-hauling railroad is electrified at 50 kv, 60 Hz and has a total traffic density of 21.2 X 10^6 GTT/year. Trains are made up of three E60C locomotives hauling 70 coal cars of 120-ton capacity.

The AiResearch train performance calculator (TPC) for this analysis used the route characteristics (grade, mileposts, curvature, speed restriction) available from track charts supplied by TSC. The output from the program was the identification of all sections of potential regeneration, a task impossible to undertake manually before the systems analysis had produced realistic operating scenarios. A detailed description is contained in Section 5 of this report.

The end result was the identification of many more candidate grades on the four representative routes, as shown in Table 3-2.

On the basis of this information, AiResearch recommended to TSC that the original intention to consider individual grades should be disregarded in favor of consideration of complete routes between major classification yards, thus enabling all costs and system design to be considered on a total system basis. TSC concurred with this request.

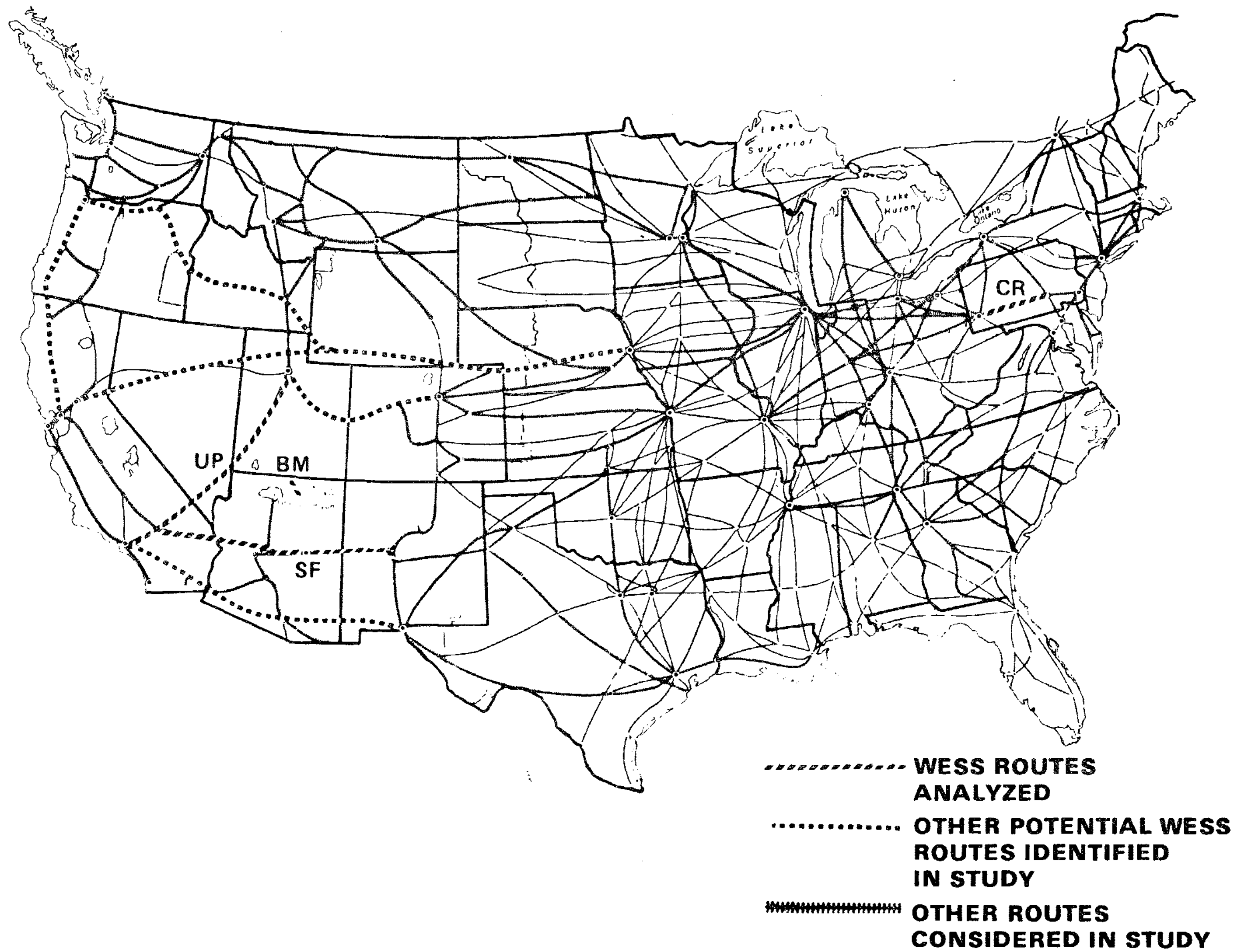


Figure 3-9. WESS Routes

TABLE 3-2

NUMBER OF ADDITIONAL CANDIDATE SITES DERIVED FROM USE OF TPC

Route	Primary Candidate Grades	Total Grades identified by TPC
Los Angeles-Belen	6	18
Los Angeles-Salt Lake City	4	10
Harrisburg-Pittsburgh	1	3
Page-Kayenta	2	2

Location Study Output

As a result of the location study, AiResearch has identified 34 prime candidate grades and ten routes with WESS potential; however, AiResearch does not claim that the location study was 100 percent complete as far as identification of all major grades was concerned, because the contract statement of work limited the contacts to not more than nine railroads. Other prime contact candidate grades and WESS routes no doubt exist on other railroads, but these remain unidentified by this analysis; however, this location study encompassed as many railroads as possible that had high traffic densities and that were located in mountainous terrain.

The preliminary calculations identified the range of flywheel sizes and power rating required to be compatible with the WESS system. Table 3-3 shows the flywheel size for the 10 most attractive grades. This range of sizes was later confirmed by the TPC.

FLYWHEEL STATION STUDY (ITEM 6)

On the basis of the energy calculations made for the individual grades, the sizing of the flywheels required for energy recuperation was determined. A design study then was conducted, which resulted in the definition of a typical flywheel station in sufficient detail to support the preparation of cost estimates.

Flywheel Sizing

The first determination was the flywheel energy storage capacity for a typical wayside station. The flywheel to be used for recuperation of braking energy in the WESS system was sized by examining the energy storage requirements from a single train on typical grades. A set of data showing the energy storage requirements for the 10 most attractive grades was shown in Table 3-3.

TABLE 3-3

ENERGY REQUIREMENTS FOR THE TEN MOST ATTRACTIVE GRADES

Grade Index No.	Railroad	Energy Storage from Single Train, Mwhr	Flywheel Capacity, Mwhr
056	UP	4.9	9.8
175	SP	10.5	21.0
195	SP	6.4	12.81
206	DRGW	9.6	19.2
230	Conrail	3.0	6.0
240	ATSF/UP	6.9	13.8
242	ATSF	5.3	10.6
248	ATSF	2.7	5.4
261(a)	BM & LP	8.3	16.6
(b)	BM & LP		

It also was assumed that on the intensively used routes under consideration there generally will be an ascending train taking at least part of the regenerated energy from a descending train. Therefore, the flywheel generally would not be required to take more than the energy resulting from the descent of more than two trains.

Then, using the baseline assumption that the flywheel should be capable of storing the energy from two trains for subsequent reuse by ascending trains, it can be seen that flywheel capacities range from 21.0 through 5.4 Mwhr. These values appear to be representative of the requirements for all WESS sites considered.

Thus, it was assumed that a flywheel of 5.5-Mwhr storage capability would be a typical size for cost-estimating purposes (multiple flywheel installations used where required), although in practice each flywheel would be sized to its specific grade application.

The power required of the flywheel station determines the capacity of the electric machine that couples energy into and out of the flywheel. Required power was found to vary from 4 to 11.6 Mw for the 34 prime candidate grades. On this basis, the assumption was made that the flywheel machine must have a 1-hr capacity of 7.5 Mw operating over the usable flywheel speed range. Again, the flywheel machine used in each WESS installation would be sized for that particular requirement.

The typical flywheel system storage capacity of 5.5 Mwhr and power rating of 7.5 Mw were used to determine the cost per kwhr of the flywheel assembly and the cost per kw of the flywheel machine and converter. These values then were used to determine the cost estimates of the wayside stations for each grade considered in the study.

Large Flywheels

The use of large flywheels for energy storage is not a new concept. At least three recent applications of large flywheels are known. The characteristics of these flywheel systems are shown in Table 3-4.

The Navy catapult system has been used on aircraft carriers to launch aircraft. This flywheel rotor is a complex steel forging with heavy hubs to provide the high power level. The catapult flywheel rotor has an energy density of over 10 w-hr per pound. Both the General Atomic and Tokamak flywheels described in Table 3-4 are used in nuclear fusion experiments to provide huge pulses of electric power from generators, of which the flywheels act as rotors. The energy densities of the nuclear program flywheels are quite low because their designs are compromised to provide the high pulse power generating capability.

Based on Table 3-4, it is theoretically possible to combine the weight of the Tokamak rotor with the energy density of the Navy flywheel. The resulting rotor would have an energy storage capacity at full speed of 10.3 Mwhr. If

TABLE 3-4

LARGE FLYWHEEL SYSTEMS

Description	Flywheel Capacity, Mwhr	Power Rating, Mw	Rotor Weight, ton	Rotor Speed, rpm	Rotor Diameter, ft
Navy Catapult	0.113	70	5.5	6000	7
General Atomic	0.444	260	200	400	20
Tokamak	1.25	475	500	375	22

this flywheel then were operated over a 2:1 speed range, its usable capacity would be 7.7 Mwhr, which would be suitable for many WESS applications. Because the catapult flywheel design requires expensive forgings, a simpler design, better suited to the WESS application, was developed.

Flywheel Design

The flywheel for the WESS should have the following characteristics based on the sizing considerations given above:

Usable energy storage (to 50 percent speed)	5.5 Mwhr
Total energy storage (100 percent speed)	7.33 Mwhr
Power level	10 Mw

Operating life with minimum maintenance — 30 years

Vertical installation

Minimum cost

Design speed (100 percent) — 1800 to 3600 rpm

Low parasitic losses

Three basic designs were considered in the study, as follows:

All-steel flywheel constructed of axial discs with a peripheral speed of 1440 fps.

A composite (fiberglass/epoxy) flywheel comprised of several concentric annular cylinders mounted upon an aluminum-spoked hub.

A hybrid design, which would contain a steel flywheel core surrounded by a multilayer composite cylinder.

The composite flywheel rings are made using two different filaments in order to use available materials to the greatest advantage:

(a) The inner rings, up to a rim speed of 2100 fps, are made using S-glass.

(b) These rings are overlaid with rings made using Kevlar filaments to a diameter that will produce a rim speed of 2500 fps. The inside/outside diameter ratio of the combination is 0.8.

The hybrid flywheel shows no real advantage over the all-steel flywheel. This is primarily because of the following three constraints arbitrarily imposed on this design as analyzed:

The rim speed of the steel portion was reduced from 1440 to 1300 fps to allow for poorer shape factor of the discs in order to provide for "spokes" to support the composite overlay.

The composite inner diameter is only 2 percent greater than the steel disc OD. This configuration reduces the length and weight of the spokes.

The ID/OD ratio of the composite cylinder is 0.8.

It is probable that with adjustment of the constraints during a complete design analysis, a more advantageous hybrid design would evolve.

Each of these designs was considered in both the 1800-rpm and the 3600-rpm versions; therefore, a total of six configurations was considered in the design study. These are summarized in Table 3-5. Additional data on the composite flywheels are shown in Table 3-6. The relative sizes of the three 1800-rpm flywheels and three 3600-rpm flywheels are illustrated in Figure 3-10.

It immediately becomes apparent from Tables 3-5 and 3-6 that there are significant advantages in cost and power loss when a composite flywheel is used; however, the composite design entails greater technical risk and a more complex installation (greater vacuum requirement). The hybrid design offers a more compact rotor than the pure composite, and has the additional advantage of accommodating magnetic levitation to reduce the hydrostatic bearing size and losses.

A second comparison of interest is the magnitude of power loss between the 1800-rpm and the 3600-rpm machines. The weight of the flywheel, for any configuration, is the same regardless of operating speed. Since the principal power loss in the flywheel system is the hydrostatic bearing and the bearing power loss is directly proportional to speed, the slower flywheel has only about half the loss of the faster one.

Flywheel Manufacture

The flywheels analyzed in the study are large structures with high rotating speeds. Any basic design--steel, composite, or hybrid--will involve special manufacturing techniques and additional facilities. Fabrication of a steel flywheel, however, involves less technical risk than the other designs. Fabrication of a composite (or hybrid) flywheel involves development of several manufacturing techniques currently being developed for much smaller units.

Steel Flywheel Fabrication

In this study, the use of steel discs in flywheels up to 15.25 ft in diameter is considered. Several steel companies were consulted and the largest material that can be supplied currently in high-grade SAE 4340 steel is 180 in. wide by 4 in. thick. The largest disc that can be heat-treated to the desired properties is 13.5 ft in diameter. The approximate maximum thickness that can be hardened uniformly is 3 in. The material given prime consideration for the steel flywheel design was Lukens Steel Company Electroslag Remelt Processed SAE 4340 steel.

With the above dimensions as limitations, a seventh flywheel type (no. 7 in Table 3-5) was defined. In this flywheel, the rotational speed is adjusted to produce 1440 ft/sec tip speed at 100 percent rpm with a 13.5-ft-dia. disc. Thus, the no. 7 design is optimized to avoid compromises in energy density due to the existing material and heat-treating limitations.

Composite Flywheel Fabrication

The composite flywheel will be fabricated by assembling a number of axial composite rim sections to form a flywheel cylinder of the required length. Each rim section would be made up of a series of annular rings one upon the other. Each one of these rings is wound and cured before the next ring is applied. This method, which is currently being used to manufacture small flywheels (up to 4-ft diameter), would be extrapolated to make the WESS flywheel.

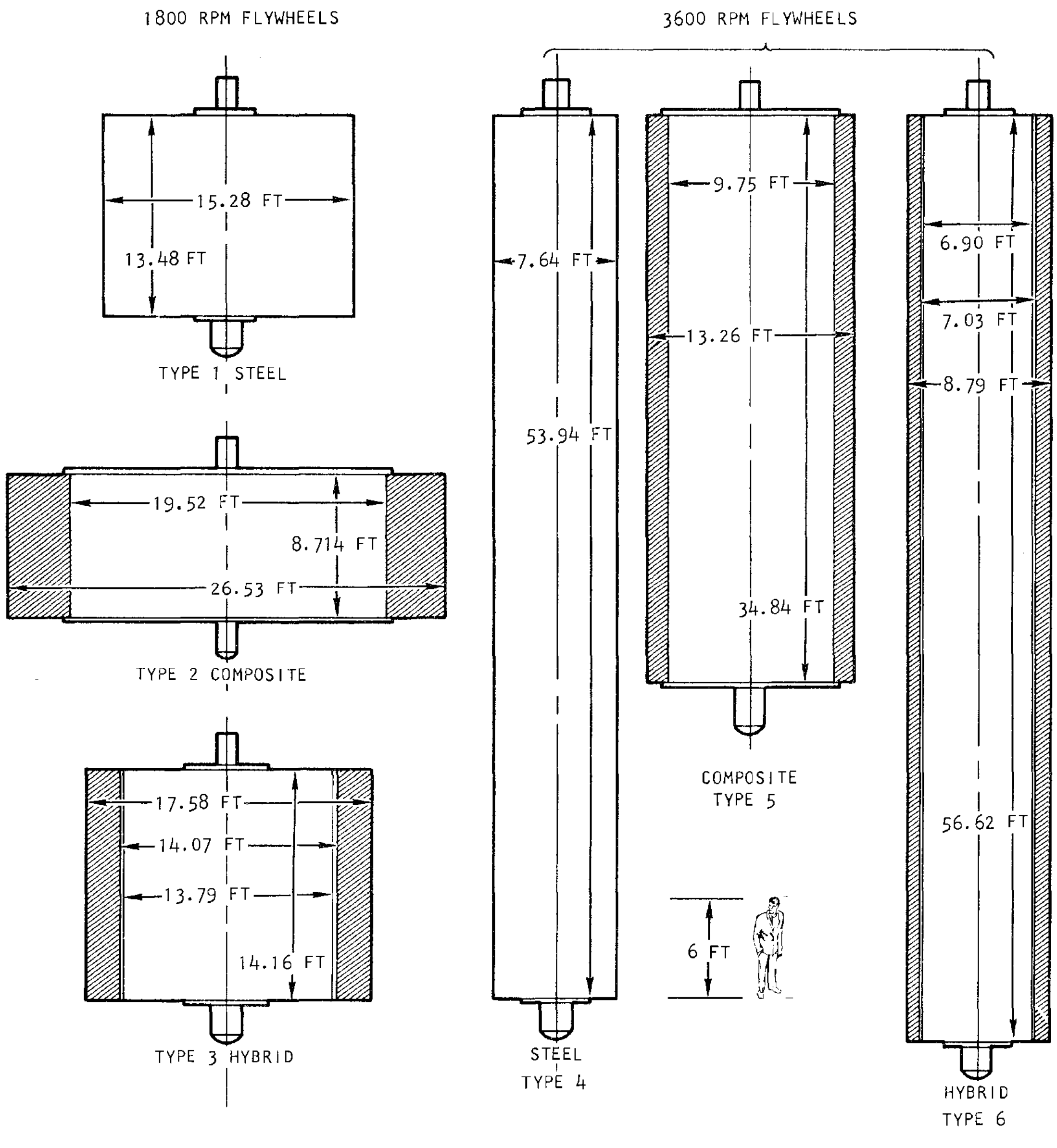


Figure 3-10. Flywheel Options

TABLE 3-5

SUMMARY OF FLYWHEEL CONFIGURATIONS

Material	Steel	1800 rpm Composite*	Hybrid	Steel	3600 rpm Composite*	Hybrid	2037 rpm Steel
Type	1	2	3	4	5	6	7
Diameter, ft							
Steel OD	15.28	19.52	13.79	7.64	-	6.895	13.5
Composite ID	-	26.53	14.07	-	9.74	7.033	-
Composite OD	-		17.58	-	13.26	8.791	-
Length, ft	13.48	8.714	14.16	53.94	34.84	56.62	17.28
Weight, tons							
Steel	604.4	-	516.8	604.4	-	516.8	604.4
Composite	-	133.5	84.4	-	133.5	84.4	-
Total	604.4	133.5	601.2	604.4	133.5	601.2	604.4
Tip Speed ft/sec							
Steel	1440	-	1300	1440	-	1300	1440
S-glass	-	2300	1657	-	2300	1657	-
Kevlar	-	2300	-	-	2500	-	-
Material Cost, $							
Steel at 0.60/lb	$ 824,368	-	$ 704,886	$824,368	-	$704,886	$824,368
S-Glass at $1.90/lb	-	$ 380,000	320,749	-	$380,000	$320,749	-
Kevlar at $4.80/lb	-	$ 321,600	-	-	$321,600	-	-
Total	824,368	$ 701,600	$1,029,633	$824,368	$701,600	$1,025,635	$824,368
Vacuum requirement, micron	1000	1	10	1000	1	10	10000
Loss at 100-percent speed, kw	120	27	120	240	54	240	136
Polar moment ft-sec^2		1,095,343			273,836		855,203

*Composite wheels made of Kevlar and S-glass. See Table 3-6

TABLE 3-6

SUMMARY OF COMPOSITE CYLINDERS

	Type (see Table 3-5)			
	2		5	
Speed, rpm	1800		3600	
Material	Kevlar	S-Glass	Kevlar	S-Glass
Tip speed, ft/sec	2500	2300	2500	2300
Outside diameter, ft	26.53	24.40	13.26	12.20
Inside diameter, ft	24.40	19.52	12.20	9.75
Length, ft			34.84	
Weight, lb	67,000	200,000	67,000	200,000
Total weight, lb	267,000		267,000	
Total weight, tons	133.5		133.5	
Material cost				
Kevlar at $4.80/lb	$321,600		$321,600	
S-Glass at $1.90/lb	$380,000		$380,000	
Total:	$701,600		$701,600	

A flywheel of the size required for the WESS application would require the construction of a winding facility that would include these items of special equipment:

A rack to hold the creels of revolving material and the devices to apply the proper tension to the roving as it leaves the creel. Probably four creels per winding machine would be used.

An evacuated wet-out box to apply the epoxy resin to the rovings.

A power-driven spindle, either vertical or horizontal, upon which to mount the winding mandrel.

Several winding mandrels upon which the layer after layer of composite material would be wound.

A curing oven into which the mandrels would be placed after each layer is made to cure the matrix.

Handling equipment (a mandrel and flywheel section might weigh five tons).

Inspection equipment.

Raw materials handling and storage.

Flywheel rim-to-hub assembly fixture.

Probably three or four parallel sets of some of this equipment would be installed in a facility in order to reduce the total manufacturing time.

Winding a flywheel of this size could take considerable time. Typically, a section might be made of 12 to 14 layers (concentric rings). Each layer would have 192 wraps. Winding four rovings at a time, it takes 10 revolutions to axially wind 1 in. A 6-in.-wide ring would take 60 revolutions of the mandrel. One concentric ring would require 11,520 (60 x 192) revolutions of the mandrel. At 8 rpm, which appears to be a practical roving feed speed for this size rim, this process would take 24 hr. A complete flywheel (17 sections of 14 layers each) would require 238 24-hr days for winding only if a single winding machine were available. In addition, there are other operations that must be performed as each layer is wound (gelling, curing, cleaning, inspection, and possible repair). Because this flywheel is considerably larger than those manufactured previously, some time would have to be devoted to developing manufacturing techniques.

Preferred Flywheel Design

After giving consideration to the availability of materials and fabrication technology, it appears that the steel flywheel is the most practical for development and deployment for at least the next 10 years. The potential of composite or hybrid flywheels is fully expected to be realized prior to the year 2000. Therefore, this decision must be reassessed periodically to assure that the optimum flywheel type will go into ultimate production for widespread application of the WESS concept.

The flywheel design considered to be optimal for the demonstration phase of the program is the steel flywheel of design no. 7 shown in Table 3-5. As pointed out above, this flywheel is designed in view of the realities of presently available materials, material cost, and limitations in heat-treating facilities. This flywheel will be made by flame-cutting unpierced 13.7-sq ft, 3-in.-thick blanks of the Luken Electroslag Remelt Processed 4340 steel. This stock is currently available in mill run quantities at approximately 60 cents per pound. These blanks will be Blanchard-ground on both faces and cut to 13.5-ft-dia discs, which will be jig-drilled for twenty-four 6-in. holes around the outer periphery. The finished discs will be heat treated to a minimum yield strength of 200,000 psi. The top and bottom discs will be forgings, which include suitable hubs on the specially shaped end discs. Consideration in final design will also be given to electron-beam or inertia welding of the hubs on the end discs. The complete 5.5-Mwhr steel flywheel will then comprise 67 center discs and two end discs.

The flywheel rotor will be assembled in situ at the WESS grade, as is the practice with large hydroelectric generators. The lower hub will be lowered into the lower bearing and then the center discs will be stacked on the lower disc. When the upper disk has been placed on the stack, 24 through-bolts will be used to hold the rotor assembly together. These bolts will be placed in tension, either by inserting and tightening heated bolts or by local tensioning of each bolt.

The 10-Mw electrical machine used to spin the flywheel and to extract energy from the rotor then will be installed. This conventional polyphase synchronous machine is essentially a standard 1800-rpm design that will be modified, if necessary, to permit operation up to 2037-rpm flywheel speed. The flywheel will be dynamically balanced by spin-up, using the flywheel machine with weights added to the rotor ends to effect balance.

The leading characteristics of this optimum steel flywheel are summarized in Table 3-7. The housing around the flywheel will be sufficient to support the bearings and to provide the capability for supporting a vacuum. The entire flywheel in its housing will be located in a waterproof concrete pit below grade level at the WESS site.

TABLE 3-7

CHARACTERISTICS OF OPTIMUM STEEL FLYWHEEL

Total capacity	7.33 Mwhr
Usable capacity (2 to 1 speed range)	5.5 Mwhr
Maximum speed	2037 rpm
Diameter	13.5 ft
Length	17.28 ft
Weight	604.4 tons
Peripheral speed	1440 ft/sec
Vacuum requirements	10 torr
Loss at 100 percent speed	136 hp
Loss at 50 percent speed	48 hp
Moment of inertia	855,800 $lb\text{-}ft\text{-}sec^2$
Spin-down time (100 to 50 percent speed)	87 hr

Flywheel Housing Evacuation

The area immediately surrounding the rotating flywheel must be evacuated for two reasons:

(a) To reduce windage losses

(b) To reduce aerodynamic heating

If a steel flywheel is used, the first reason, windage losses, predominates. If the housing is evacuated sufficiently to reduce the windage to a reasonable value, aerodynamic heating will be low enough to be no problem. Also, the vacuum requirements are not very severe, and an absolute pressure of 10 torr (or even higher) will reduce windage to a negligible value. This pressure is compatible with the oils that might normally be used in the bearing system. Furthermore, the steel flywheel is not very sensitive to an increase in housing pressure, and can, in fact, be made to survive a sudden loss of vacuum without damage.

On the other hand, the composite flywheel requires a much higher vacuum because of the higher tip speed and the sensitivity of the epoxy binder to temperature. A composite flywheel will require an absolute pressure environment in the neighborhood of 1 to 10 microns (1000 microns = one torr), and any significant increase in pressure could almost immediately result in damage to the surface of the flywheel. The high temperature resulting from windage makes the surface vulnerable because of the low specific heat and the low thermal conductivity of the laminate. Therefore, much more complicated evacuation system would be required. Some considerations of this system would be:

(a) Better sealed housing (including shaft seal)

(b) Great vacuum pump capability

(c) Better controls to sense pressure and changes in pressure that might indicate an impending problem

(d) Any oils that are exposed to the low pressure must have corresponding low vapor pressure at the expected operating temperature

(e) Special provisions for rapidly slowing down the flywheel in the event of loss of vacuum

The requirements for the hybrid type of flywheel would be the same as those for the composite flywheel.

For either type of installation, commercially available vacuum pumps would be used. If the housings were manufactured with reasonable care, the principal source of leakage would be the shaft seal. Therefore the pump basically is designed to accommodate the shaft seal leakage. A 1-hp unit (15 cfm displacement) should be sufficient for a steel flywheel installation, but a somewhat larger unit (possibly 5 hp and 80 cfm capacity) might be required for a composite flywheel. The evacuation system could be a demand type so that power would be consumed only as required to maintain the desired condition. In any event, the pump power requirement for the steel wheel is very small, compared with the hydrostatic bearing power requirements. Also, with a composite flywheel, vacuum pump power should be no more than 5 percent of total installation power requirements. Therefore, the choice of the steel flywheel minimizes the vacuum requirements considered.

Flywheel Bearings

The flywheel for the WESS is installed with a vertical rotational axis. At least one bearing would have to support the weight of the flywheel as an axial load. Design objective is to have a very long service life. Conventional rolling element bearings (ball or roller bearings) would be ideal from a frictional point of view, but the lifetime of rolling element bearings is limited under heavy load. Therefore, other longer-life types were investigated for the bearing to support the weight of the flywheel.

Rolling element bearings were still considered for two locations in the flywheel:

1. The upper shaft bearing that would be relatively lightly loaded, functioning only to keep the rotor vertical.

2. An emergency bearing to receive the weight of the flywheel rotor in the event of a failure of the main thrust bearing. A rolling element bearing is well-suited to this type of service because it can withstand high overloads for a short period of time.

Fluid Film Bearings

Two main types of fluid film bearings exist: self-acting and externally pressurized (hydrostatic). For large loads and high speeds they have the advantage over rolling element bearings of potentially infinite life; this is due to lack of contact between the rotating and stationary elements, and operation at much lower stress levels. The self-acting type is not load-supporting on the oil film alone until the design operating speed is nearly reached. This leads to problems in startup and shutdown. On the other hand, the hydrostatic type is supported from standstill on the pressurized oil cavity. This type of bearing was selected to support the flywheel in the WESS application.

Magnetic Suspension

Magnetic suspension could be used to support the weight of the flywheel; or, at least, to partially support the weight and lessen the load on the other thrust bearing. To be effective, a magnetically supported flywheel should be short and have a rather large diameter in order to present sufficient axially exposed surface area per unit of weight. This configuration is not compatible with the high rotative speeds desired in this application. Also, application of magnetic levitation to an object the size of this flywheel would be very experimental and is not recommended to be included in the present design.

Selected Design

The selected design for the flywheel bearings is shown in Figure 3-11. The flywheel is supported principally by means of a spherically radiused hydrostatic bearing as shown in Figure 3-12. This hydrostatic bearing has four pockets through which oil at high pressure is fed to the bearing. The pressure-projected area product is sufficient to support the entire weight of the rotor. The spherical shape tends to maintain the axis of the rotor coincident with the axis of the bearing.

Before operation, the weight of the rotor is supported by the rolling element thrust bearing (item A of Figure 3-12). The weight of the rotor depresses the unpressurized bearing, B, which is supported by several weak springs, S. At this time there is a gap, D, between the bearing shoe B, and the stator, C. At startup, oil under pressure is supplied to the cavity, E, under the bearing shoe. This oil is communicated to the four pockets in the bearing shoe and the resulting force lifts the rotor and supports it on a thin film of oil leaking from the bearing pockets to the edge of the shoe. At the same time the entire bearing shoe is lifted by the pressure in the lower cavity, closing the gap, D, and lifting the rotor clear of thrust bearing, A. Thus the entire rotor assembly is then supported by the hydrostatic bearing only. The support of the hydrostatic bearing is not a function of rotor speed so the rotor is supported from standstill to maximum speed.

If the hydraulic system fails, the hydrostatic bearing would collapse, but the rotor would again be supported by the rolling element thrust bearing, A. This bearing would be sufficient to support the rotor until it is slowed to a standstill.

A hydrostatic bearing has two principal sources of power consumption: (1) the power required to pump the pressurized oil to the bearing; and (2) the power consumed in shearing the oil at the shaft/shoe interface. These relationships are considered in the bearing detail design to optimize the various factors and bring the power consumption to a minimum. The approximate size of the bearing for the proposed flywheel system is shown in Figure 3-12.

The upper end of the flywheel shaft is supported in the radial direction by means of a roller bearing as shown in Figure 3-13. This bearing is reseliently mounted and loaded so it will have an extremely long life. The outer race of the bearing is eliptical to maintain positive contact between the rollers and the race ways. This bearing is cooled by oil flowing under the inner race, and lubricated by a minute amount of oil that is allowed to flow through the bearing.

Flywheel Shaft Seal

Some sort of air seal must be provided to separate the flywheel cavity from the surrounding ambient air. If a steel flywheel is used the flywheel cavity pressure needs to be reduced to approximately 1 to 10 torr; but if a composite flywheel had been used the pressure would have been less than 10 microns. This lower pressure puts a much more severe requirement on the shaft seal.

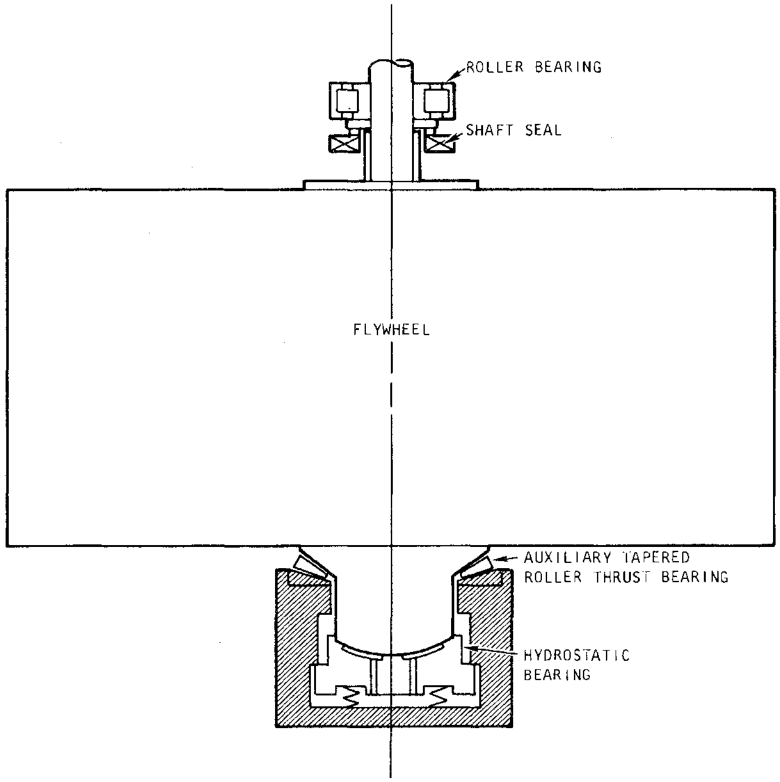


Figure 3-11. Flywheel Lower Bearing Arrangement

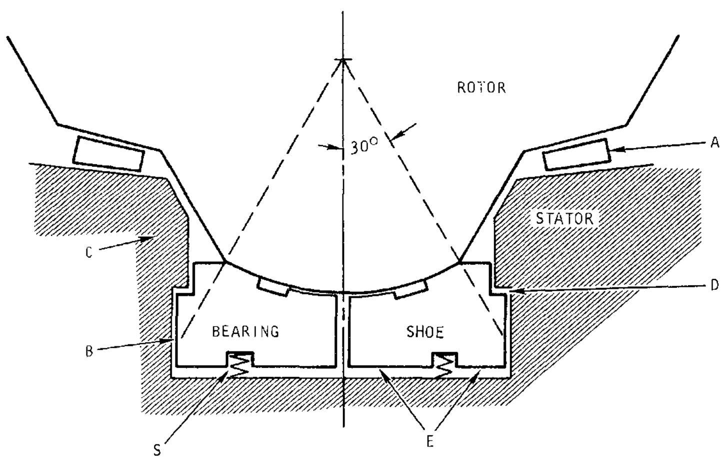


Figure 3-12. Hydrostatic Thrust Bearing

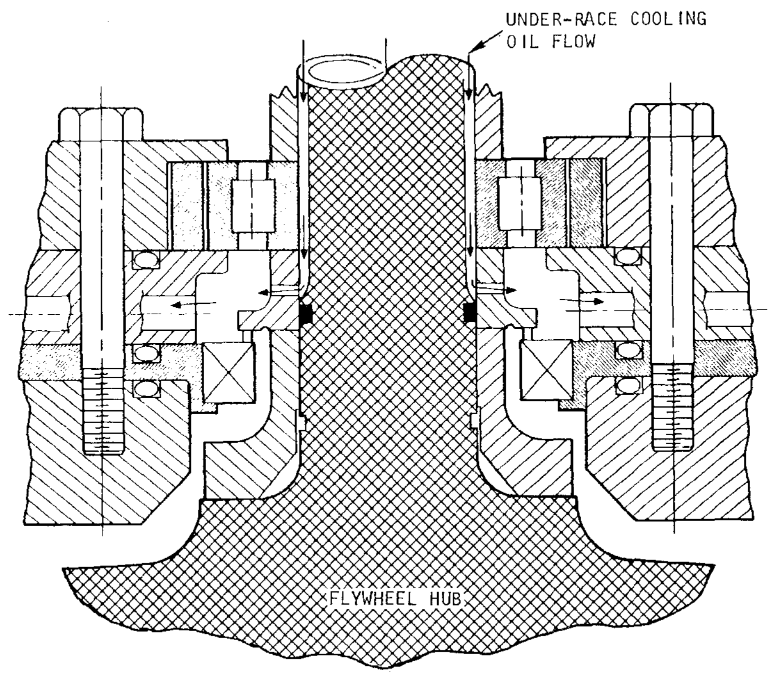


Figure 3-13. Upper Flywheel Bearing and Shaft Seal Assembly

Face seals have been used effectively on smaller and higher-speed flywheel applications, but the service life is limited as to that desired for the WESS flywheel. Special care in seal design and installation might permit the use of a face seal, especially if the design permitted easy replacement after possibly 20,000 hours of operation. At the present time this type of seal probably is the best option with other designs, discussed below, being investigated for possible application when proven feasible.

Ferro-Fluid Seal

This type of seal has been suggested for a number of similar applications, but no high-speed long-duration applications are known. The principle of operation, as shown in Figure 3-14, involves a fluid into which there is a colloidal (100 angstroms) suspension of magnetic particles that are retained in the seal area by means of permanent magnets in the housing. While this arrangement will provide an excellent near-zero friction seal for low-speed shafts, the combination of problems incurred by viscous heating and centrifugal forces associated with a high surface speed (3000 fpm) shaft make this application an advance in the state of the art.

Slinger Seal

Another type of seal that may work in this application is the slinger seal, as shown in Figure 3-15. In this seal, a slug of oil is held in an

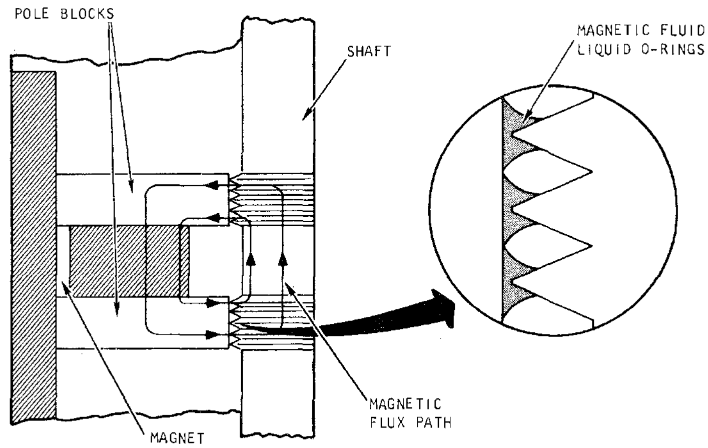


Figure 3-14. Ferro-Fluid Seal

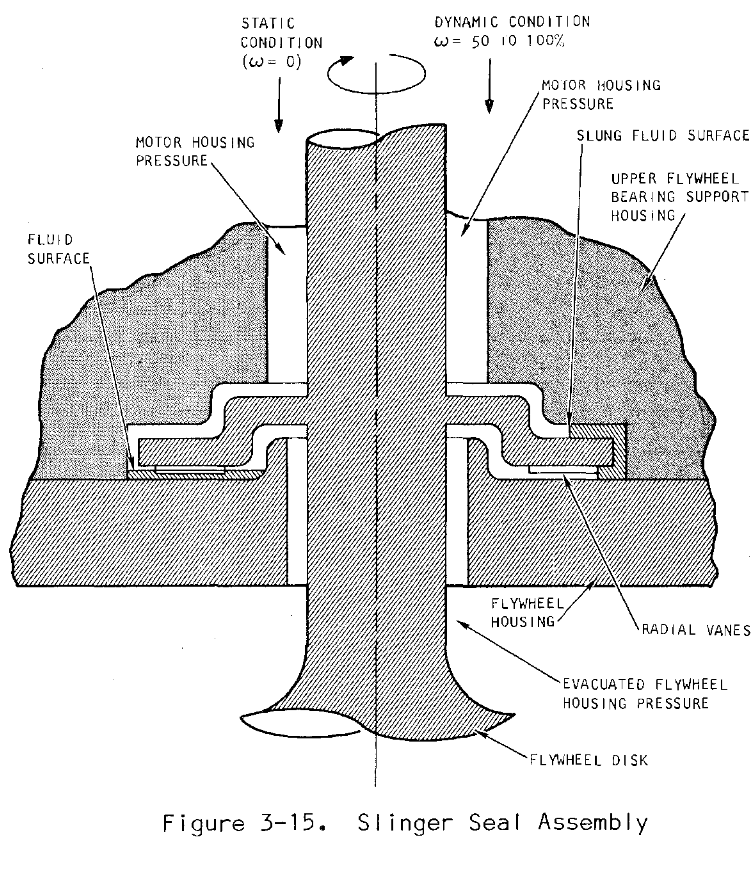


Figure 3-15. Slinger Seal Assembly

annular groove in the housing by the centrifugal force on the oil slug. The rotating oil slinger, which puts the oil into this groove, also acts as a dam whose outer periphery is submerged in the oil pool. In this design, a number of criteria must be simultaneously satisfied if proper sealing is to be obtained; any upset could lead to sudden and catastrophic pressurization of the flywheel cavity in the case of a composite or hybrid rotor. Also, this design requires that the shaft be rotating at some speed before the seal can be initially formed. In order to retain the pressure differential across the seal, an equivalent head must be developed by the fluid column across the seal.

Flywheel Machine

The 7.5-Mw flywheel machine used for estimating purposes is a conventional, utility type of brushless (rotating rectifier), synchronous, four-pole, electrical machine that can be operated either as a motor or generator at a 7.5-Mw power level over the full operating speed range (1018 to 2037 rpm). The typical efficiency of this air-cooled machine at rated power level is 97 percent. The machine is mounted with a vertical rotational axis above the flywheel. It weighs 150,000 lb.

Because the flywheel machine is typical of small utility generators, cost estimates for the 7.5-Mw capacity were obtained from the large machinery department at General Electric Corporation (GE) and Westinghouse. The average cost for machines of this type in the 7.5-Mw capacity range was found to be $60 per kw. This cost was also used in the economic analysis.

A general outline of the machine is shown in Figure 3-16 (as supplied by GE), and is a commercially available, small-size utility generator.

Flywheel Converter

The static power converter (Figure 3-17), which connects the flywheel machine to the railroad electrification system, converts 2-phase, high-voltage 60-Hz power to variable-frequency, 3-phase power to operate the flywheel machine. The output frequency range of the converter in normal operation varies from 34 to 68 Hz at a continuous power rating of 7.5 Mw as the flywheel is operated over its 2:1 speed range. In addition, the converter must provide controllable, low-frequency power capable of being varied from about 1 to 34 Hz at reduced power levels. This capability is used only infrequently, for flywheel startups after inspection or after an unscheduled shutdown.

The decision regarding operating voltage involves a detailed design study to trade off the cost of transformers against the cost of devices. For this study, the cost of $30 per kw is based on using sufficient series bridges to accommodate 50 kv without using transformers.

The configuration used allows direct phase-to-phase regeneration without the need to pass through the flywheel. The addition of a bridge for phase C would allow balanced 3-phase regeneration to the utility. This third bridge also could be used to accommodate situations where the railroad uses all three phases for the catenaries (as may be the case on the Harrisburg-Pittsburgh route).

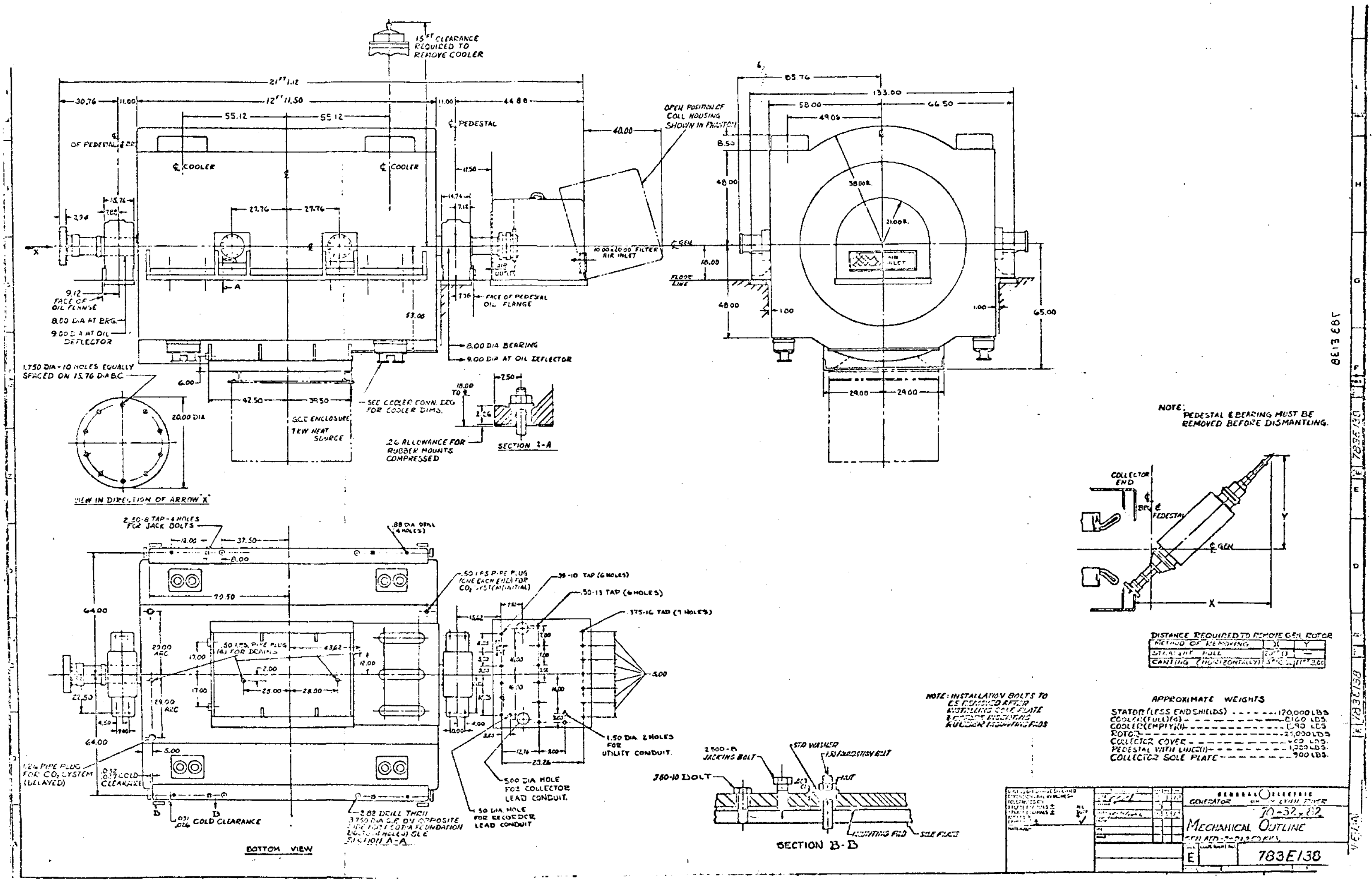


Figure 3-16. Mechanical Outline of Flywheel Machine

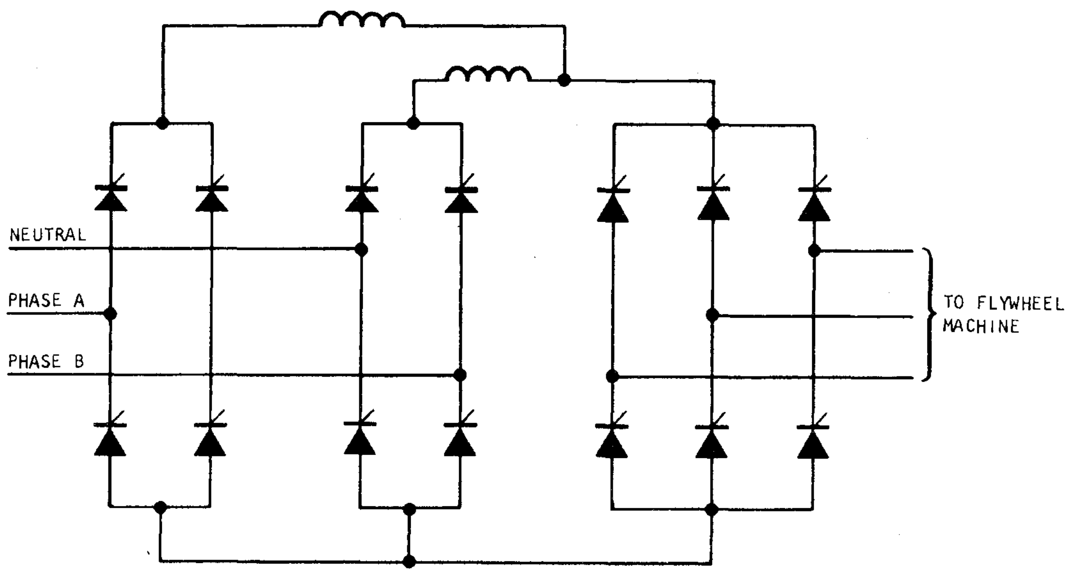


Figure 3-17. Simplified Schematic of Flywheel Converter

Flywheel Station Construction

The construction of a WESS flywheel station at a remote site was analyzed by Bechtel, based on their broad experience in products such as pumped hydroelectric stations. The flywheel assembly building concept recommended by Bechtel is shown in Figure 3-18. The flywheel is located in a concrete pit below grade to preclude any safety hazard due to flywheel failure; the flywheel machine and system ancillaries are located in the steel building above grade.

The plan layouts of the flywheel building and the adjacent converter building are shown in Figure 3-19. The overall WESS site, the building, adjacent electrification, equipment, and access to the site are shown in Figure 3-20.

The $160,000 cost derived from the Bechtel estimates for construction of the flywheel energy storage station does not include the costs of electrification; this cost is separately estimated under item 5, Wayside.

Flywheel Cost

The cost of the flywheel has been analyzed in detail and the results are shown in Appendix D. Most of the cost is attributable to the flywheel material, and an accurate assessment of this cost element is clearly essential. A cost of $0.60/lb for mill run quantities of SAE 4340 steel was supplied by Luker Steel. (For two flywheel discs only, the cost would be $0.65 per lb). This firm price for the major cost item ensures the acceptability of the AiResearch estimate.

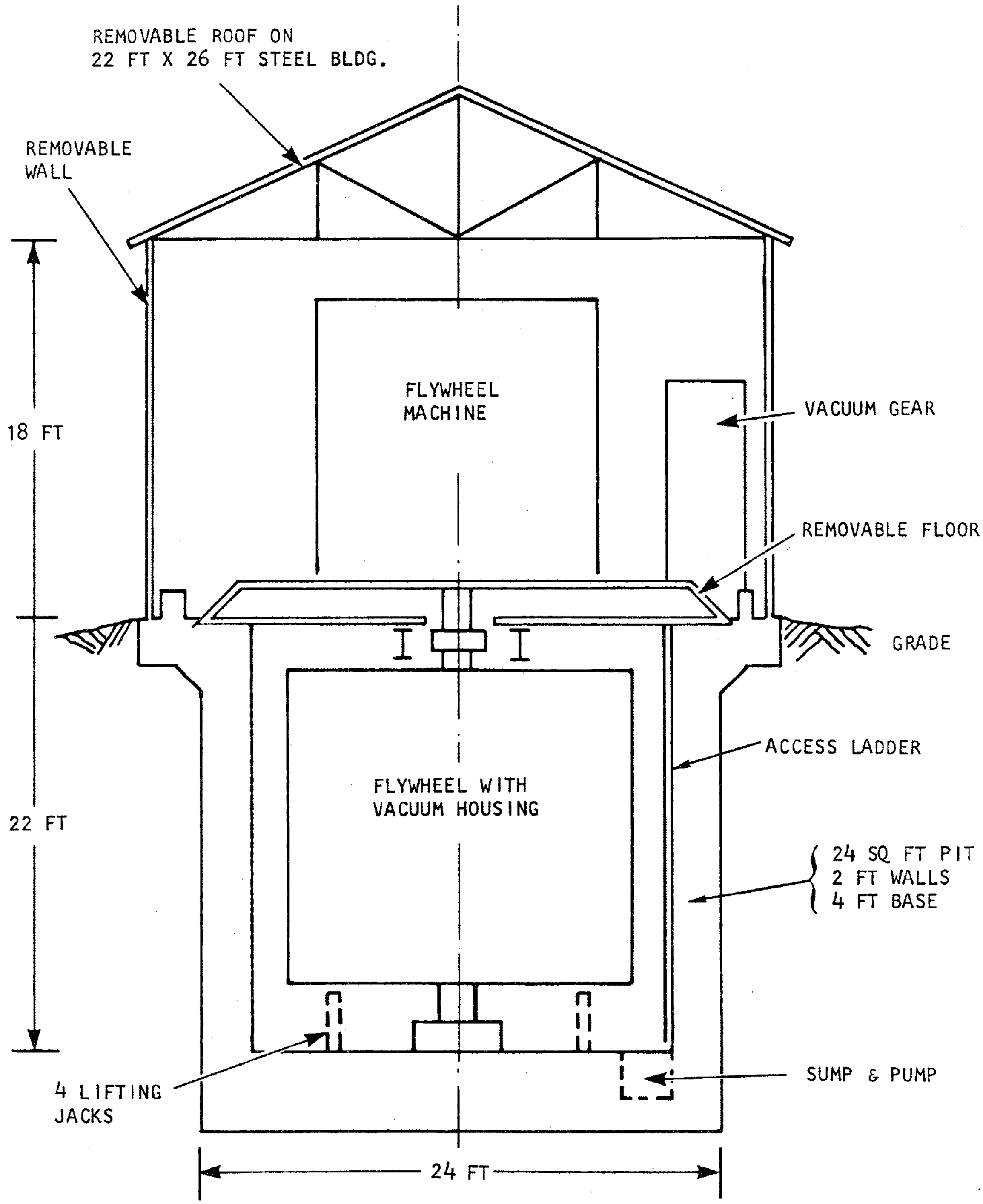
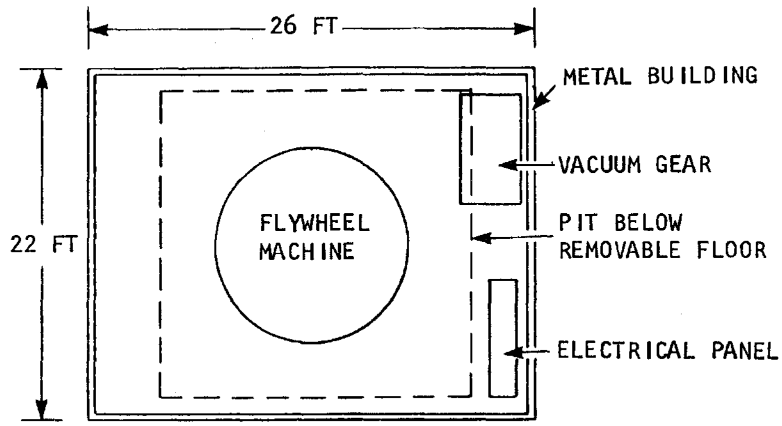
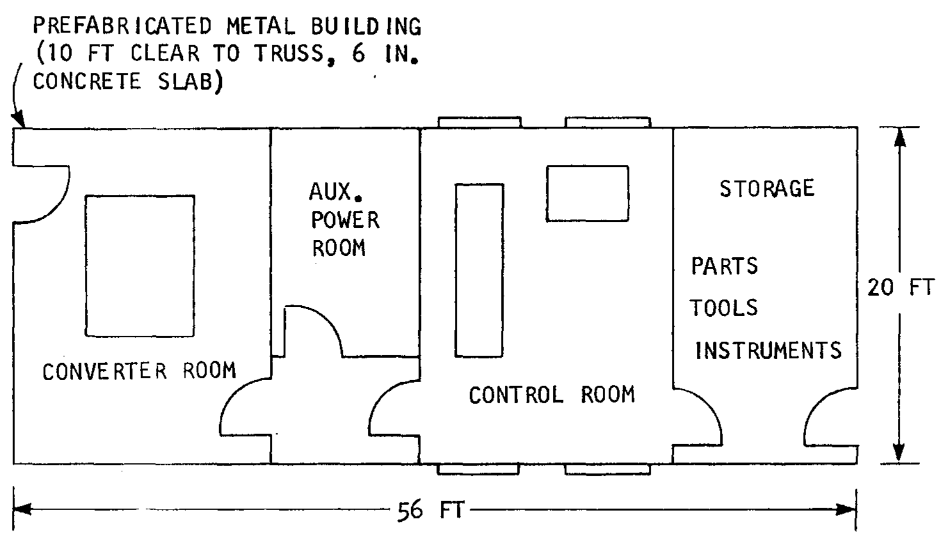


Figure 3-18. Flywheel Housing



a. PLAN - FLYWHEEL BUILDING



b. CONVERTER BUILDING

Figure 3-19. Flywheel and Converter Buildings

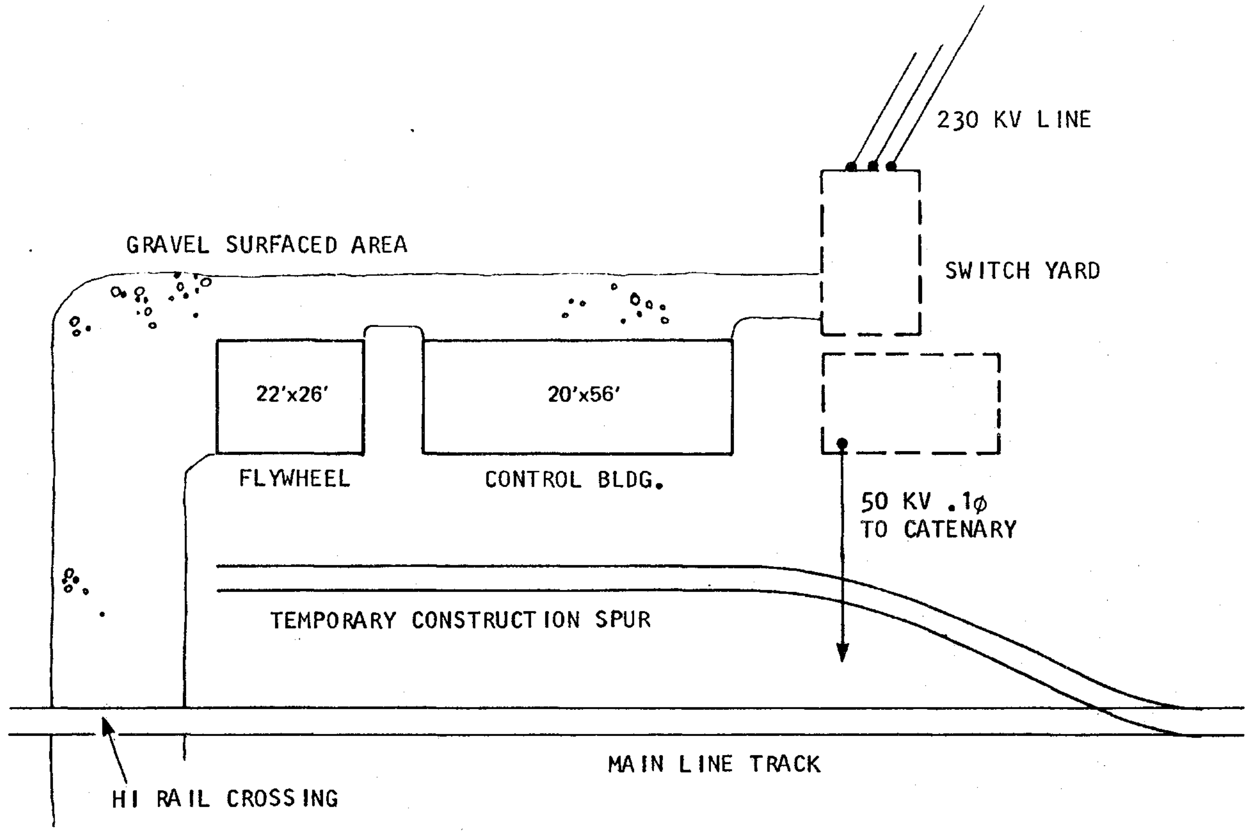


Figure 3-20. WESS Site Plan

SECTION 4

ECONOMIC SOURCES AND METHODOLOGY

The potential benefits of wayside flywheel stations are largely economic. No particular social benefit results from the deployment of WESS, although reduced fuel consumption is a desirable material goal. The major savings are locomotive fuel or energy and reduced size of the locomotive fleet; other savings are reduced track, brake system, and wheel maintenance, and possibly higher and more uniform consist speeds. These savings must be compared on a time-consistent basis with the initial investment cost and maintenance costs for the flywheel system equipment.

The comparison of savings to costs has been performed by using the several accepted economic techniques. The wayside energy storage system can be considered economically viable if (1) the savings exceed the costs sufficiently to provide a reasonable return on invested capital, including interest charges, and (2) savings compensate for the uncertainties associated with the introduction of new technology.

ECONOMIC ANALYSIS TECHNIQUES

To simplify the calculation of return on investment (ROI) in the economic analysis, it was assumed that all investments were made in year zero of the 30-year economic life of the system. (Year zero is defined as 1990 for the purpose of this study, this being the earliest that a production WESS system could be deployed). Savings were calculated at the mid-year point for each of the 30 years.

The economic techniques to be employed in this study were agreed upon by TSC and FRA at an early stage, when an attempt was made to assess the viability of the WESS concept using the techniques with which industry and government are most familiar. These techniques are described below.

Office of Management and Budget Circular A-94

This is a net present worth or net present value technique and, as the name implies, is concerned with assessing the value of monies spent or saved in future years in terms of today's money value; however, this is not a technique for dealing with inflation. OMB A-94 allows relative inflation to be taken into account. Inflation factors are shown in Table 4-1.

A crucial discussion to be presented is the rate at which future monies should be discounted. OMB A-94 dictates that 10 percent be used because this represents an estimate of the average rate of return on private investment, before taxes and after inflation; however, railroads typically realize only a 5 to 6 percent rate of return and therefore the applicability of the OMB A-94 guidelines to WESS is questionable. For this reason the results derived from this technique were not used as the baseline case.

TABLE 4-1

SUMMARY OF INFLATION RATES

Analysis Technique	Diesel Fuel	Electricity	Maintenance	General Price Level
OMB A-94	2	1	2	0
4R Act	0	0	0	0
Sensitivity 1	8	7	8	6
Sensitivity 2	10	7	8	6

Railroad Revitalization and Regulatory Reform (4R) Act-1976

The purpose of the 4R Act was to provide financial assistance for the U.S. railroads to enable them to invest in essential new projects (such as track maintenance, track reconfiguration, etc.). It was considered prudent to assess the benefit of WESS using the guidelines of the 4R Act even though WESS would probably not qualify for 4R assistance as the Act is currently structured.

Because the 4R Act guidelines make no allowance for general or relative inflation, AiResearch feels that the results do not reflect the real world. Therefore, the results from this technique were not used as the baseline case.

Sensitivity Analyses I and II

These analyses were recommended by AiResearch as being a real-world case, taking inflation into account and producing an output based on current dollars. Like the 4R Act, they employ ROI techniques, the only difference being the recognition of inflation. The inflation factors for the two analyses are shown in Table 4-1.

Sensitivity I was used as the baseline case for the economic analyses because this is considered to be the most realistic scenario.

INFLATION

In a study such as this, when the year of decision is 1990 and the hardware is designed for a 30-year economic life, the choice of inflation factor is a crucial decision. Many different components make up the total costs and annual savings; historically, each of these components has increased in cost at different rates relative to general price level (GPL).

General Price Level

When the inflation factors were formulated in September 1977, the GPL was rising at 6 percent per year. This figure has been used in the study, although at the date of this report, the GPL is rising at 10 percent per year.

Diesel Fuel

The diesel fuel inflation is difficult to predict since, more than any other item, it is subjected to international political pressure. Reference 9 suggests that diesel fuel will probably escalate at between 2 and 4 percent above the GPL over the next 25 years, and Figure 4-1 is based on a 2-percent differential inflation rate. Therefore, 2 percent above GPL is considered to be the most realistic estimate for fuel inflation.

Electrical Energy

Because electrical energy may be derived from various sources (oil, gas, coal, nuclear, and--in the future--solar and geothermal), it is less sensitive to the variation in relative price of any one lb-base fuel. Reference 9 suggests that electrical energy will inflate at 1 percent per year for the next 25 years; this agrees with the predictions of Figure 4-1.

Maintenance

Department of Commerce (Bureau of Labor) projections of increased costs in manufacturing and nonmanufacturing industry have historically shown an increase in maintenance costs of 2 percent above GPL. This level of increase has been assumed to continue for the life of the WESS.

ECONOMIC ANALYSIS METHODOLOGY

Economic Scenario

Four economic scenarios have been developed, based on the three operating scenarios described in section 2 of this report. They are:

Dual-Mode Locomotive--All motive power normally operating on this route is converted to the dual-mode concept, and credit is taken for the reduction in fleet size that results from the increased tractive effort of these locomotives. Electrification is available only at grades.

Electric Helper--Regenerative electric locomotives are stationed at the grades and a saving in diesel locomotives is claimed due to the easing of the gradient duty imposed on the diesel locomotives. Electrification is available only at grades.

Electrified Railroad--Where the railroad is already electrified, the only costs to WESS are for the installation of the flywheel station and modification of electric locomotives.

Concurrent Electrification and WESS--The diesel railroad is converted to electric operation and all the associated changes are considered with the cost of the WESS stations.

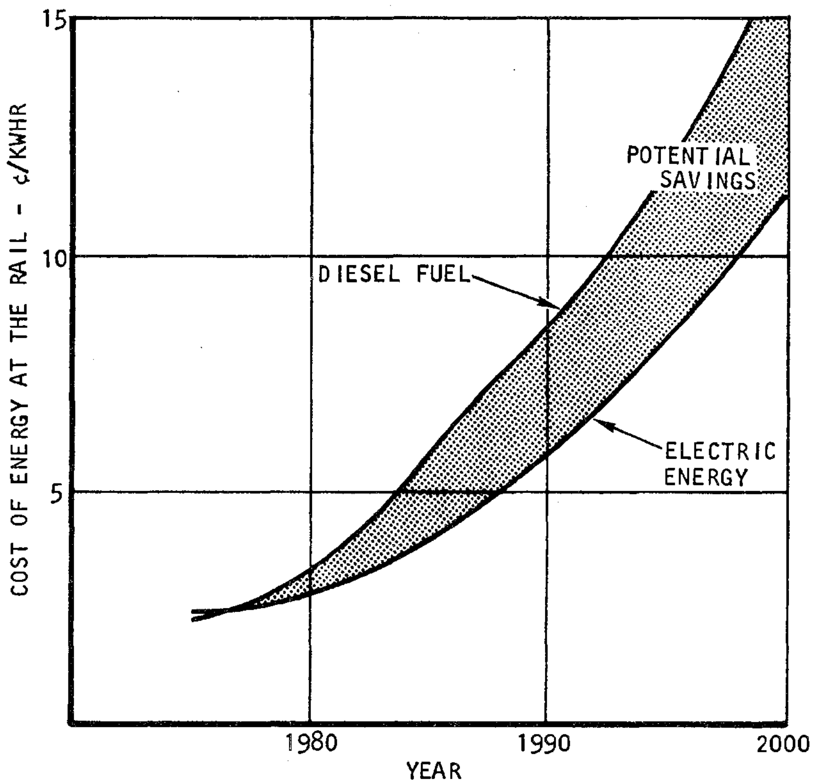


Figure 4-1. Comparison of Cost Projections, Railroad Diesel Fuel and Electric Energy (Ref 7)

Economic Computer Program

To accommodate the large amount of data in the economic analysis, AiResearch generated a computer program, for which a simplified flow chart is shown in Figure 4-2. The program listing is contained in Appendix E. It has been written for the Univac 1100 computer.

1. Description of Program

Main program: WESS - calls subroutines INPUT and DETAIL

Subroutines:

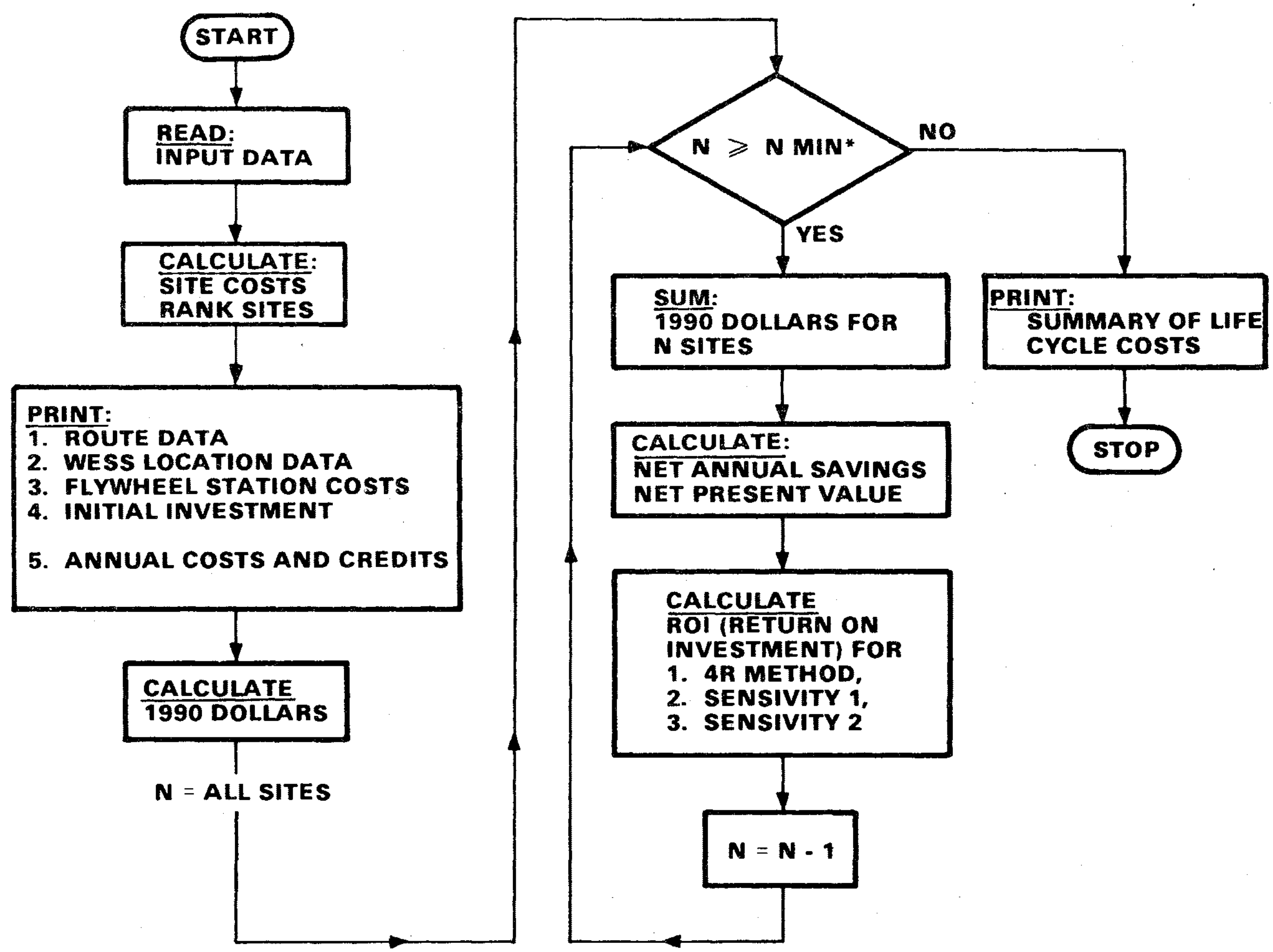
1.	INPUT	Reads input data from cards
2.	DETAIL	Main subroutine: Organizes data for site rankings, calls subroutines for economic analysis; calls subroutines TREE, G1990D, SUM90, NPVNAS and REPORT.
3.	TREE	Sorts subroutine, aids in site rankings.
4.	G1990D	Converts 1977 dollars into 1990 dollars
5.	SUM90	Sums 1990 dollars--initial investment and annual costs.
6.	NPVNAS	Calculates net present values, net annual savings. Calls subroutine RONINV.
7.	RONINV	This subroutine determines the return on investment. Calls subroutine ITRAT.
8.	ITRAT	Auxiliary subroutine that aids in the iterative solution for return on investment.
9.	REPORT	Prints final report, called by subroutine DETAIL.
10.	BLKDAT	Fortran block data element that contains initial values for most variables used in the program.

The program size is approximately 15,000 decimal words.

2. Description of Input Data

Input data can be stored in the block data subroutine and also input via four namelists in subroutine INPUT. Any data input always override data stored in the program.

Fortran namelists can be used to input any necessary data or titles for the WESS program. The names of these four namelists are: ONE, TWO, INVEST, and ANNUAL. Tables 4-2 through 4-5 define the variables in each namelist.



*N_{MIN} = MINIMUM NO OF SITES CONSIDERED AS A GROUP

Figure 4-2. Simplified Flow Chart

TABLE 4-2

INPUT VARIABLES IN NAMELIST ONE

1.	IROUTE	- Points to ROUTE analyzed; can have a value of 1, 2, 3 or 4 (1)*
2.	ISEN	- ScENario; can have a value of 1, 2, 3 or 4 (I) Points to scenario used.
3.	IANANO	- ANAlysis Number; four characters can be input which identify the analysis number. (A4 format)
4.	NOSITT	- Maximum number of sites per route (I)
5.	KSTART	- Minimum number of sites to be analyzed. Note: NOFIX≤ KSTART≤NOSITT (1)
6.	RMILES	- Route MILES (1)
7.	TDENEB	- Traffic DENsity East Bound (millions of tons), (R)**
8.	TDENWB	- Traffic DENsity West Bound (millions of tons), (R)
9.	GTTONS	- Gross Trailing TONS (I)
10.	NOLOC	- Number Of LOComotives (I)
11.	LOCTYP	- LOComotive TYPe (4A6 format)
12.	LOCUSE	- LOComotive USEage (R)
13.	LOCFMI	- LOComotive Fleet MIleage (R)
14.	SCENIO	- SCENarIO description title - (6A6, A4 format)
15.	FLYCOS	- FLYwheel COSt (R)
16.	IRNAME	- Route Title - up to 24 characters can be used to describe route. (4A6 format)
17.	IRROAD	- Railroad Title - up to 10 characters. (A6, A4 format).
18.	IPR	- Debug print flag - IPR = 0 gives no debug print & IPR = 3 gives maximum debug print (1).
19.	NOFIX	- Number Of sites to be FIXed (I).
20.	FIX	- Site numbers to be FIXed (always to be included in economic analysis). Up to 10 sites can be fixed (I).

* (I) indicates integer (no decimal point).

** (R) indicates real number (decimal point).

TABLE 4-3

INPUT VARIABLES IN NAMELIST TWO*

1.	ISITES	-	Array which contains numbers which Identify each SITE
2.	MILEPF	-	MILEPosts, From-array, (I)
3.	MILEPT	-	MILEPosts, To-array, (I)
4.	ESAVMP	-	Energy SAVed at railroad Metering Point. Units of KWH for scenario #3; otherwise the units are in gallons.(R).
5.	REGPL	-	REGeneration Power Level, MW (R)
6.	FLYSC	-	FLYwheel Storage Capacity, MWH (R)
7.	STABLD	-	STAtion BuiLDing (constant), flywheel station costs ($M)** (R)
8.	ELEHEL	-	ELEctric HELpers (I)
9.	EHCREW	-	Electric Helper CREWs (I)

TABLE 4-4

INPUT VARIABLES IN NAMELIST INVEST***

1.	NEWLOC	-	Number of NEW LOComotives required. (I)
2.	COSNEW	-	COSt ($M) for each NEW locomotive (R)
3.	MODLOC	-	MODified LOComotives Required (I)
4.	COSMOD	-	COSt ($M) for each MODified locomotive. (R)
5.	LOCTRA	-	Number of LOComotives TRAnsferred. (I)
6.	COSTRA	-	COS ($M) for each locomotive TRAnsferred (R)
7.	ROUTEE	-	ROUTE Electrification $M. (R)
8.	COSEND	-	Route END of program COSt $M. (R)
9.	SITELE	-	SITe ELEctrification $M. (R)
10.	ELECHI	-	Cost of ELECtric Helpers per site, $M. (R)

* All input variables for namelist TWO represent arrays which require a value for each site.

** Dollars in Millions.

*** The variables input thru Namelist INVEST are all for initial investment.

TABLE 4-5

INPUT VARIABLES IN NAMELIST ANNUAL*

1.	CILMCS	-	Change In Locomotive Maintenance CostS (route dependent), $ per mile. (R)
2.	TCILMC	-	Total Change In Locomotive Maintenance Cost for route, $M. (R)
3.	EMATPM	-	Route Electrification Maintenance, $M per mile. (R)
4	TEMTPM	-	Total Route Electrification Maintenance, $M. (R)
5.	DFSMPG	-	Diesel Fuel Saving (train movement & route dependent) $ Per Gal. (R)
6.	TDFSTM	-	Total route Diesel Fuel Saving (Train Movement) $M. (R)
7.	DFSIPG	-	Diesel Fuel Saving (train idling & route dependent) $ Per Gal. (R)
8.	TDFSTI	-	Total route Diesel Fuel Saving (Train Idling) $M. (R)
9.	SAVLRP	-	SAVing in Locomtive RePlacement, $ per locomotive, route dependent. (R)
10.	TSAVLR	-	Total SAVings in Locomotive Replacement, route dependent, $M. (R)
11.	ELEENE	-	ELEctrical ENErgy, route dependent, $M. (R)
12.	ADDLAB	-	ADDitional LABor, route dependent. $M. (R)
13.	NYRCON	-	Number of YeaRs CONsidered after Jan 1, 1990, YRS. (I)
14.	DISCON	-	DISCOuNt rate, fraction. (R)
15.	EHELPM	-	Electric HELPer Maintenance per site, $M. (R)
16.	ADLABR	-	ADditional LABoR per site, $M. (R)
17.	RPEAKD	-	Site Reduction in PEAK Demand, $M. (R)
18.	EMAINT	-	Electrification MAINTenance per site, $M. (R)

* Data for ANNUAL cost & credits.

ECONOMIC VARIABLES

It can be seen from the above that the costs and credits for the system application have been considered as those that are route-dependent and those that are site-dependent.

Route-Dependent Costs and Credits

(a) New Electric Locomotives--Dependent on the traffic flows between classification yards and applies only to economic scenario 4.

(b) Modified Locomotives Required--As in item (a), dependent on traffic flow between classification yards.

(c) Locomotives Transferred--Reflects reduction in locomotive fleet size owing to introduction of WESS locomotives. Each transferred locomotive is assumed to be worth half the new cost.

(d) Route Electrification--Considered only in scenario 4, when whole route electrification is applied.

(e) Saving in Locomotive Replacement--Based on not having to replace as many locomotives each year due to the reduction in fleet size.

(f) Change in Locomotive Maintenance Costs--Dependent on change in number or type of locomotive considered.

(g) Electrification Maintenance--Only applicable in scenario 4, where new electrification is installed throughout.

(h) Electrical Energy--Only applicable in scenario 4, where diesel oil consumption is replaced by electrical energy considered over the entire route.

(i) Diesel Fuel Saving (Train Movement)--Only applicable to scenario 4, as in item (h) above.

(j) Diesel Fuel Saving (Train Idling)--Applies when the number of diesel locomotives in the fleet is reduced and unnecessary idling is eliminated.

(k) Additional Labor--Charges WESS with the additional labor required at classification yards for changing motive power, which would normally run through.

Site Dependent Costs and Credits

(a) Flywheel Station--Includes building, flywheel, flywheel machine, and flywheel converter.

(b) Site Electrification--includes catenary signaling, utility tie-in, and substation.

(c) Electric Helpers--Dependent on traffic flow and grade length and applies only to scenario 2.

(d) Electric Helper Maintenance--Estimated at $0.35/mile and applies only to scenario 2.

(e) Additional Labor--Includes manpower for the electric helpers.

(f) Energy Saving at the Railroad Metering Point--Calculated from TPC and assigned the appropriate monetary value.

(g) Reduction in Peak Demand--The flywheels have been sized to accommodate a reduction in peak demand of 6 Mw at each location. This savings applies only to scenarios 3 and 4.

(h) Electrification Maintenance--Where electrification is available only at the site (scenarios 1 and 2), then electrification maintenance is site-dependent.

Sensitivity Analysis

The use of the computer enabled AiResearch to carry out a sensitivity analysis on the following cost elements, which were identified as being of particular interest in the study:

Flywheel cost $\pm$50 percent

Dual-mode locomotive cost $\pm$50 percent

Energy saving $\pm$25 percent, -50 percent

ECONOMIC ANALYSIS STRUCTURE

Before using the economics program it is necessary to determine the ruling grades so that when claiming a reduction in locomotives, the remaining locomotives are able to negotiate the route at the required speed or journey time.

Having inputted all the variables listed, the program will then analyze all the grade information and output the results of each economic analysis technique for a diminishing number of grades. The selection procedure is based on the combination of grades that will give the next best (or worst) ROI so that the ROI shown represents the best possible combination of grades for those grades tified on that route.

The output from the computer program is contained in Volume 3. A detailed description of the sensitivity analysis applied to each route is contained in section 5 of the present volume.

CALCULATION OF ECONOMIC DATA

Motive Power Related Data

Consider a route of length "L" miles carring a total traffic of T MGTT/year, operating with locomotives that achieved a utilization of n locomotives/10^9

GTTM/year. Therefore, the number of locomotives (N) required to operate the route is given by

$$N = n\ TXL \times 10^{-3}$$

As previously discussed, the value of n is dependent on the locomotive type under consideration and the dispatching policy of the railroad. Having established the existing fleet size, it is possible then to determine the reduction in fleet size due to either the dual-mode, electric helper, or electrified railroad scenarios, and this gives the number of locomotives to be transferred and modified.

The determination of the reduction in the diesel fleet allows the maintenance and idling fuel saving to be calculated. Knowing the ton miles/year for the route and the average train size, it is possible to determine the total locomotive miles for each scenario and the change from the existing condition. Locomotive maintenance costs have been obtained from reference 5.

It is well known that diesel locomotives spend long periods idling due to many operational considerations such as battery condition, climate, etc. Reference 8 provided information to formulate Table 4-6, which shows that a typical SD40 locomotive spends 12 hr per day idling. If the locomotive fleet is reduced, then so is the total amount of fuel consumed during idling. AiResearch judged that of the 12 hr spent idling, 8 hr of this could be termed unnecessary (i.e., not while the locomotive is on the road). Therefore, if the fleet is reduced in size, the saving due to elimination of idling would be conservatively calculated as:

locomotives saved × 5.5 gal/hr × 8h/day × 310 day/yr

TABLE 4-6

EXAMPLE OF A TYPICAL DAILY EMD SD40 DIESEL LOCOMOTIVE UNIT OPERATION

Throttle Position	Delivered Horsepower	Operation, hrs	Fuel Rate, gal/hr
8	3100	3.6	168
7	2550	1.0	146
6	2000	1.0	108
5	1450	1.0	79
4	950	1.0	57
3	500	1.0	41
2	200	1.0	25
1	58	1.2	7.5
Idle		12.0	5.5
Dynamic Brake		1.2	25
Total	-	24.0	-

The diesel fuel saving due to train movement is derived directly from the AiResearch TPC and is applicable only in scenario 4.

To determine the number of electric helpers (and hence crews) required, it is necessary to know the average number of helpers per train (N), the journey time over the grade (T hours), and the total number of trains over the grade per hour (X). Then the number of helpers becomes the next highest integer multiple of N given by the product of NTX.

The electric helper maintenance is dependent on the annual milage and was assumed to be $0.35/mile, this being based on the AiResearch judgment that the electric helper, because of its usually remote location, would cost more to maintain than the $0.30/mile for a standard electric locomotive (ref 5).

The cost of the electric helper locomotive, including an allowance of 10 percent for centrally held spare locomotives, was based on $191/rph (ref. 5) giving a locomotive cost of $1.43 million.

The use of run-through agreements, allowing the locomotives of one railroad to carry on to the ultimate train destination on other railroad tracks, is increasing. Therefore, in this study, where running through is a normal practice, it has been assumed the 20 percent of the trains must have out-of-course motive power changes, and this has been factored into the economic analysis by allowing 2 man-hours for each change of motive power.

Flywheel-Related Data

The cost of the flywheel, flywheel machine, flywheel converter, and flywheel building have been derived in Section 3. Knowing the energy and power levels, the cost of all flywheel-related items is calculable.

Electrification-Related Costs

As already discussed, initial costs of railroad electrification have been determined by Bechtel, Inc. on a per-route mile basis. Maintenance costs were derived from reference 5 on a per-route mile basis. Therefore, knowing the length of the site or route under consideration, the all-electrification costs are available.

SECTION 5

WESS APPLICATION TO SPECIFIC RAILROADS

Based on the location study, one may logically conclude that rather than apply WESS to specific grades, prime consideration should be given to routes that lie between major classification yards. The four such routes considered in the study are analyzed below.

Generally, the results of the economic analysis show that WESS applied to today's railroads has an attractive return on investment (ROI). Except for the special case of BM&LP, these WESS installations provide an ROI in excess of 20 percent. Other routes, such as those identified in the location study and those on railroads not considered in this study, would be expected to reflect this minimum ROI.

TRAIN PERFORMANCE CALCULATOR

The train performance calculator (TPC) developed by AiResearch for the analysis of WESS is a digital computer program that simulates the operation of multiple trains over a railroad route. The TPC contains the characteristics of the locomotives and rolling stock as internal program parameters. The route and schedule data are input to the program. The program computes speed, time, distance, acceleration, locomotive input power, efficiency, power factor, apparent power, and energy input from the pantograph. It also computes tractive effort during motoring and braking from the propulsion and friction braking systems. It performs analysis of specific energy consumption in watt-hours per ton-mile for each train and accumulates the power and energy required for all trains operating over specific sections of the route to define substation power versus time and energy requirements. Simulation of up to 100 trains over a 24-hr period of operation can be performed by the program. The program outputs the time history of a selected train over the route and a listing of 5-min power demands for each subdivision of the route (up to 10 subdivisions); it also lists the 5-min power demands over the total route for an entire 24-hr period. Total energy requirements for each division and the total route also are output for the 24-hr period.

Complete details of the program, including a program listing, program nomenclature, key algorithms, and input data requirements are presented in Appendix F.

ATCHISON TOPEKA AND SANTA FE RAILROAD

The Los Angeles-Belen route, which forms part of the AT&SF major artery, is characterized as a 100-percent, high-speed manifest service that operates typically at 2.6 hp/GT; it currently has a total traffic level of some 50 $\times$ 10^6 GTT/year. The route negotiates the Southern Rocky Mountains and Southern California mountains during its 900 route miles of predominantly double track. A total of 18 potential WESS sites has been identified on this route.

Traffic is expected to increase at an annual average rate of 2 percent until at least 1990 (ref 10). Traffic projections beyond 1990 are not available and therefore zero growth has been assumed after 1990. The results of the power and energy calculations are shown in Table 5-1 for the entire route.

TABLE 5-1

ANNUAL ENERGY SAVING FOR LOS ANGELES-BELEN ON 18 WESS SITES

Scenario	Annual Energy Savings at 1990 Traffic Levels
Dual mode	27.82 Mgal
Electric helper	25.04 Mgal
Electrified railraod	291,000 Mwhr

The results of the sensitivity analyses are discussed below.

Dual-Mode Locomotive Scenario

The AT&SF dispatching policy requires that medium-sized trains attain a minimum speed on the ruling grade of 17.5 mph. To be conservative, it has been assumed that the dual-mode locomotive utilization will be 4.44 locomotives per 10^9 GTM/year, compared with 6.8 locomotives per 10^9 GTM/year for the existing diesel fleet.

Therefore, 395 diesel locomotives will be required in 1990 on this route, compared with 258 dual-mode locomotives. This results in a saving of 137 diesel locomotives that may be transferred to other duties. Assuming that locomotives are replaced on a 15-year cycle, the reduction in fleet size by 137 locomotives results in an annual saving of 9 replacement locomotives.

Other savings resulting from the reduction in fleet size are calculated in Section 4 and are tabulated in Volume 3.

1. Baseline (Analysis 1/1)

In this baseline analysis, the following assumptions were made:

- Flywheel, $0.270 million/Mwhr stored
- Dual-mode conversion, $0.211 million
- Energy saving, as calculated by TPC

Figure 5-1 shows the results of the baseline analysis and it can be seen that the ROI increases as the number of locomotives decreases. This is because the major savings are achieved by the route-dependent rather than the site-dependent factors. The decision as to how many grades would be equipped with WESS depends on:

(a) Funding level available

(b) Whether other projects exist that show a better ROI. That is, there may not be a project which can show an ROI greater than that for seven locations, in which case seven locations would be equipped.

2. Flywheel Cost Sensitivity (Analysis 1/2)

In this analysis, flywheel costs ranging ±50 percent from the baseline are assumed; the results of the study are shown in Figure 5-2. The ROI is not significantly affected by the change in flywheel cost because the major portion of the system costs is route-dependent and constant.

3. Dual-Mode Locomotive Cost Sensitivity (Analysis 1/3)

In this analysis, it is assumed that costs of the dual-mode locomotive range ±50 percent from the baseline analysis, as shown in Figure 5-3. The 50 percent increase in locomotive cost results in a 15 percent change in ROI. This is the most sensitive variable.

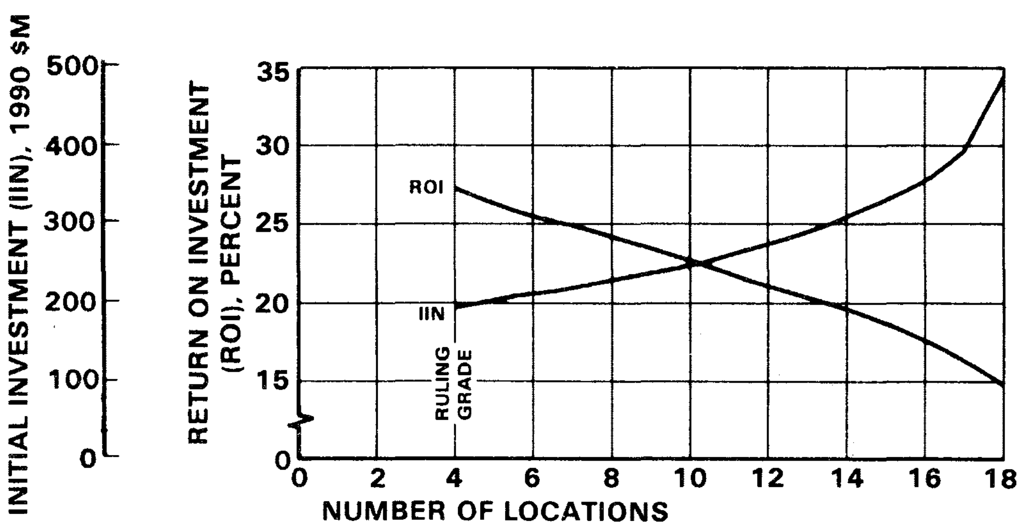


Figure 5-1. Los Angeles to Belen Dual-Mode Locomotive: Baseline Case

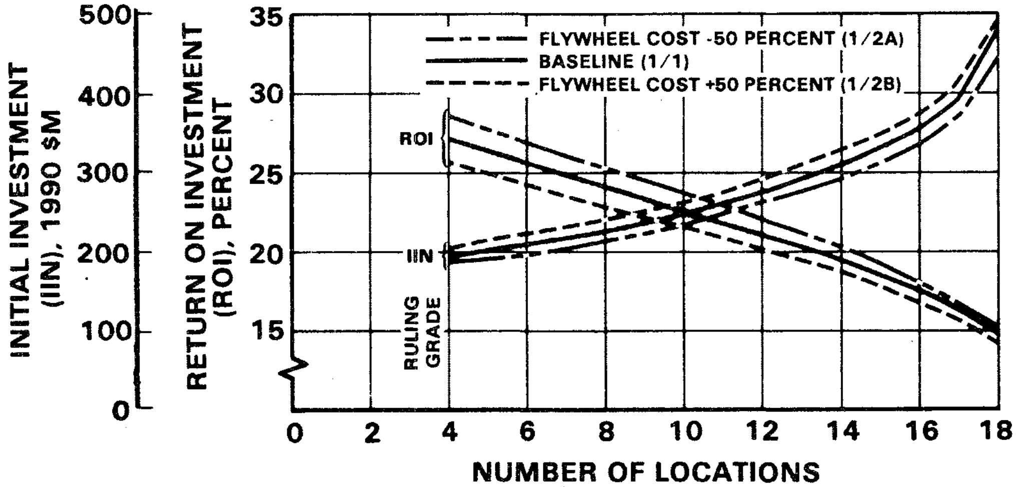


Figure 5-2. Los Angeles to Belen Dual-Mode Locomotive Sensitivity Analysis: Flywheel Cost

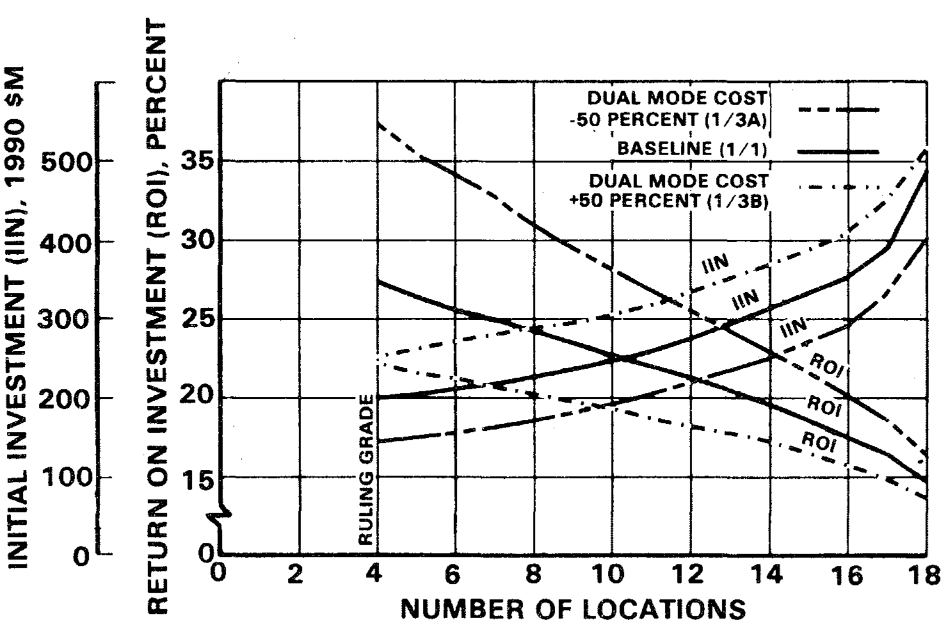


Figure 5-3. Los Angeles to Belen Dual-Mode Locomotive Sensitivity Analysis: Dual-Mode Locomotive Cost

4. Energy Saving Sensitivity (Analysis 1/4)

In this analysis, it is assumed that energy saving levels are ± 25 percent and -50 percent of the baseline analysis. The purpose of this analysis is to test the sensitivity of the results to differences in railroad policy and driving techniques as far as the use of electric braking is concerned. The results are shown in Figure 5-4 and it may be seen that the results are not very sensitive to the level of energy saving assumed because most cost and credit elements are route-dependent.

5. Dual-Mode Locomotive Only (Analysis (1/5)

The purpose of this analysis is to define the benefit of the WESS when applied to a dual-mode railroad. The results are shown in Figure 5-5, from which it can be seen that the addition of WESS to a project to convert a railroad to dual-mode operation would result in an increase in the ROI of 12.5 percent.

Electric Helper Scenario

The same locomotive fleet economies calculated from the dual-mode locomotive scenario apply to this scenario. The increase in journey time resulting from this method of operation has not been quantified due to lack of information from the railroad.

1. Baseline (Analysis 2/1)

In this baseline analysis, the following assumptions are made:

- Flywheel cost, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

Figure 5-6 shows the results of the baseline analysis and it can be seen that, as in the case of the dual-mode locomotive, the ROI increases as the number of locations decreases. The logic of the dual-mode locomotive scenario also applies to this scenario. The relatively low ROI (16 percent maximum) and the inept operations procedure involved make it doubtful whether this scenario would be considered past this study. Examination of Figure 5-6 shows that the ROI steadily decreases until a negative value is reached. These values have not been plotted because the computer program was not equipped to deal with negative ROI's and the results may be erroneous.

2. Flywheel Cost Sensitivity (Analysis 2/2)

For this analysis, it was assumed that flywheel costs varied ±50 percent from the baseline. As shown in Figure 5-7, the ROI is not significantly affected by the change in flywheel cost because most of the flywheel costs are route-dependent and constant.

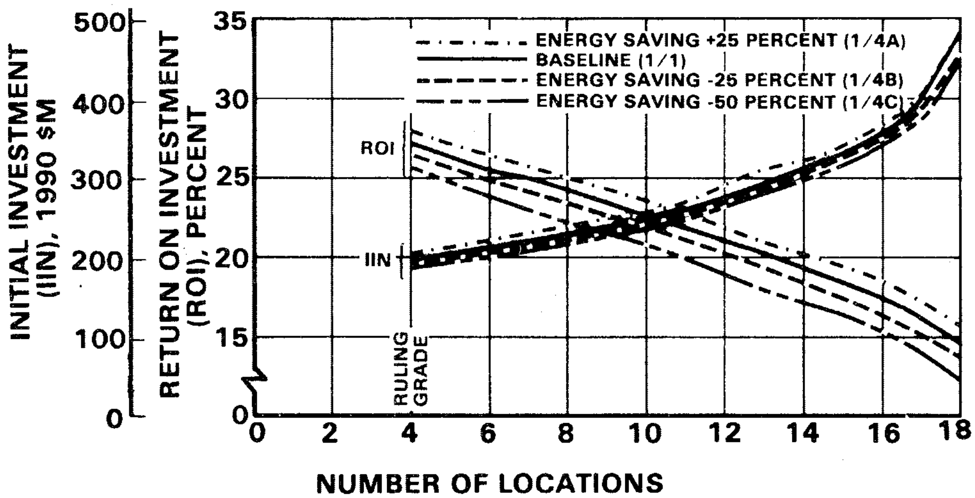


Figure 5-4. Los Angeles to Belen Dual-Mode Locomotive Sensitivity Analysis: Energy Saving

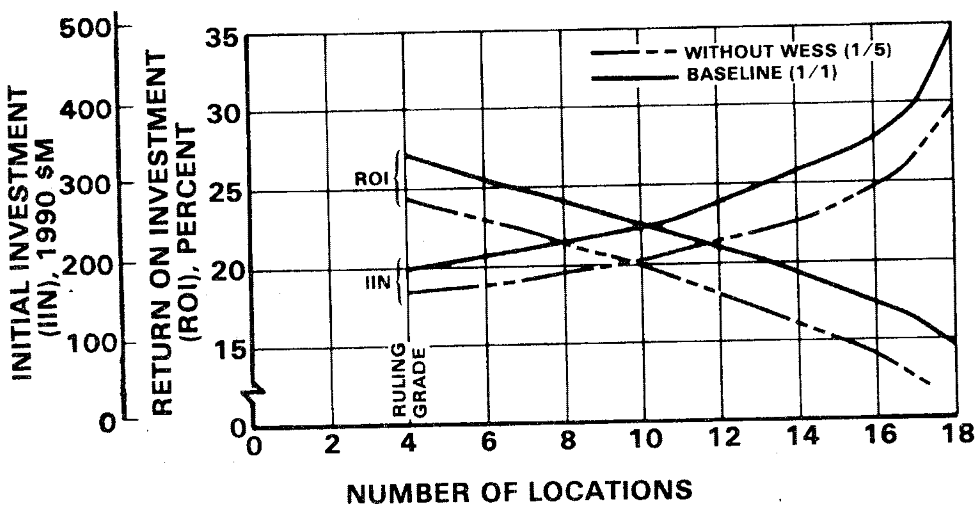


Figure 5-5. Los Angeles to Belen Dual-Mode Locomotive Only

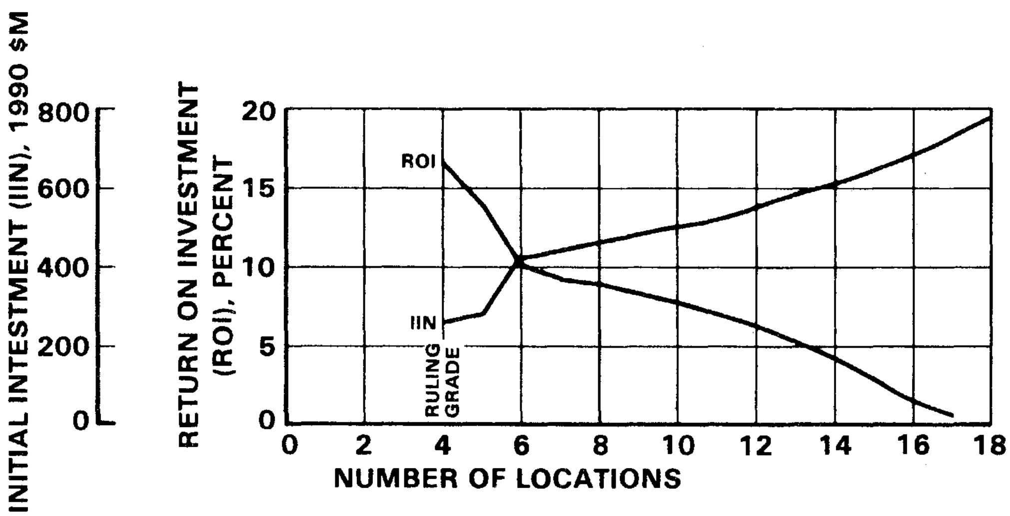


Figure 5-6. Los Angeles to Belen Electric Helper: Baseline Case

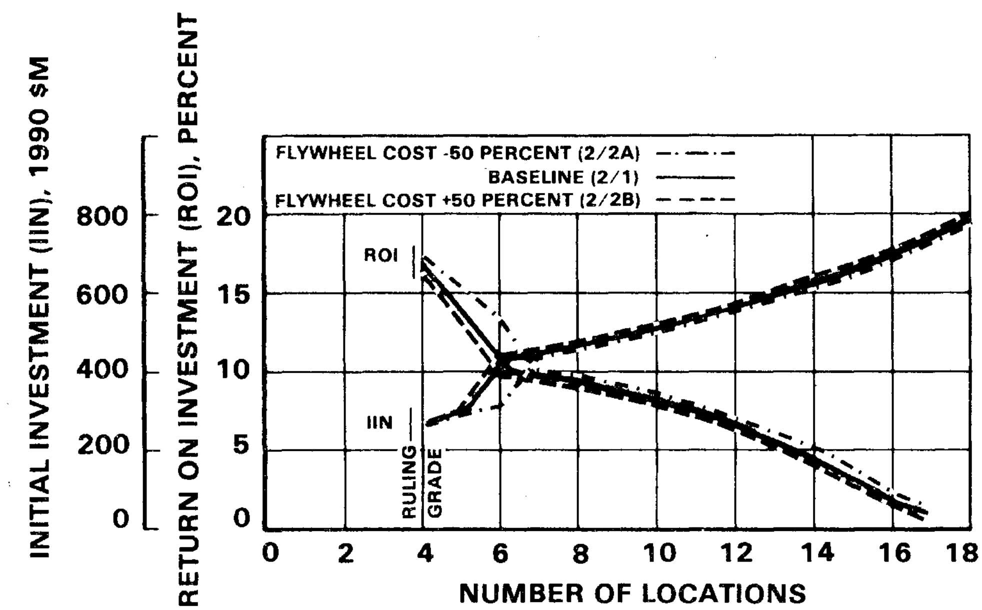


Figure 5-7. Los Angeles to Belen Electric Helper Sensitivity Analysis: Flywheel Cost

3. Energy Saving Sensitivity (Analysis 2/3)

Here energy savings ranging ±25 percent and -50 percent from the baseline analysis were assumed. From Figure 5-8, it may be seen that the results are not unduly affected by the variation in flywheel cost.

4. Electric Helper Only (Analysis 2/4)

The purpose of this analysis is to define the benefit of WESS when applied to a railroad that makes extensive use of electric helpers. It will be seen from Figure 5-9 that for the case of ruling grades only, the addition of WESS to a project to implement the use of electric helpers at the ruling grades increases the ROI by 11 percent. The effect is much greater when considering less attractive grades.

Electrified Railroad Scenario

Assuming no change in the AT&SF dispatching policy and the average locomotive utilization of 3.6 locomotives per 10^9 TM/year, 209 electric locomotives will be required to operate this route in 1990. Also, because they are assumed to exist, these locomotives will require modification to a regenerative system. Because the base performance at the locomotive remains unaltered, there is no reduction in the fleet size.

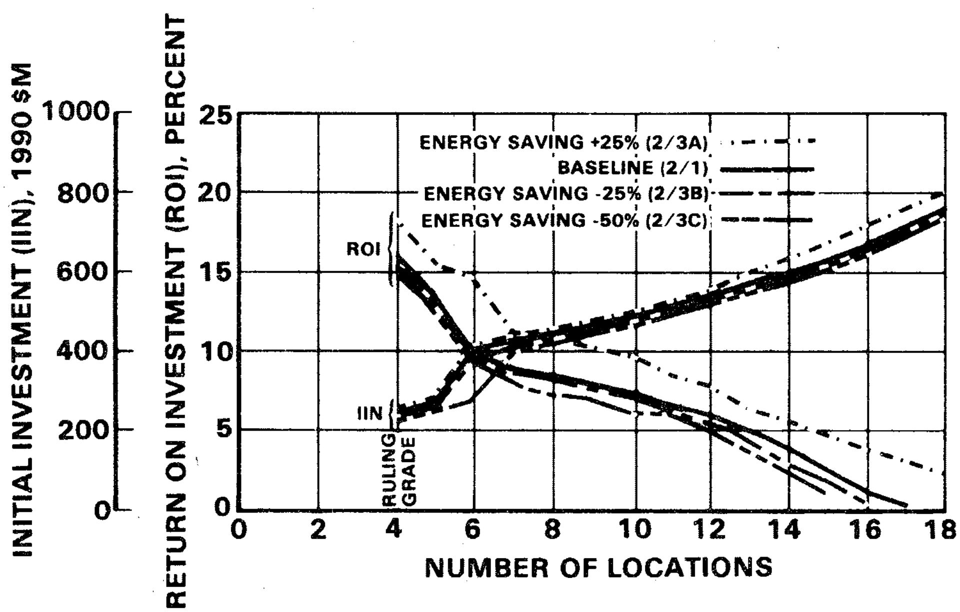


Figure 5-8. Los Angeles to Belen Electric Helper Sensitivity Analysis: Energy Saving

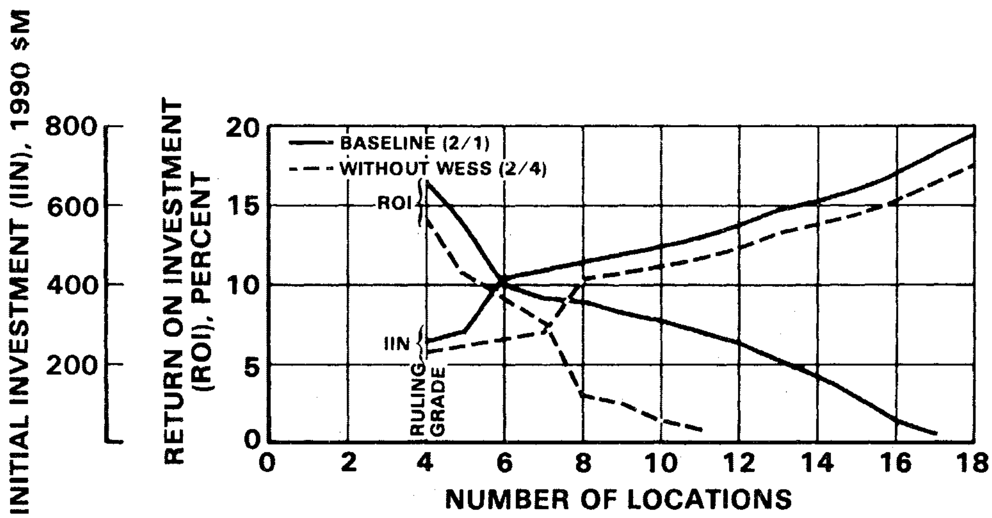


Figure 5-9. Los Angeles to Belen, Electric Helper Only

1. Baseline (Analysis 3/1)

In the baseline analysis, the following is assumed:

- Flywheel cost, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

Figure 5-10 shows the results of the baseline analysis and it can be seen that as the number of locations increases, so does the ROI until a maximum value would have been reached if more grades had been included. (AiResearch did not consider grades that gave an energy saving of less thant 450 kwhr). This maximum ROI, estimated to be 23.5 percent, occurs when the weighting of the site-dependent costs and savings is the same as the weighting of the route-dependent costs in the ROI calculation. It is because the site-dependent costs and savings predominate for the lower number of locations that the ROI increases, whereas in the two scenarios previously considered, route-dependent elements predominated throughout.

2. Flywheel Cost Sensitivity (Analysis 3/2)

In this analysis, flywheel costs ranging ±50 percent from the baseline were assumed. As shown in Figure 5-11, the ROI is not significantly affected by the increased cost of the flywheel, although it will be seen that the optimum ROI is achieved due to the increased site-dependent cost.

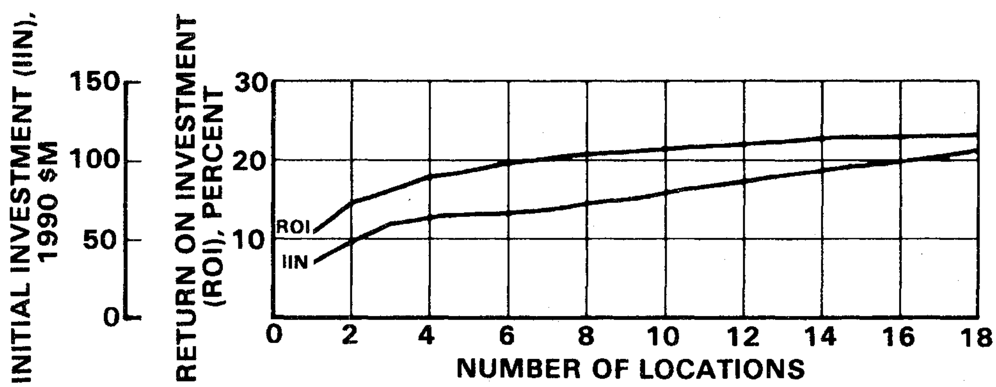


Figure 5-10. Los Angeles to Belen Electrified Railroad: Baseline Case

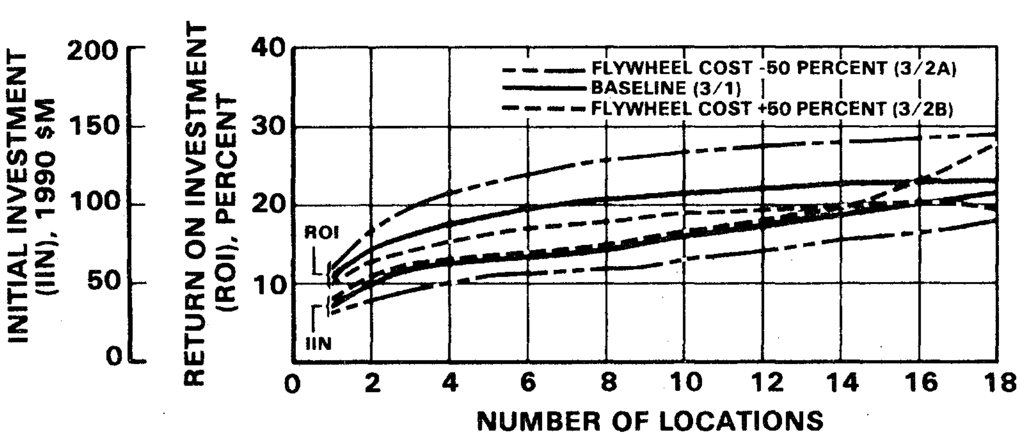


Figure 5-11. Los Angeles to Belen Electrified Railroad
Sensitivity Analysis: Flywheel Cost

3. Energy Saving Sensitivity (Analysis 3/3)

Here, it was assumed that energy savings were ±25 percent and -50 percent of the baseline analysis. As shown in Figure 5-12, the effect on the ROI was insignificant.

Concurrent Electrification and WESS

As for the electrified railroad scenario, it is assumed that the AT&SF dispatching policy is unaltered by the changeover from diesel to electric operation. This means that in 1990, some 395 diesel locomotives in use on this route may be transferred and replaced by 209 electric locomotives. Each year, the replacement of 26 diesel locomotives will be saved.

Other savings resulting from the change in locomotive type (idling fuel and maintenance) are tabulated in Volume 3.

1. Baseline (Analysis 4/1)

In this baseline analysis the following is assumed:

- Flywheel, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

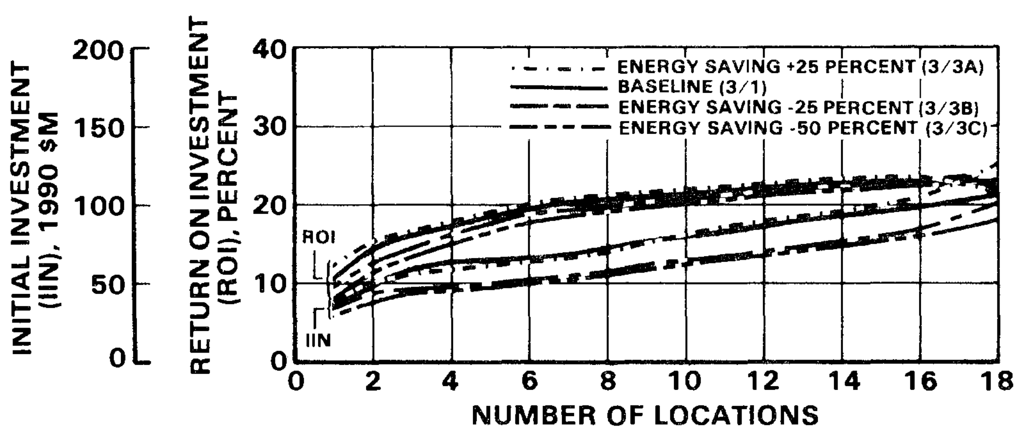


Figure 5-12. Los Angeles to Belen Electrified Railroad Sensitivity Analysis: Energy Savings

Figure 5-13 shows the large initial investment required when considering electrification and WESS. The ROI increases as the number of locations increases until a maximum ROI is reached at more than 18 grades. This is because the site-dependent savings are larger when compared with the site-dependent costs since electrification is route-dependent in this scenario. (See Volume 3.) The low ROI's determined for this scenario are put into perspective in the discussion of the "electrification only" case, para 4 below.

2. <u>Flywheel Cost Sensitivity (Analysis 4/2)</u>

In this analysis, flywheel costs of ±50 percent from the baseline were assumed. The results are shown in Figure 5-14, from which it can be seen that the flywheel cost does not unduly affect the ROI for WESS deployment.

3. <u>Energy Saving Sensitivity (Analysis 4/3)</u>

Here, energy savings of ±25 percent and -50 percent from the baseline were assumed. As shown in Figure 5-15, the maximum effect is to reduce the ROI for 18 locations by 7 percent, which is insignificant.

4. <u>Electrification Only (Analysis 4/4)</u>

The purpose of this analysis is to test the benefit of incorporating WESS at the same time as an electrification scheme is implemented. It may be seen from Figure 5-16 that the ROI can be increased by up to 22 percent if

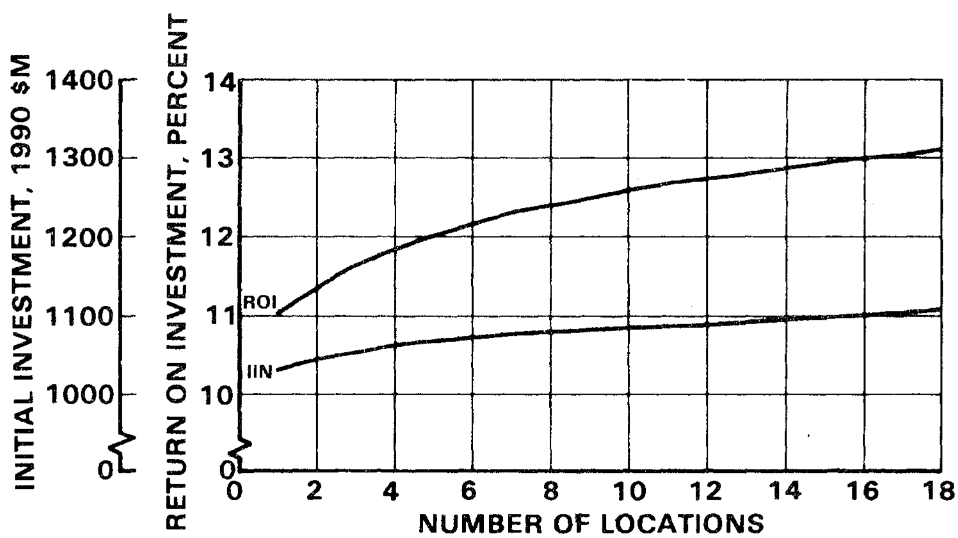


Figure 5-13. Los Angeles to Belen Concurrent Electrification and WESS: Baseline Case (4/1)

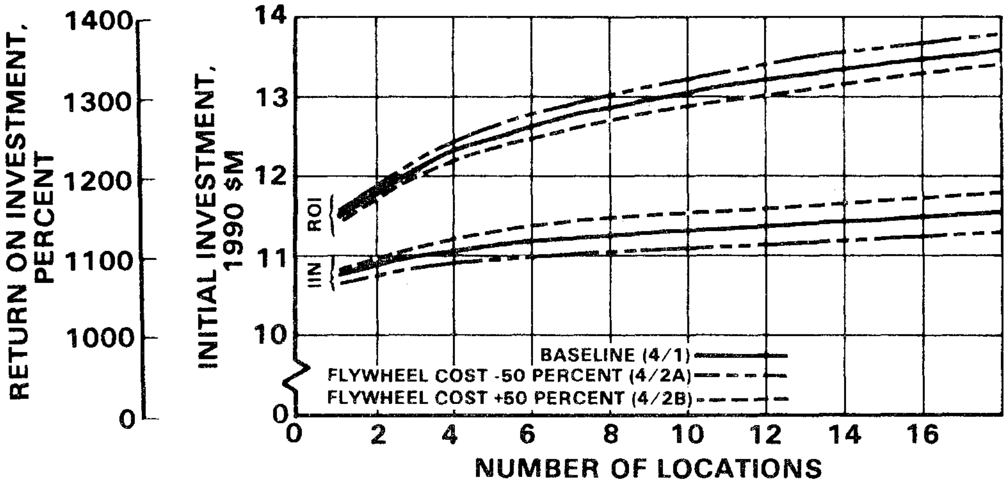


Figure 5-14. Los Angeles to Belen Concurrent Electrification and WESS Sensitivity Analysis: Flywheel Cost

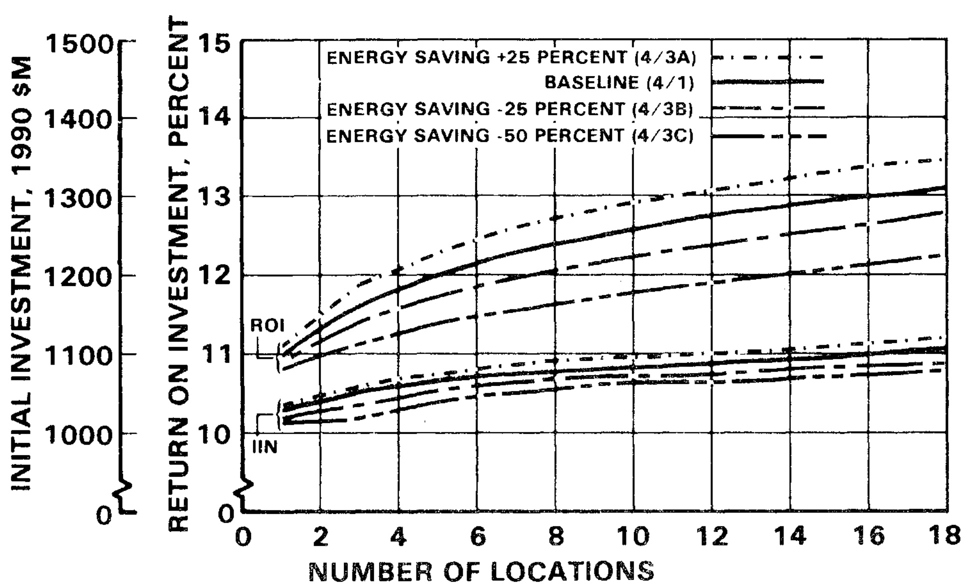


Figure 5-15. Los Angeles to Belen Concurrent Electrification and WESS Sensitivity Analysis: Energy Saving

WESS is added to the electrification scheme. It is known that typically, the railroad's own studies (but not necessarily for AT&SF on this route) generally show an ROI for electrification of 15 to 17 percent. The low value calculated in this economic study represents an extremely conservative approach and the assumption of worst-case conditions throughout.

Summary of WESS Application on AT&SF

The above analysis shows that WESS, when applied to a diesel railroad between Los Angeles and Belen using dual-mode locomotives, is economically attractive. The electric helper scenario is not economically attractive and would probably not be acceptable from the operational standpoint.

If the route were already electrified, WESS could be installed on at least 18 grades with an attractive ROI.

Should AT&SF decide to electrify this route, then the application of WESS would significantly enhance the economic justification for that electrification.

The only variable to which the results are particularly sensitive is the cost of the dual-mode locomotive. For this reason a detailed analysis was carried out to determine this cost (see Section 2 of this report).

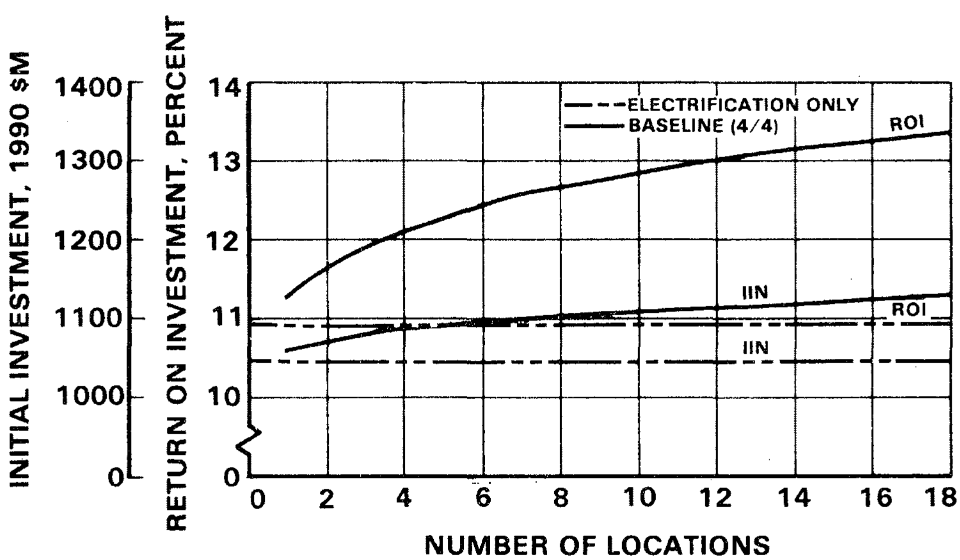


Figure 5-16. Los Angeles to Belen, Electrification Only

UNION PACIFIC RAILROAD

The Los Angeles-Salt Lake City route of UP is characterized as a mixed traffic route that operates at power/ratios of up to 5 hp/GT and that currently has a total traffic level of some 39 x 10^6 GTT/year. The route negotiates the Southern California mountains during its 782 route miles, which are predominantly single track. Ten potential WESS sites have been identified on this route.

Traffic is expected to increase at an average annual rate of 2 percent until at least 1990 (ref 10). Zero growth has been assumed beyond 1990. The results of the power and energy calculations are shown in Table 5-2 for the entire route.

TABLE 5-2

ANNUAL ENERGY SAVING FOR LOS ANGELES-
SALT LAKE CITY ON 10 WESS SITES

Scenario	Annual Energy Saving at 1990 Traffic Levels
Dual mode	22.04 Mgal
Electric helper	19.84 Mgal
Electrified railroad	237,000 Mwhr

The results of the sensitivity analyses are discussed below.

Dual-Mode Locomotive Scenario

The UP dispatching policy requires that medium-sized trains attain a minimum speed on the ruling grade of 17.5 mph. To be conservative, it has been assumed that the dual-mode locomotive utilization will be 4.44 locomotives per 10^9 GTM/year, compared with 6.8 locomotives per 10^9 GTM/year for the existing diesel fleet.

Therefore, 266 diesel locomotives will be required in 1990 on this route, compared with 174 dual-mode locomotives. This results in a saving of 92 diesel locomotives that may be transferred to other duties. Assuming that locomotives are replaced on a 15-year cycle, the reduction in fleet size by 92 locomotives results in an annual saving of 6 replacement locomotives.

Other savings resulting from the reduction in fleet size are calculated in Section 4 and are tabulated in Volume 3.

1. Baseline (Analysis 1/1)

In this baseline analysis, the following assumptions were made:

- Flywheel, $0.270 million/Mwhr stored

- Dual-mode conversion, $0.211 million

- Energy saving, as calculated by TPC

Figure 5-17 shows the results of the baseline analysis and it can be seen that the ROI increases as the number of locomotives decreases. This is because the major savings are achieved by the route-dependent rather than the site-dependent factors. The decision as to how many grades would be equipped with WESS depends on:

(a) Funding level available

(b) Whether other projects exist that show a better ROI. That is, there may not be a project that can show an ROI greater than that for seven locations, in which case seven locations would be equipped.

2. Flywheel Cost Sensitivity (Analysis 1/2)

In this analysis, flywheel costs ranging ±50 percent from the baseline are assumed; the results of the study are shown in Figure 5-18. The ROI is not significantly affected by the change in flywheel cost because the major portion of the system costs are route-dependent and constant.

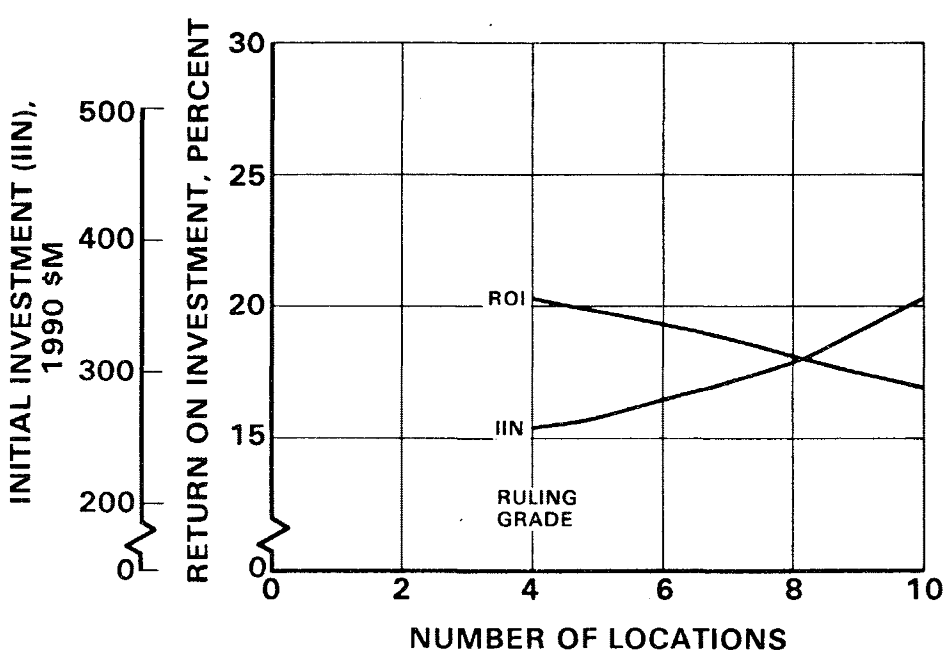


Figure 5-17. Los Angeles to Salt Lake City Dual-Mode Locomotive: Baseline Case

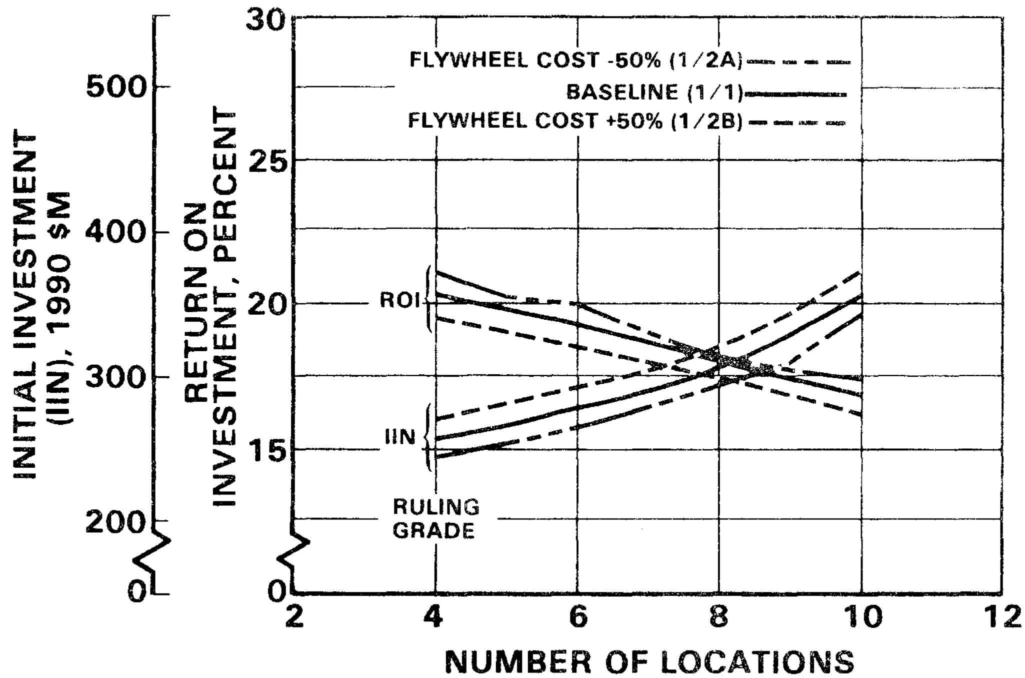


Figure 5-18. Los Angeles to Salt Lake City Dual-Mode Locomotive Sensitivity Analysis: Flywheel Cost

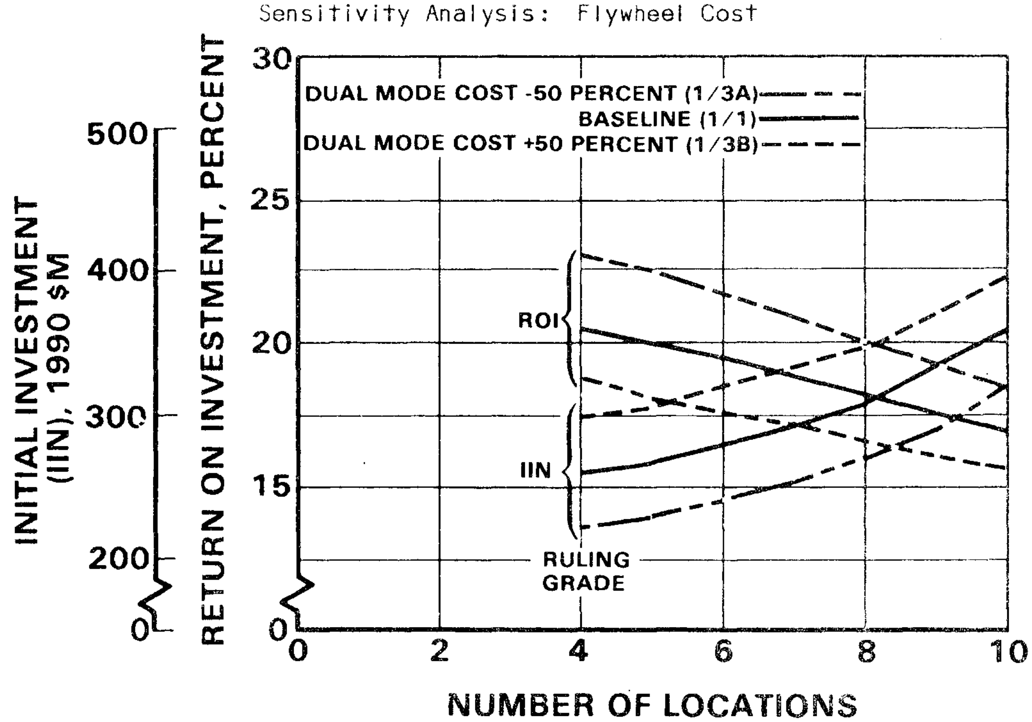


Figure 5-19. Los Angeles to Salt Lake City Dual-Mode Locomotive Sensitivity Analysis: Dual-Mode Locomotive Cost

3. Dual-Mode Locomotive Cost Sensitivity (Analysis 1/3)

In this analysis, it is assumed that costs of the dual-mode locomotive range ±50 percent from the baseline analysis, as shown in Figure 5-19. The 50 percent increase in locomotive cost results in a 10 percent change in ROI. This is the most sensitive variable.

4. Energy-Saving Sensitivity (Analysis 1/4)

Here, it is assumed that energy-saving levels are ± 25 percent and -50 percent of the baseline analysis. The purpose of this analysis is to test the sensitivity of the results to differences in railroad policy and driving techniques as far as the use of electric braking is concerned. The results are shown in Figure 5-20 and it may be seen that the results are not very sensitive to the level of energy saving assumed because most cost and credit elements are route-dependent.

5. Dual-Mode Locomotive Only (Analysis (1/5)

The purpose of this analysis is to define the benefit of the WESS when applied to a dual-mode railroad. The results are shown in Figure 5-21, from which it can be seen that the addition of WESS to a project to convert a railroad to dual-mode operation would result in an increase in the ROI of 21.5 percent.

Electric Helper Scenario

The same locomotive fleet economies calculated from the dual-mode locomotive scenario apply to this scenario. The increase in journey time resulting from this method of operation has not been quantified due to lack of information from the railroad.

1. Baseline (Analysis 2/1)

In this baseline analysis, the following assumptions are made:

- Flywheel cost, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

Figure 5-22 shows the results of the baseline analysis and it can be seen that, as in the case of the dual-mode locomotive, the ROI increases as the number of locations decreases. The logic of the dual-mode locomotive scenario also applies to this scenario. The relatively low ROI (5 percent maximum) and the inept operations procedure involved make it doubtful whether this scenario would be considered past this study. Examination of Figure 5-22 shows that the ROI quickly decreases until a negative value is reached. These values have not been plotted because the computer program was not equipped to deal with negative ROI's and the results may be erroneous.

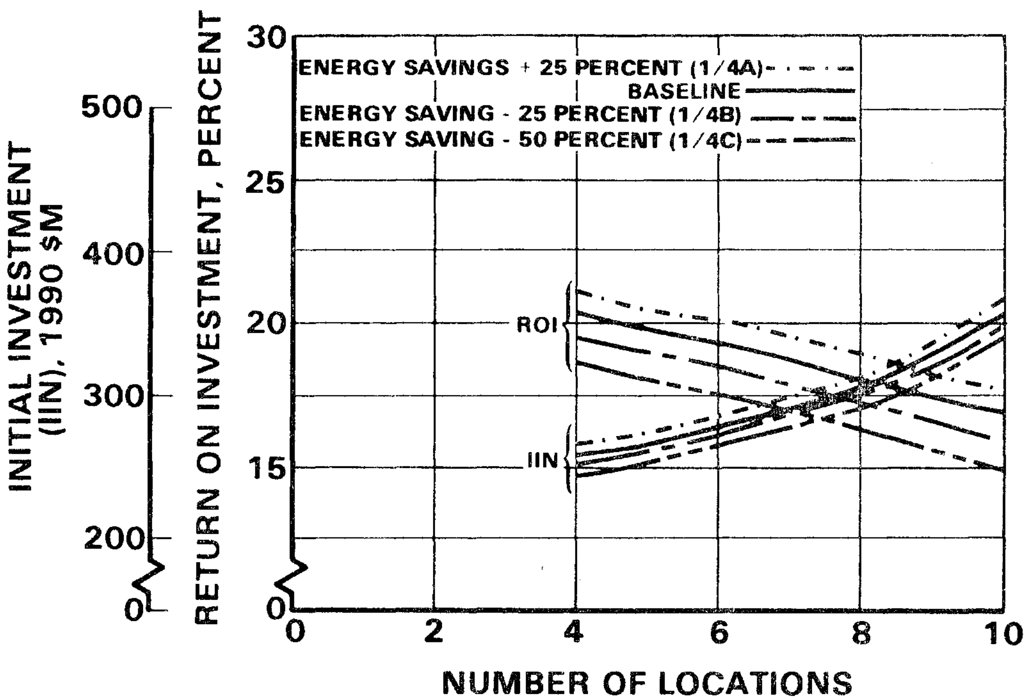


Figure 5-20. Los Angeles to Salt Lake City Dual-Mode Locomotive Sensitivity Analysis: Energy Saving

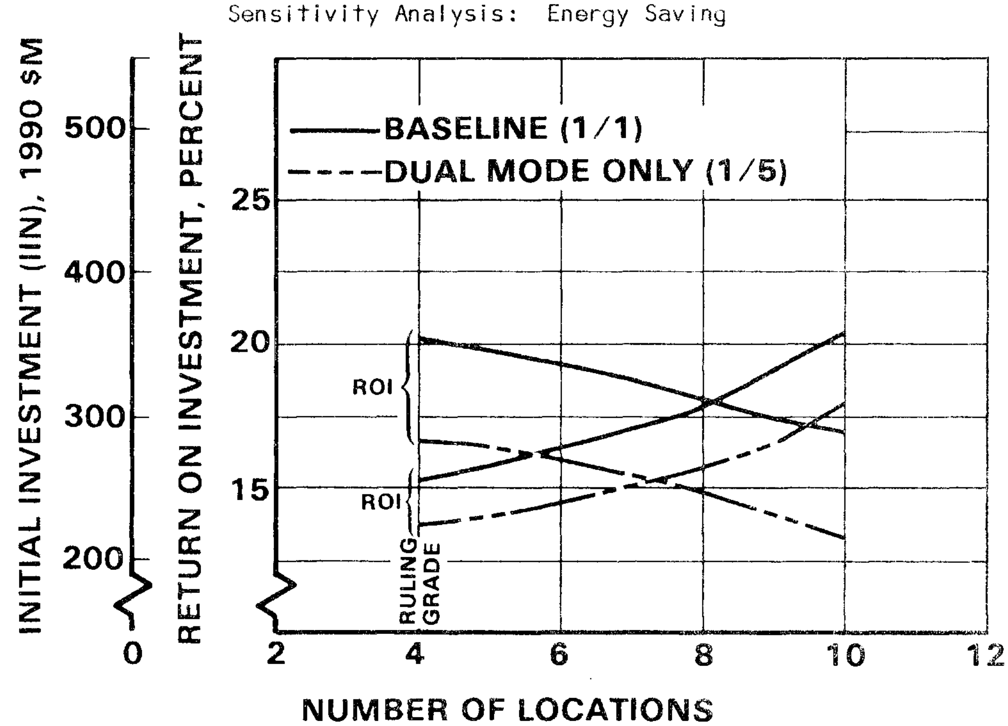


Figure 5-21. Los Angeles to Salt Lake City, Dual-Mode Locomotive Only

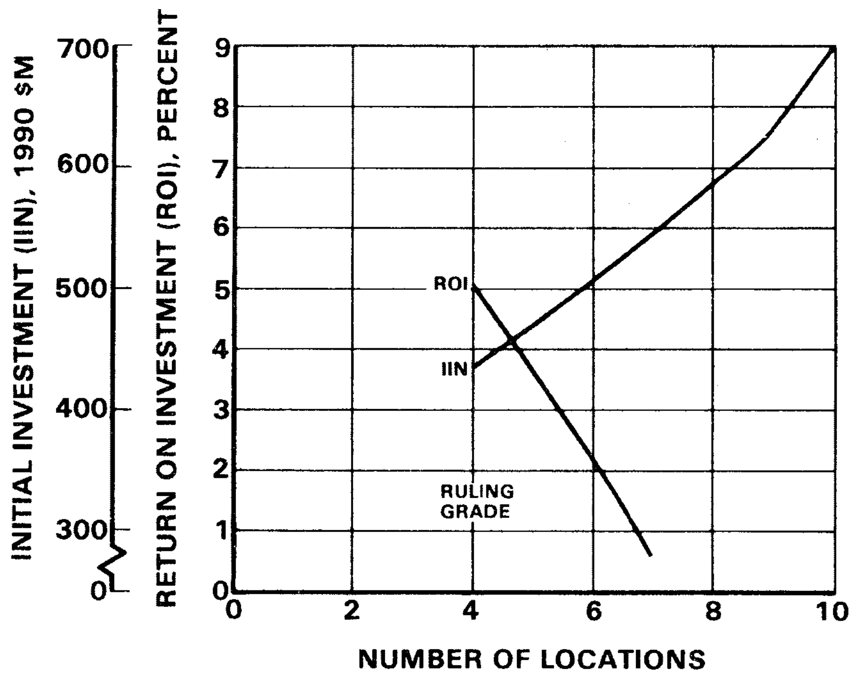


Figure 5-22. Los Angeles to Salt Lake City Electric Helper: Baseline Case

2. Flywheel Cost Sensitivity (Analysis 2/2)

For this analysis, it was assumed that flywheel costs varied ±50 percent from the baseline. As shown in Figure 5-23, the ROI is not significantly affected by the change in flywheel cost because most of the flywheel costs are route-dependent and constant.

3. Energy Saving Sensitivity (Analysis 2/3)

Here energy savings ranging ±25 percent and -50 percent from the baseline analysis were assumed. From Figure 5-24, it may be seen that the results are not unduly affected by the variation in energy saving at the low ROI's considered in this case.

4. Electric Helper Only (Analysis 2/4)

The purpose of this analysis is to define the benefit of WESS when applied to a railroad that makes extensive use of electric helpers. It will be seen from the analysis in Volume 3 that the electric helper scenario alone cannot achieve a positive ROI on the UP route, thus confirming the undesirability of this scenario.

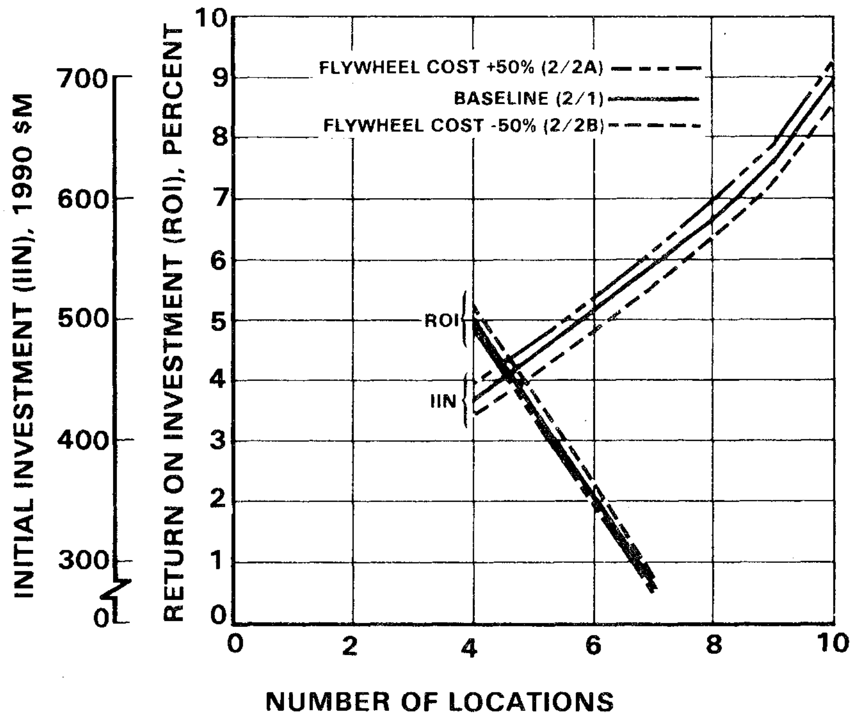


Figure 5-23. Los Angeles to Salt Lake City Electric Helper Sensitivity Analysis: Flywheel Cost

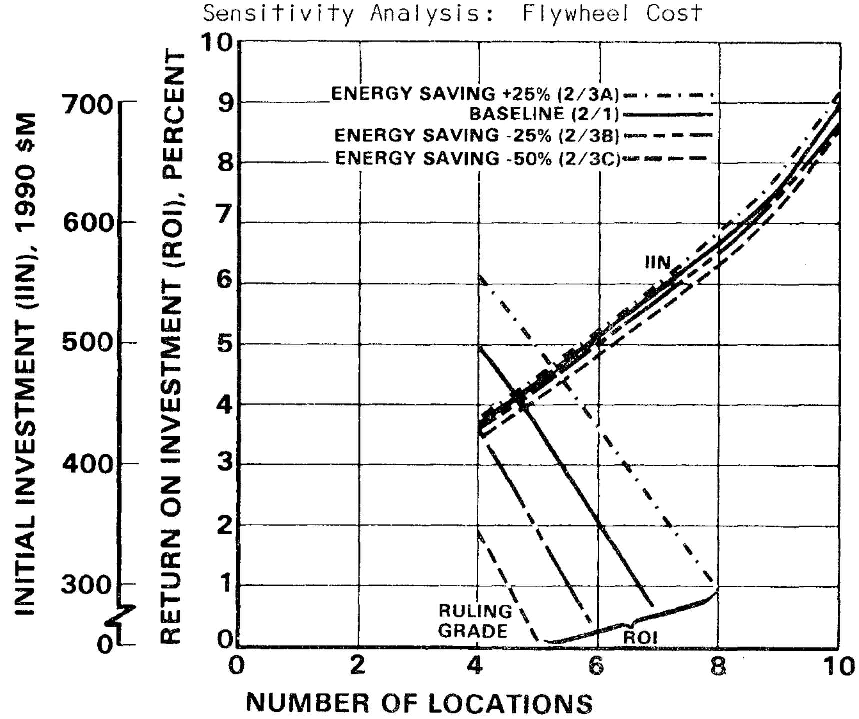


Figure 5-24. Los Angeles to Salt Lake City Electric Helper Sensitivity Analysis: Energy Saving

Electrified Railroad Scenario

Assuming no change in the UP dispatching policy and the average locomotive utilization of 3.6 locomotives per 10^9 TM/year, 141 electric locomotives will be required to operate this route in 1990. Also, because they are assumed to exist, these locomotives will require modification to a regenerative system. Because the base performance at the locomotive remains unaltered, there is no reduction in the fleet size.

1. Baseline (Analysis 3/1)

In the baseline analysis, the following is assumed:

- Flywheel cost, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

Figure 5-25 shows the results of the baseline analysis and it can be seen that as the number of locations increases, so does the ROI until a maximum value is reached at nine grades. This maximum ROI (23.33 percent) occurs when the weighting of the site-dependent costs and savings is the same as the weighting of the route-dependent costs in the ROI calculation. It is because the site-dependent costs and savings predominate for the lower number of locations that the ROI increases, whereas in the two scenarios previously considered, route-dependent elements predominated throughout.

2. Flywheel Cost Sensitivity (Analysis 3/2)

In this analysis, flywheel costs ranging ±50 percent from the baseline were assumed, as shown in Figure 5-26. The maximum deviation in ROI due to increased cost of the flywheel is less than 10 percent.

3. Energy Saving Sensitivity (Analysis 3/3)

Here, it was assumed that energy savings were ±25 percent and -50 percent of the baseline analysis. As shown in Figure 5-27, the effect on the ROI was not significant.

Concurrent Electrification and WESS

As for the electrified railroad scenario, it is assumed that the UP dispatching policy is unaltered by the changeover from diesel to electric operation. This means that in 1990, some 266 diesel locomotives in use on this route may be transferred and replaced by 141 electric locomotives. Each year, the replacement of 8 diesel locomotives will be saved.

Other savings resulting from the change in locomotive type (idling fuel and maintenance) are tabulated in Volume 3.

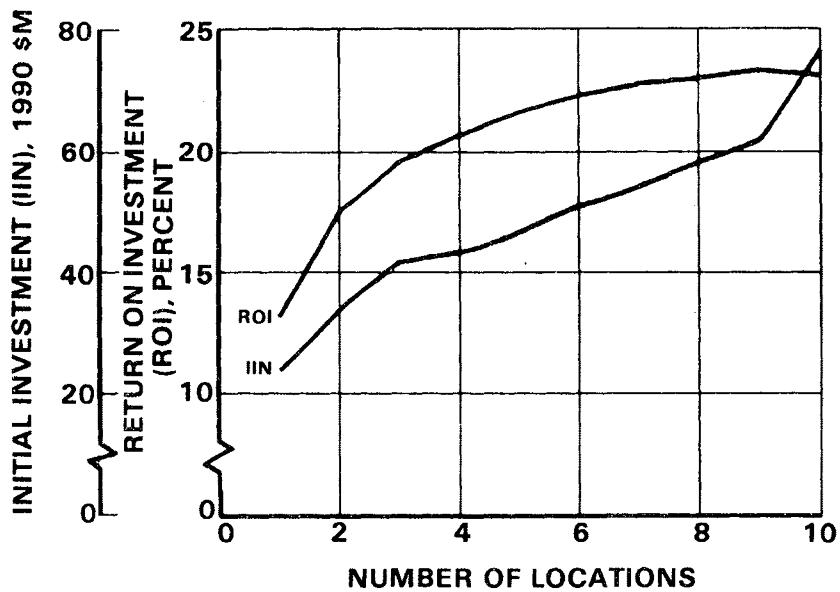


Figure 5-25. Los Angeles to Salt Lake City Electrified Railroad: Baseline Case

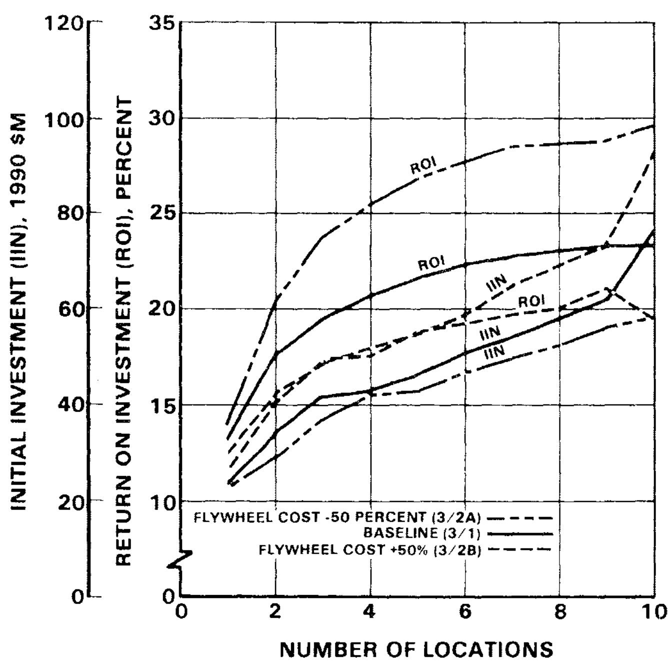


Figure 5-26. Los Angeles to Salt Lake City Electrified Sensitivity Analysis: Flywheel Cost

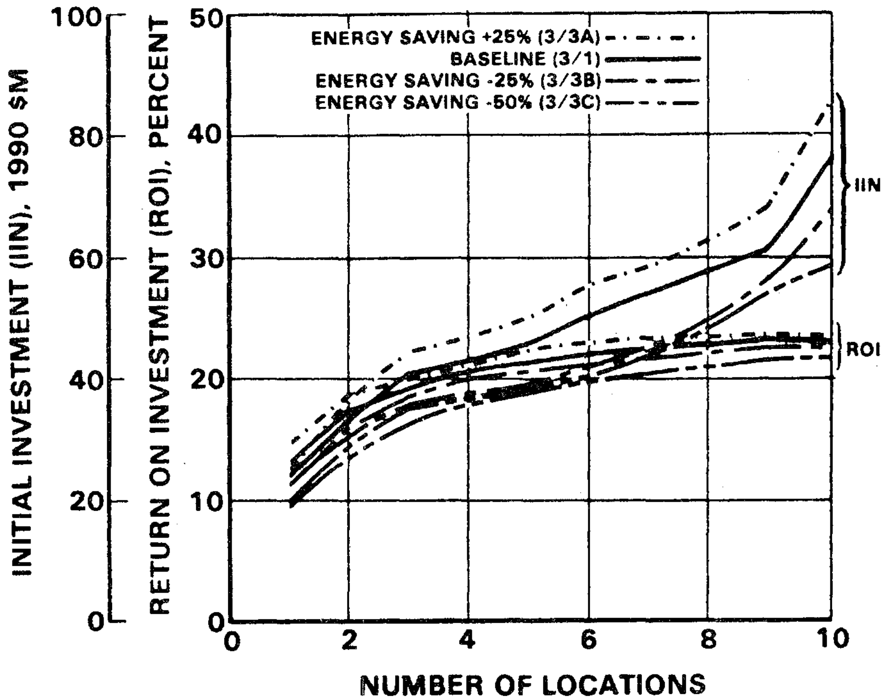


Figure 5-27. Los Angeles to Salt Lake City Electrified Railroad Sensitivity Analysis: Energy Saving

1. Baseline (Analysis 4/1)

In this baseline analysis the following is assumed:

- Flywheel, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

Figure 5-28 shows the relatively large initial investment required when considering electrification and WESS. The ROI increases as the number of locations increases until a maximum ROI is reached at more than 10 grades. This is because the site-dependent savings are larger when compared with the site-dependent costs since electrification is route-dependent in this scenario (see Volume 3). The low ROI's determined for this scenario are put into perspective in the discussion of the "electrification only" case, para. 4. below.

2. Flywheel Cost Sensitivity (Analysis 4/2)

In this analysis, flywheel costs of ±50 percent from the baseline were assumed. The results are shown in Figure 5-29, from which it can be seen that the flywheel cost does not significantly affect the ROI for WESS deployment.

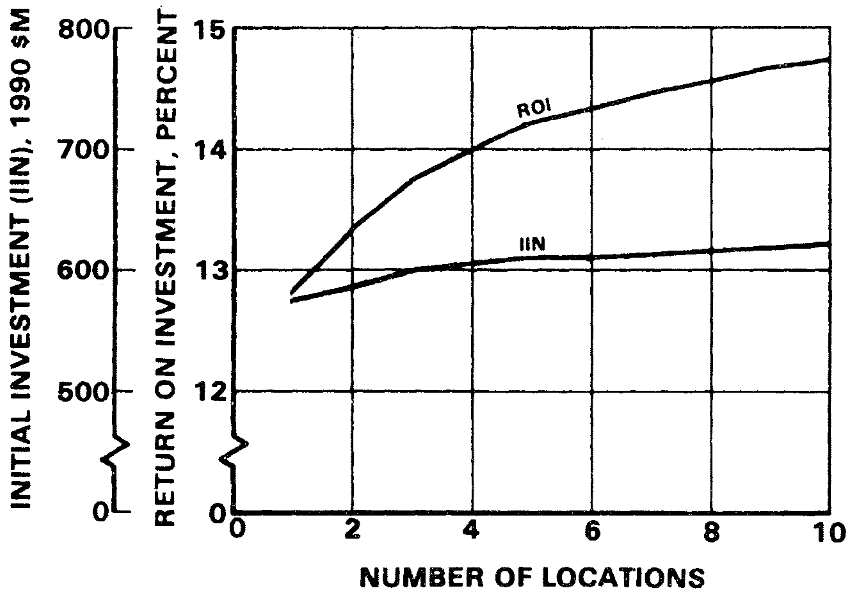


Figure 5-28. Los Angeles to Salt Lake City Concurrent Electrification and WESS: Baseline Case (4/1)

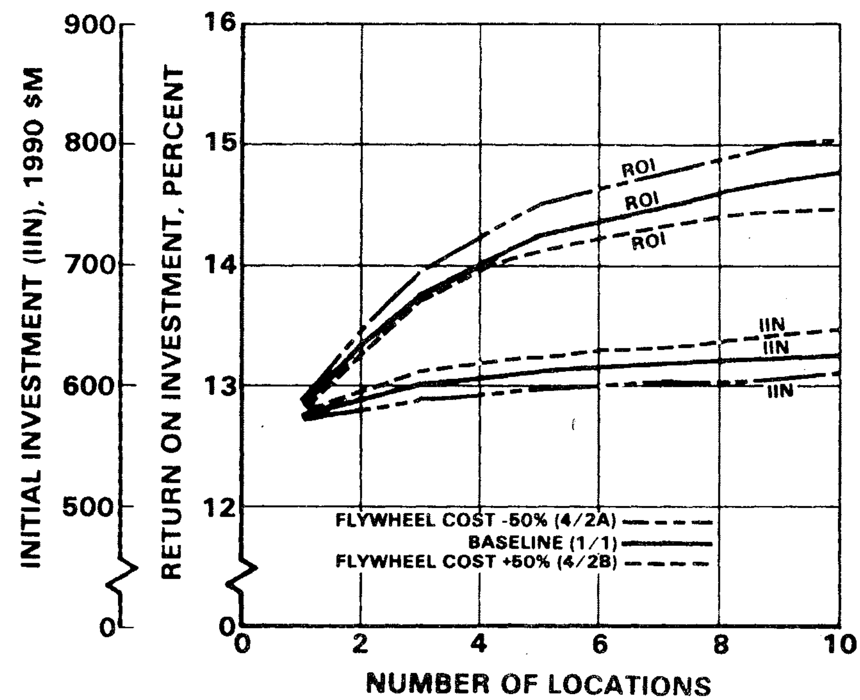


Figure 5-29. Los Angeles to Salt Lake City Concurrent Electrification and WESS Sensitivity Analysis: Flywheel Cost

3. Energy Saving Sensitivity (Analysis 4/3)

Here, energy savings of ±25 percent and -50 percent from the baseline were assumed. As shown in Figure 5-30, the maximum effect is to reduce the ROI for 10 locations by 6 percent, which is insignificant.

4. Electrification Only (Analysis 4/4)

The purpose of this analysis is to test the benefit of incorporating WESS at the same time as an electrification scheme is implemented. It may be seen from Figure 5-31 that the ROI can be increased by up to 16 percent if WESS is added to the electrification scheme. It is known that typically the railroad's own studies (but not necessarily for UP on this route) generally show an ROI for electrification of 15 to 17 percent. The low value calculated in this economic study represents an extremely conservative approach and the assumption of worst-case conditions throughout.

Summary of WESS Application on UP

The above analysis shows the WESS, when applied to a diesel railroad between Los Angeles and Salt Lake City using dual-mode locomotives, is economically attractive. The electric helper scenario is not economically attractive and would probably not be acceptable from the operational standpoint.

If the route were already electrified, WESS could be installed on at least 10 grades with an attractive ROI.

Should UP decide to electrify this route, then the application of WESS would significantly enhance the economic case for that electrification.

The only variable to which the results are particularly sensitive is the cost of the dual-mode locomotive. For this reason a detailed analysis was carried out to determine this cost as shown in Section 2 of this report.

CONSOLIDATED RAIL CORPORATION

The Harrisburg-Pittsburgh route of CR is widely cited as a candidate for electrification in the near future. It is characterized as a slow-speed route consisting of coal and ore unit trains as well as other mixed traffic, and currently has a traffic level of 112 x 10^6 GTT/year. The route negotiates the Allegheny Mountains during its 245 route miles that typically accommodate three or four tracks. Three potential WESS sites have been identified on this route. Traffic is not expected to increase during the period under question (ref 10) and therefore zero growth has been assumed. The results of the power and energy calculations are shown in Table 5-3.

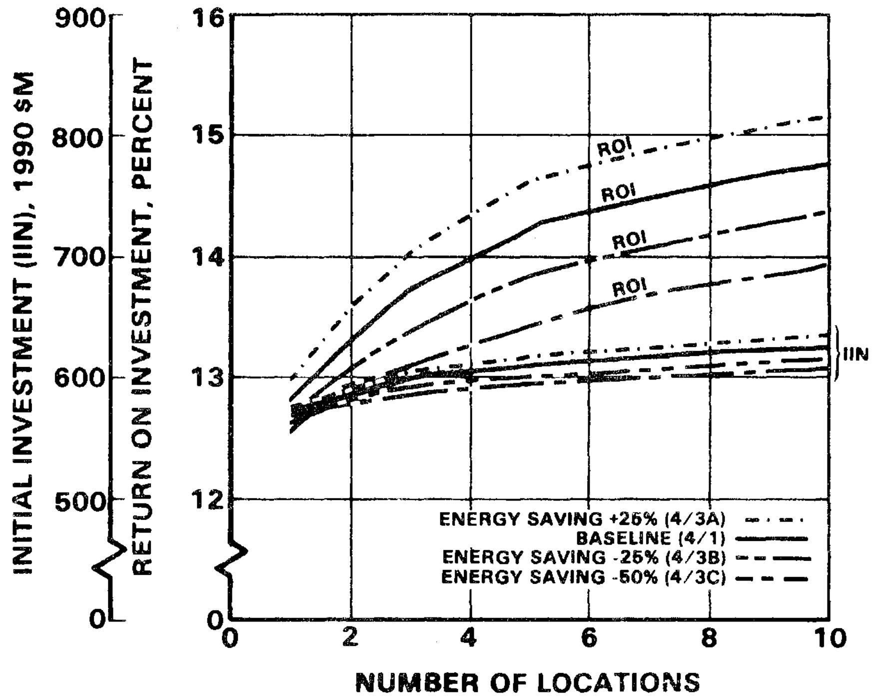


Figure 5-30. Los Angeles to Salt Lake City Concurrent Electrification and WESS Sensitivity Analysis: Energy Saving

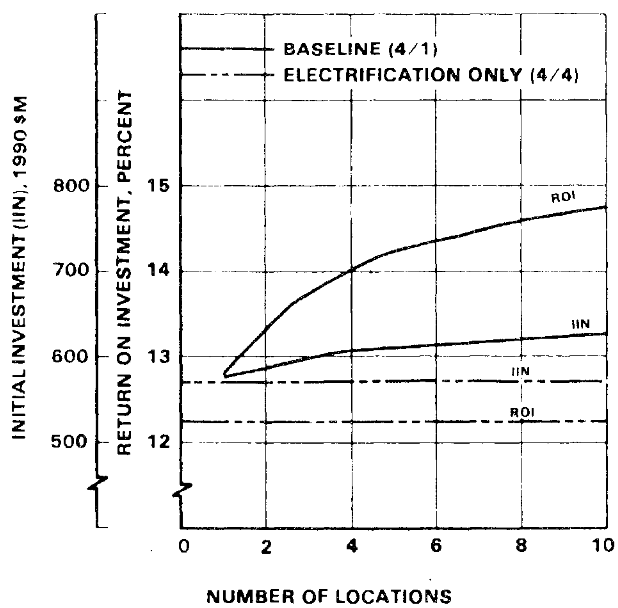


Figure 5-31. Los Angeles to Salt Lake City: Electrification Only

TABLE 5-3

ANNUAL ENERGY SAVING FOR HARRISBURG-PITTSBURGH ON THREE WESS SITES

Scenario	Annual Energy Saving at Zero Traffic Growth
Dual mode	6.5 Mgal
Electric helper	5.86 Mgal
Electrified railroad	66,400 Mwhr

The results of the sensitivity analyses are discussed below.

Dual-Mode Locomotive Scenario

The Conrail dispatching policy requires that medium-sized trains attain a minimum speed on the ruling grade of 11 mph. To be conservative, it has been assumed that the dual-mode locomotive utilization will be 5.1 locomotives per 10^9 GTM/year, compared with 6.8 locomotives per 10^9 GTM/year for the existing diesel fleet.

Even assuming zero traffic growth, 190 diesel locomotives will be required in 1990 on this route, compared with 142 dual-mode locomotives. This results in a saving of 48 diesel locomotives that may be transferred to other duties. Assuming that locomotives are replaced on a 15-year cycle, the reduction in fleet size by 48 locomotives results in an annual saving of 3 replacement locomotives.

Other savings resulting from the reduction in fleet size are calculated in Section 4 and are tabulated in Volume 3.

1. Baseline (Analysis 1/1)

In this baseline analysis, the following assumptions were made:

- Flywheel, $0.270 million/Mwhr stored
- Dual-mode conversion, $0.211 million
- Energy saving, as calculated by TPC

Figure 5-32 shows the results of the baseline analysis and it can be seen that the ROI increases as the number of locomotives decreases. This is because the major savings are achieved by the route-dependent rather than the site-dependent factors. The decision as to how many grades would be equipped with WESS depends on:

(a) Funding level available

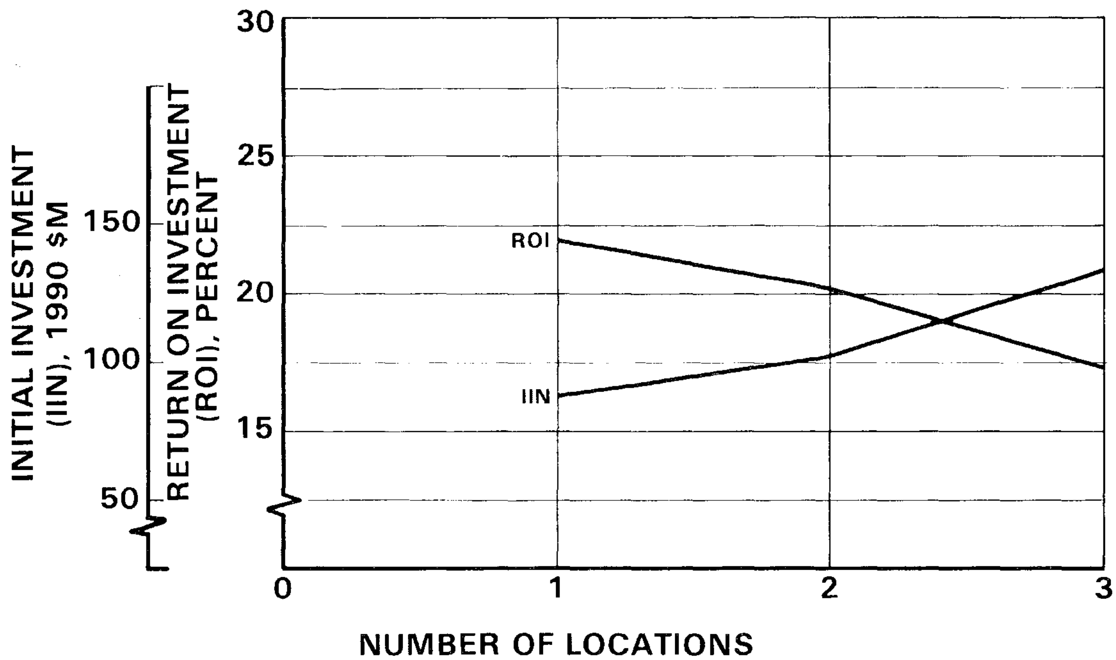


Figure 5-32. Harrisburg to Pittsburgh Dual-Mode Locomotive: Baseline Case

(b) Whether other projects exist that show a better ROI. That is, there may not be a project that can show an ROI greater than that for three locations, in which case three locations would be equipped.

2. Flywheel Cost Sensitivity (Analysis 1/2)

In this analysis, flywheel costs ranging ±50 percent from the baseline are assumed; the results of the study are shown in Figure 5-33. The ROI is not significantly affected by the change in flywheel cost because the major portion of the system costs is route-dependent and constant.

3. Dual-Mode Locomotive Cost Sensitivity (Analysis 1/3)

In this analysis, it is assumed that costs of the dual-mode locomotive range ±50 percent from the baseline analysis, as shown in Figure 5-34. The 50 percent increase in locomotive cost results in a 20 percent change in ROI. This is the most sensitive variable.

4. Energy-Saving Sensitivity (Analysis 1/4)

In this analysis, it is assumed that energy-saving levels are ± 25 percent and -50 percent of the baseline analysis. The purpose of this analysis is to test the sensitivity of the results to differences in railroad policy and driving techniques as far as the use of electric braking is concerned. The results

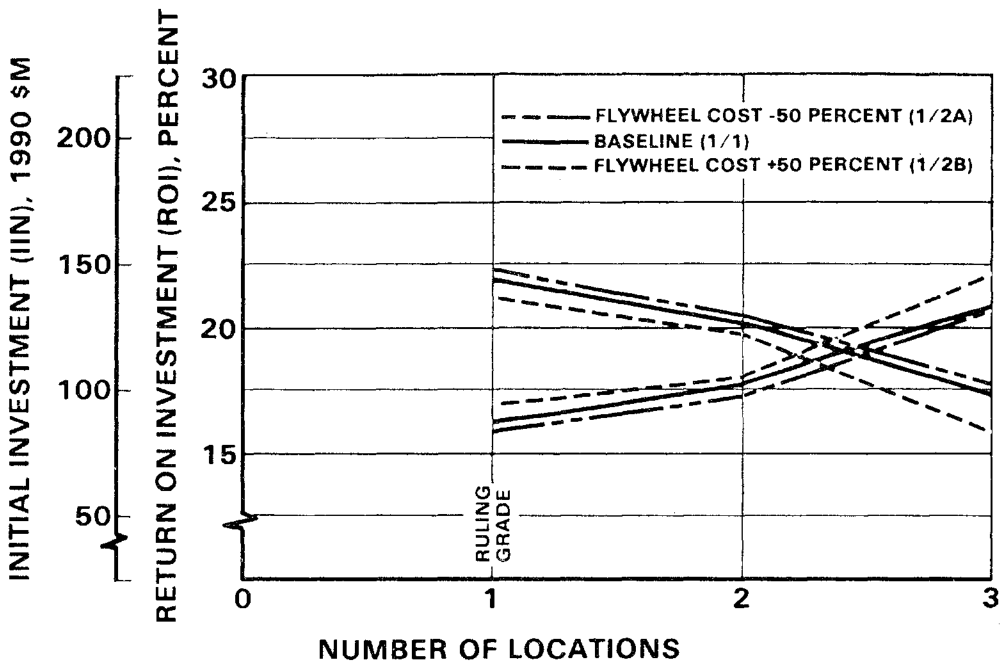


Figure 5-33. Harrisburg to Pittsburgh Dual-Mode Locomotive Sensitivity Analysis: Flywheel Cost

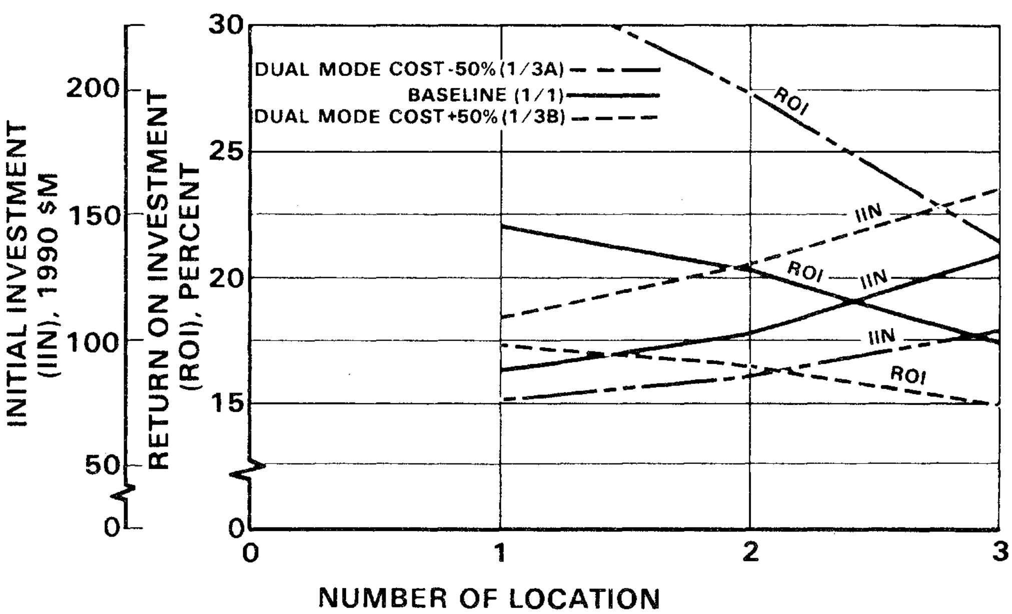


Figure 5-34. Harrisburg to Pittsburgh Dual-Mode Locomotive Sensitivity Analysis: Dual-Mode Locomotive Cost

are shown in Figure 5-35 and it may be seen that the results are not very sensitive to the level of energy saving assumed because most cost and credit elements are route-dependent.

5. Dual-Mode Locomotive Only (Analysis (1/5)

The purpose of this analysis is to define the benefit of the WESS when applied to a dual-mode railroad. The results are shown in Figure 5-36, from which it can be seen that the addition of WESS to a project to convert a railroad to dual-mode operation would result in an increase in the ROI of 19 percent.

Electric Helper Scenario

The same locomotive fleet economics calculated from the dual-mode locomotive scenario apply to this scenario. The increase in journey time resulting from this method of operation has not been quantified due to lack of information from the railroad.

1. Baseline (Analysis 2/1)

In this baseline analysis, the following assumptions are made:

- Flywheel cost, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

The analysis results given in Volume 3 show that this scenario has a positive ROI for site 1 only--an ROI of 2.06 percent. Therefore, the sensitivity analyses are plotted for site 1 only by depicting ROI and initial investment against the percentage of change in the variable under consideration. This confirms the undesirability of this scenario, but does not have any relevance to the existing diesel helper operation on this route.

2. Flywheel Cost Sensitivity (Analysis 2/2)

For this analysis, it was assumed that flywheel costs varied ±50 percent from the baseline. As shown in Figure 5-37, the ROI is not significantly affected by the change in flywheel cost because most of the flywheel costs are route-dependent and constant.

3. Energy Saving Sensitivity (Analysis 2/3)

Here energy savings ranging ±25 percent and -50 percent from the baseline analysis were assumed. From Figure 5-38, it may be seen that the energy savings do have an effect on this already very low ROI.

4. Electric Helper Only (Analysis 2/4)

The purpose of this analysis is to define the benefit of WESS when applied to a railroad that makes extensive use of electric helpers. The unattractive results of this scenario are confirmed by the results of analysis 2/4 in Volume 3, where it can be seen that the electric helper alone cannot achieve a positive ROI.

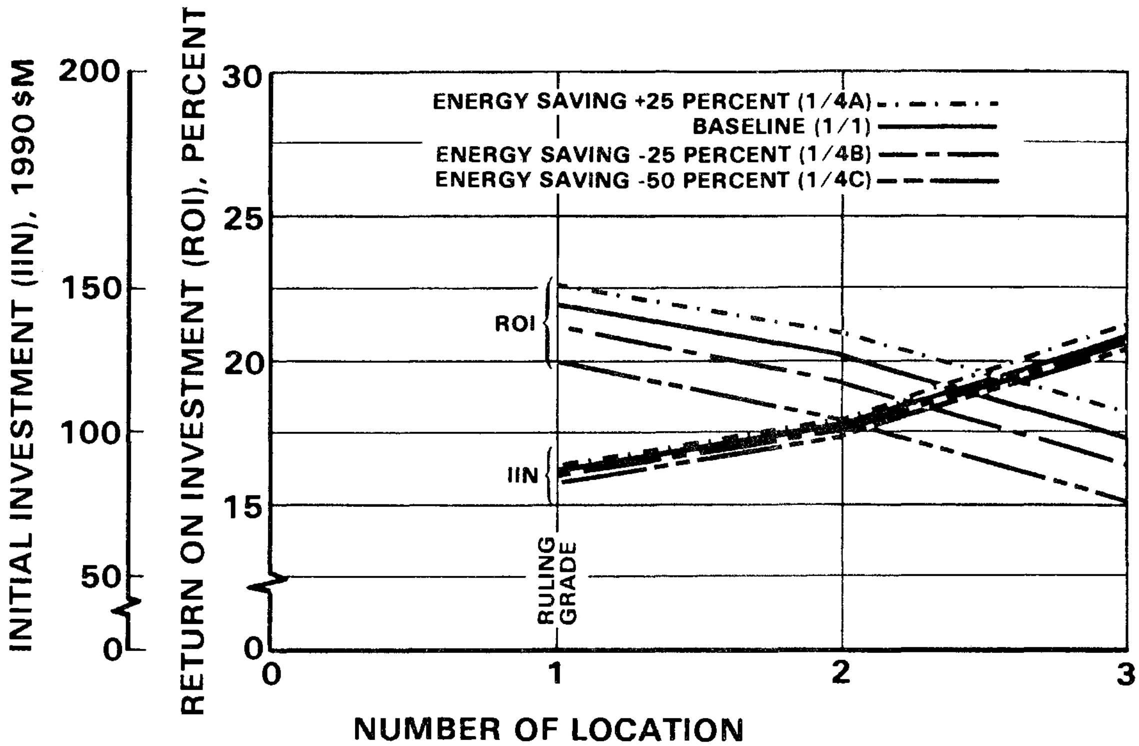


Figure 5-35. Harrisburg to Pittsburgh Dual-Mode Locomotive Sensitivity Analysis: Energy Saving

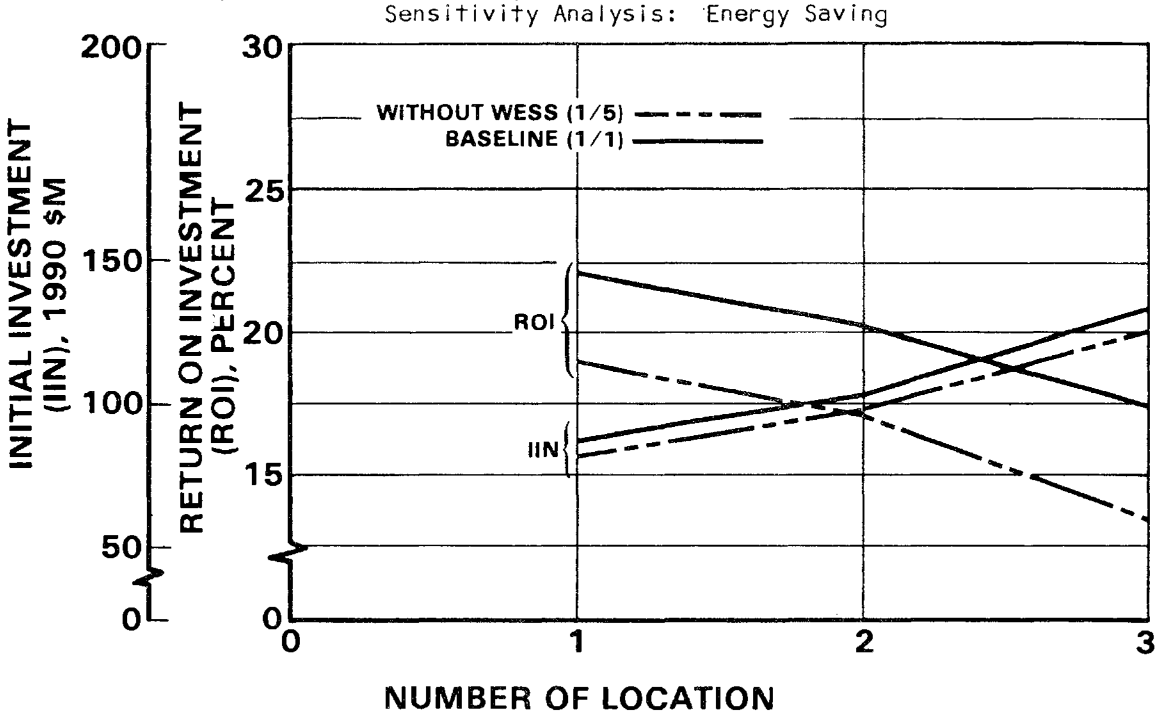


Figure 5-36. Harrisburg to Pittsburgh, Dual-Mode Locomotive Only

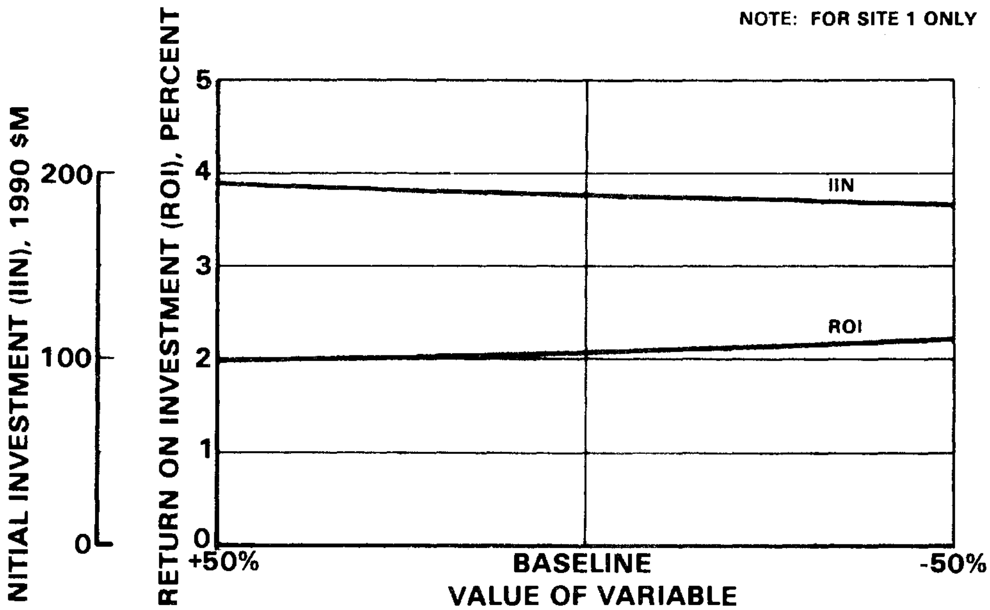


Figure 5-37. Harrisburg to Pittsburgh Electric Helper Sensitivity Analysis: Flywheel Cost

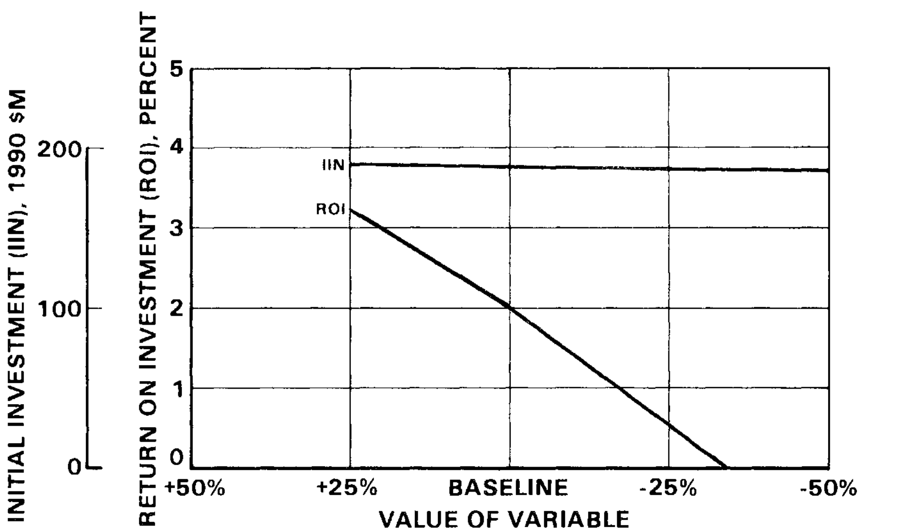


Figure 5-38. Harrisburg to Pittsburgh Electric Helper Sensitivity Analysis: Energy Saving

Electrified Railroad Scenario

Assuming no change in the Conrail dispatching policy and the average locomotive utilization of 3.6 locomotives per 10^9 TM/year, 100 electric locomotives will be required to operate this route in 1990. Also, because they are assumed to exist, these locomotives will require modification to a regenerative system. Because the base performance at the locomotive remains unaltered, there is no reduction in the fleet size.

1. Baseline (Analysis 3/1)

In the baseline analysis, the following is assumed:

- Flywheel cost, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

Figure 5-39 shows the results of the baseline analysis and it can be seen that as the number of locations increases, so does the ROI.

2. Flywheel Cost Sensitivity (Analysis 3/2)

In this analysis, flywheel costs ranging ±50 percent from the baseline were assumed. As shown in Figure 5-40, the ROI is not significantly affected by the increased cost of the flywheel.

3. Energy Saving Sensitivity (Analysis 3/3)

Here, it was assumed that energy savings were ±25 percent and -50 percent of the baseline analysis. As shown in Figure 5-41, the effect on the ROI was only significant for the extreme case of saving only 50 percent of the calculated energy.

Concurrent Electrification and WESS

As for the electrified railroad scenario, it is assumed that the Conrail dispatching policy is unaltered by the changeover from diesel to electric operation. This means that in 1990, some 188 diesel locomotives in use on this route may be transferred and replaced by 100 electric locomotives. Each year, the replacement of 6 diesel locomotives will be saved.

Other savings resulting from the change in locomotive type (idling fuel and maintenance) are tabulated in Volume 3.

1. Baseline (Analysis 4/1)

In this baseline analysis the following is assumed:

- Flywheel, $0.270 million/Mwhr stored
- Energy saving, as calculated by TPC

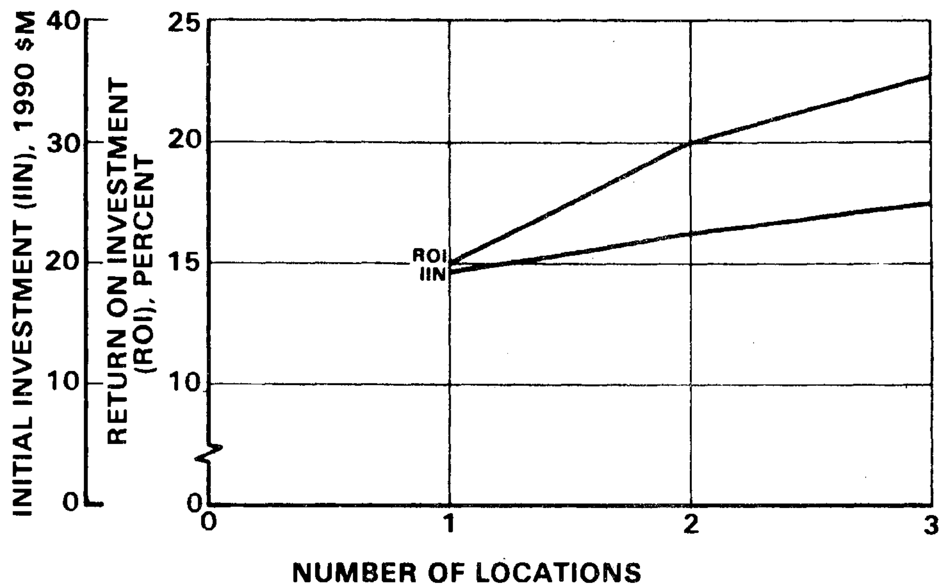


Figure 5-39. Harrisburg to Pittsburgh Electrified Railroad, Baseline Case (3/1)

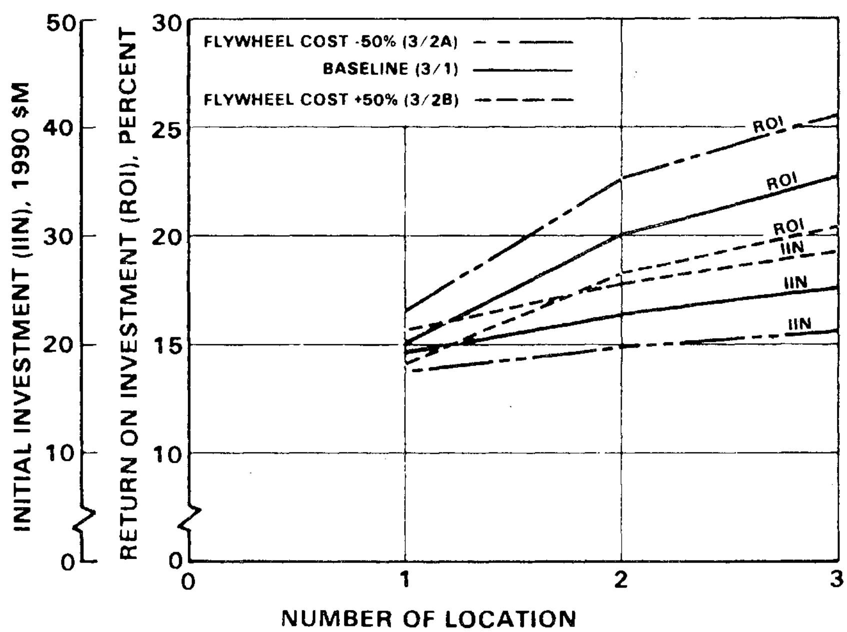


Figure 5-40. Harrisburg to Pittsburgh Electrified Railroad Sensitivity Analysis: Flywheel Cost

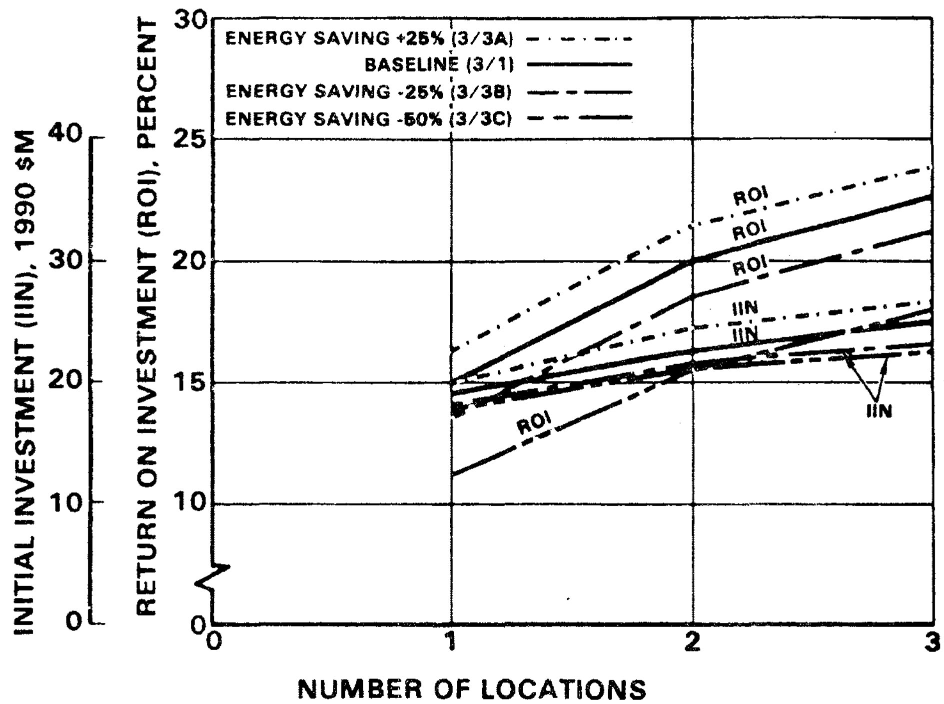


Figure 5-41. Harrisburg to Pittsburgh Electrified Railroad Sensitivity Analysis: Energy Saving

Figure 5-42 shows the large initial investment required when considering electrification and WESS. The ROI increases slightly as the number of locations increases until a maximum ROI is reached at more than 18 grades. The low ROI's determined for this scenario are put into perspective in the discussion of the "electrification only" case, para 4 below.

2. Flywheel Cost Sensitivity (Analysis 4/2)

In this analysis, flywheel costs of ±50 percent from the baseline were assumed. The results are shown in Figure 5-43, from which it can be seen that the flywheel cost does not unduly affect the ROI for WESS deployment.

3. Energy Saving Sensitivity (Analysis 4/3)

Here, energy savings of ±25 percent and -50 percent from the baseline were assumed. As shown in Figure 5-44, the maximum effect is to reduce the ROI for 18 locations by 4 percent, which is insignificant.

4. Electrification Only (Analysis 4/4)

The purpose of this analysis is to test the benefit of incorporating WESS at the same time as an electrification scheme is implemented. It may be seen from Figure 5-45 that the ROI can be increased by up to 10 percent if WESS is added to the electrification scheme. It is known that typically, the railroad's own studies (but not necessarily for Conrail on this route) generally

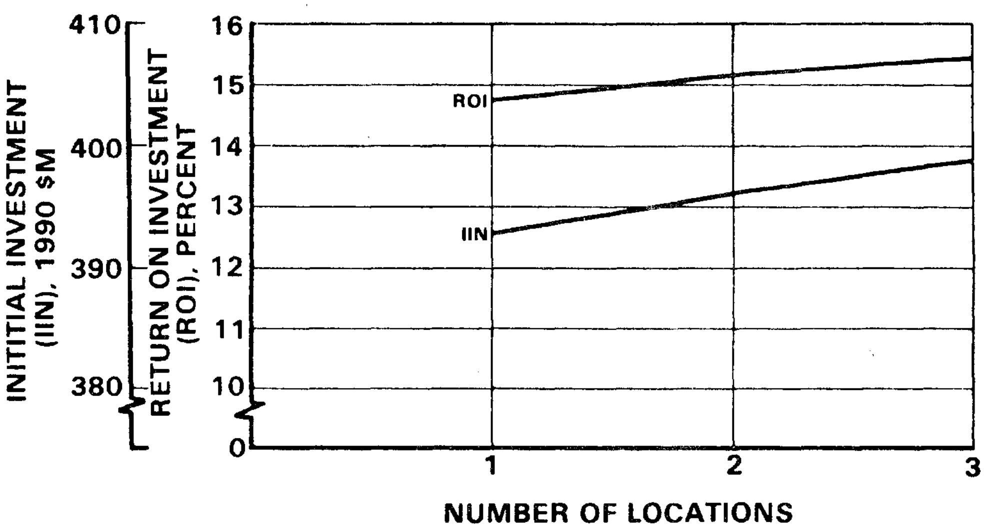


Figure 5-42. Harrisburg to Pittsburgh Concurrent Electrification and WESS: Baseline Case (4/1)

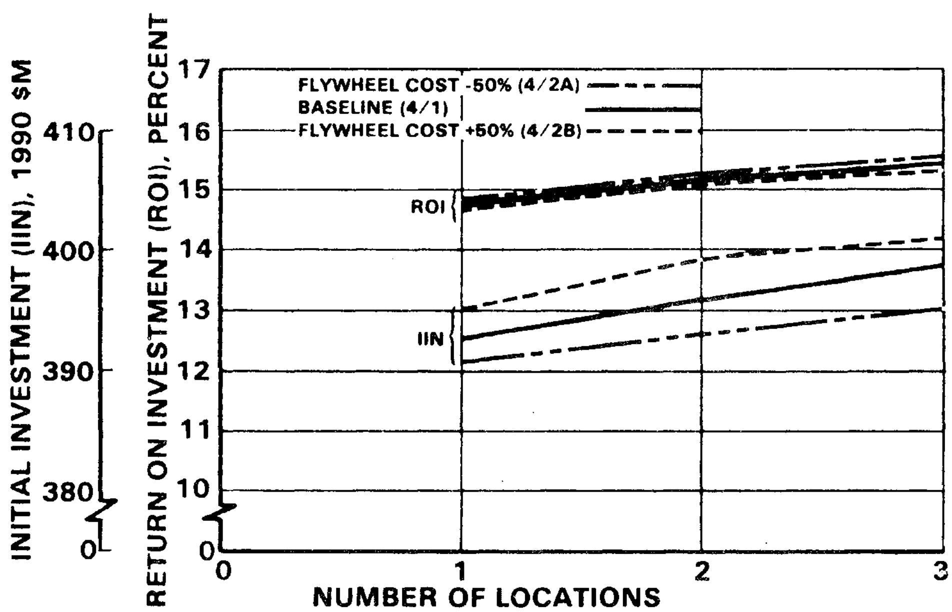


Figure 5-43. Harrisburg to Pittsburgh Concurrent Electrification and WESS Sensitivity Analysis: Flywheel Cost

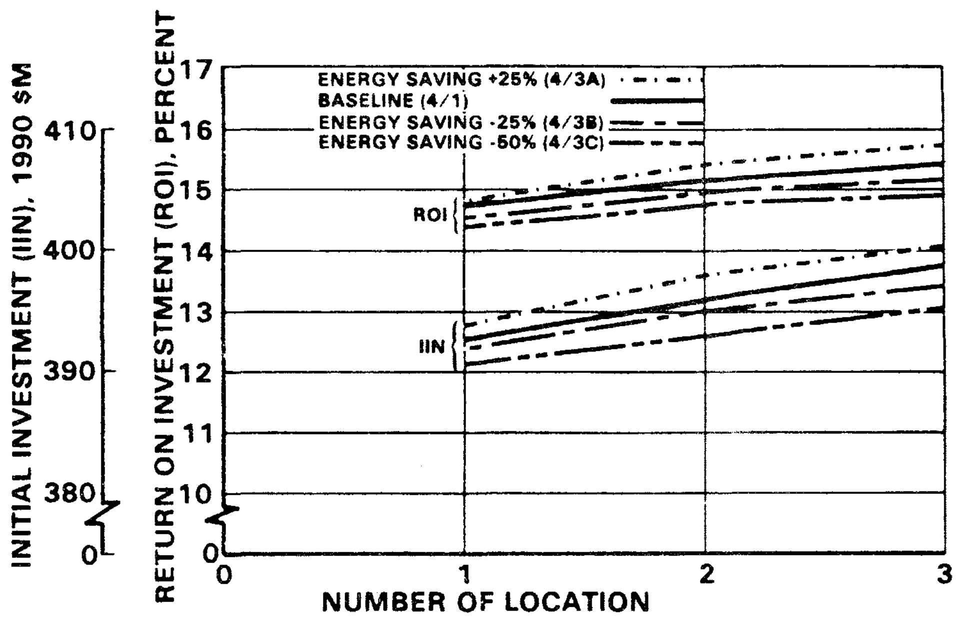


Figure 5-44. Harrisburg to Pittsburgh Concurrent Electrification and WESS Sensitivity Analysis: Energy Saving

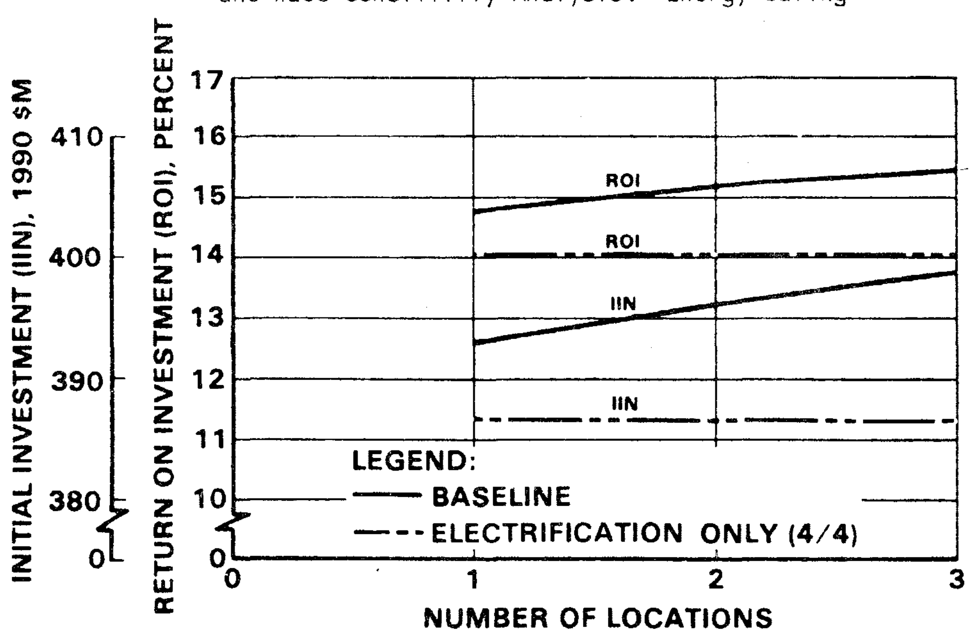


Figure 5-45. Harrisburg to Pittsburgh Concurrent Electrification and WESS Sensitivity Analysis: Electrification Only

show an ROI for electrification of 15 to 17 percent. The low value calculated in this economic study represents an extremely conservative approach and the assumption of worst-case conditions throughout.

Summary of WESS Application on Conrail

The above analysis shows the WESS, when applied to a diesel railroad between Harrisburg and Pittsburg using dual-mode locomotives, is economically attractive. The electric helper scenario is not economically attractive and would probably not be acceptable from the operational standpoint.

If the route were already electrified, WESS could be installed on at least 18 grades with an attractive ROI.

Should Conrail decide to electrify this route, then the application of WESS would significantly enhance the economic case for that electrification.

The only variable to which the results are particularly sensitive is the cost of the dual-mode locomotive. For this reason a detailed analysis was carried out to determine this cost as shown in Section 2 of this report.

BLACK MESA AND LAKE POWELL

The Black Mesa and Lake Powell (BM&LP) railroad is electrified at 50 kv, 60 Hz and was constructed for the sole purpose of delivering coal from the Kayenta Mine to the Navajo Generating Station. It has no rail connection to the main line U.S. railroad system. The railroad currently has a traffic level of 18.2×10^6 GTT/year and this is not expected to change unless a fourth generating unit is added at the power station. During its 78 miles of single-track, the railroad descends from the mine before rising to climb the Black Mesa; it then descends into the Colorado Valley near Page, Arizona.

The results of the power and energy calculations are shown in Table 5-4 for the entire route, which is treated as one grade for the purpose of the calculations.

TABLE 5-4

ANNUAL ENERGY SAVING FOR THE BLACK MESA AND LAKE POWELL ROUTE

Scenario	Annual Energy Saving
Electric railroad	12,000 Mwhr

The results of the sensitivity analyses are discussed below.

Timetable Variations (Analysis 3/1)

Because the energy charge is extremely low, the major saving from the deployment of WESS on this railroad is attributable to the reduction in demand charges the railroad must pay to the Navajo Tribal Utility Authority (NTUA). The peak 1-hr demand in any 1-hr period sets the demand rate for the next

12 mos and is charged at $5.09/kw/mo. Therefore, this analysis tests methods of inherently reducing the demand charge by operating a larger number of smaller trains rather than the few large trains which are operated at this time. Figure 5-46 shows the existing timetable used in analysis 3/1A; Figures 5-47 and 5-48 show the proposed timetables used for analyses 3/1B and 3/1C, respectively. Discussions with BM&LP did not identify any objections to these time-table changes, provided that the additional labor required was included in the economic analysis.

From Volume 3, it can be seen that the resulting ROI's are:

Current timetable (3/1A), 10.12 percent

25-hr timetable (3/1B), 17.26 percent

24-hr timetable (3/1C), 12.82 percent

For this study, analysis 3/1B was taken as the baseline case in the subsequent sensitivity analyses.

Flywheel Cost Sensitivity (Analysis 3/2)

In this analysis, flywheel costs of ±50 percent from the baseline are assumed. The results are shown in Figure 5-49. Since the flywheel cost is the major cost item, it can be seen that the increase in flywheel cost reduces the ROI by 17 percent.

Energy Saving (Analysis 3/3)

In this analysis energy saving levels ±25 percent and -50 percent of the baseline analysis are used. The purpose of this analysis is to test the sensitivity of the results to differences in driving techniques, as far as the use of the electric brake is concerned. From the results shown in Figure 5-50, the ROI is insensitive to the energy savings because the value of the energy savings is low, compared with the value of the demand savings.

Summary of WESS Operation on BM&LP

The above analysis shows that the application of WESS to the already-electrified BM&LP railroad is economically attractive, provided that changes are made to the operating timetable. The only variable to which the results are particularly sensitive is the flywheel cost. For this reason, a detailed analysis was carried out to determine this cost, as shown in Section 3 of this report.

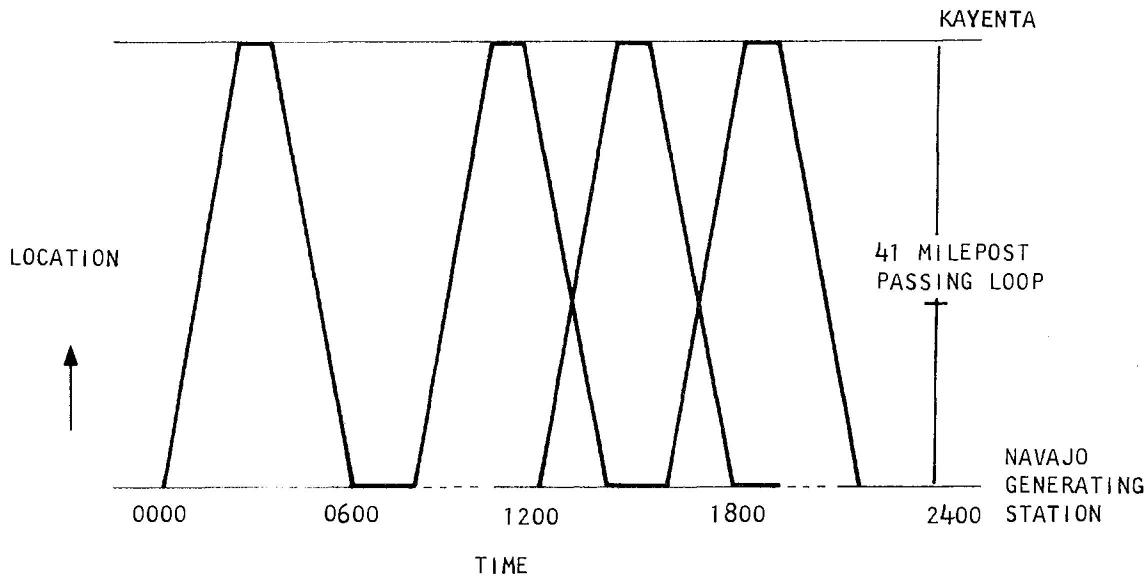


Figure 5-46. Existing BM&LP Timetable

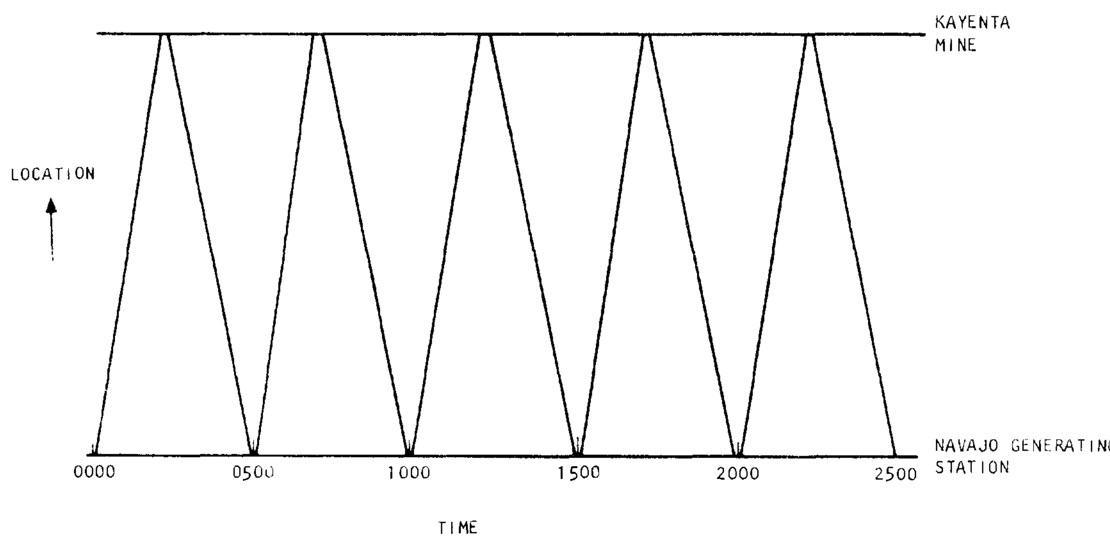


Figure 5-47. Proposed 24-hr Cycle Timetable on BM&LP

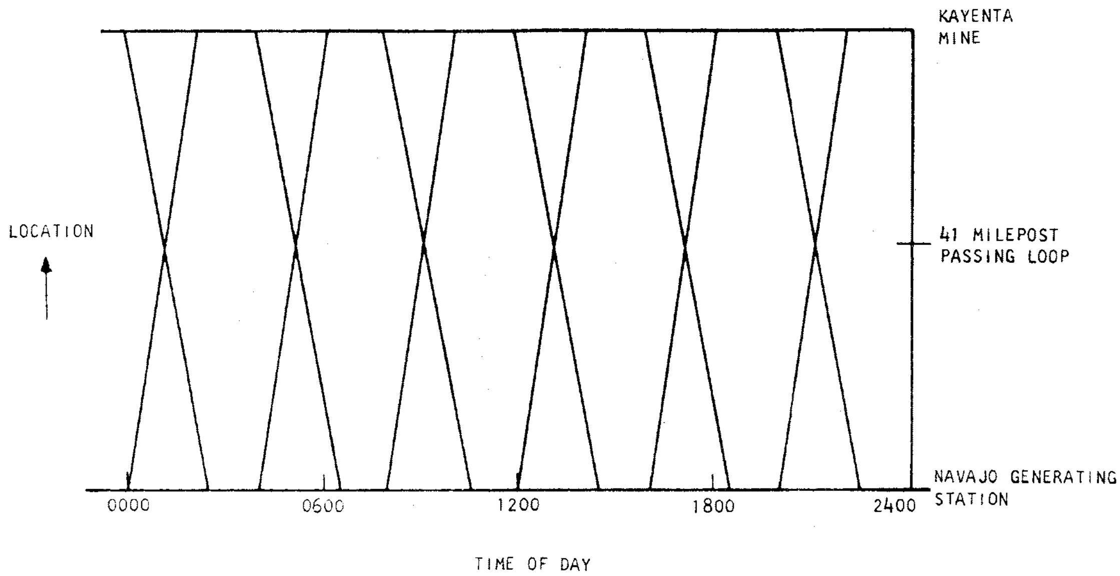


Figure 5-48. Proposed 24-hr Cycle Timetable on BM&LP

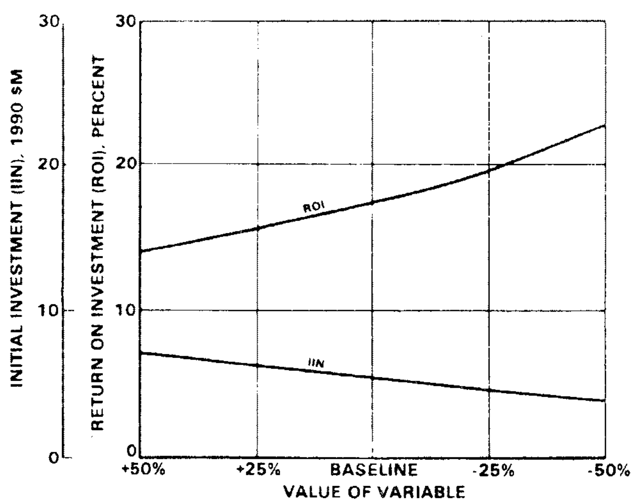


Figure 5-49. BM&LP Electrified Railroad Sensitivity Analysis: Flywheel Cost

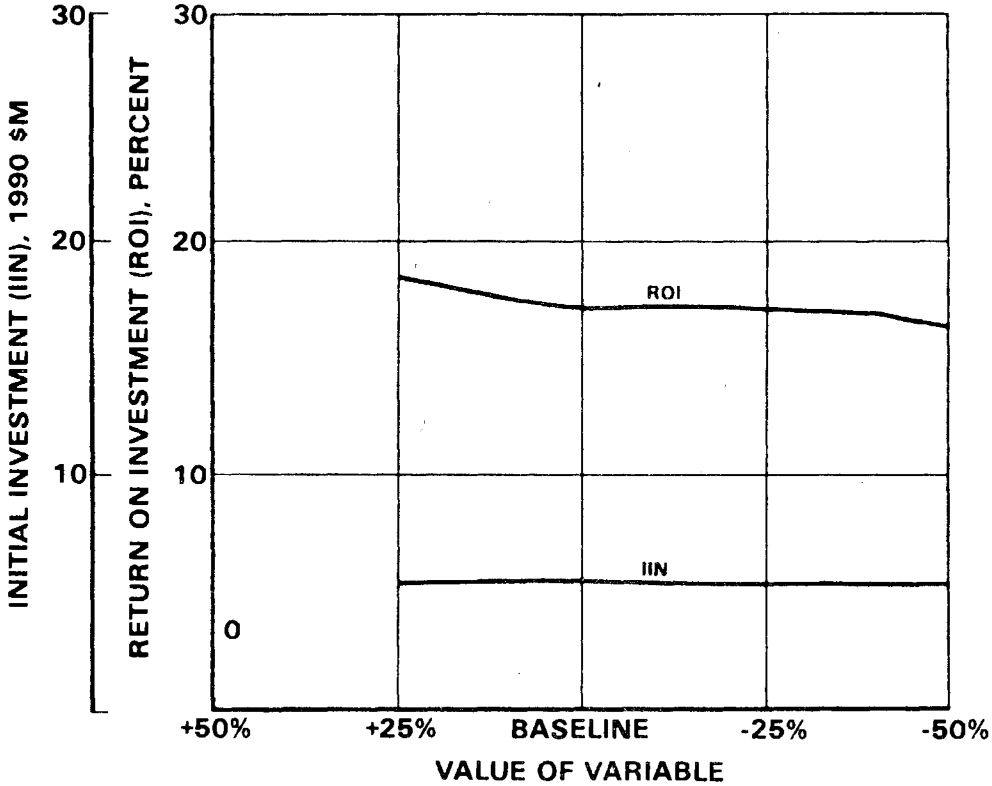


Figure 5-50. BM&LP Electrified Railroad Sensitivity Analysis: Energy Saving

SECTION 6

DEVELOPMENT PROGRAM PLANS

The results of the Wayside Energy Storage Study have shown the operational feasibility and economic advantages of the wayside energy storage system (WESS). This concept may be employed on either fully electrified railroads or on present diesel routes by electrifying grades and using dual-mode locomotives. On this basis, a development program that will lead to the ultimate widespread deployment of WESS has been formulated. the overall program is structured to initially address the areas of technical risk identified for the WESS concept. Once these risks have been satisfactorily controlled, the program follows a logical process of design, fabrication, testing, and demonstration of the WESS concept.

The three major areas of risk identified in the study are the following:

- Large flywheel
- Dual-mode locomotive
- Regenerative electric locomotive operation

The development program will continue to address these risks until their complete resolution makes this no longer necessary. The first phase of the three-phase development program comprises design studies; these are followed by detailed design of the complete WESS system in suitable form for a Phase II demonstration at the Pueblo Transportation Test Center. The third phase of the program will entail full-scale deployment of a WESS system on an operating railroad like Black Mesa and Lake Powell. The proposed schedule for the development program is shown in Figure 6-1.

PHASE I, DESIGN AND DEVELOPMENT

This program will start with a series of design studies to establish that the three risk areas can be controlled throughout the entire program. These studies will be followed by the detailed design of all the elements of the WESS system required for demonstration of both dual-mode locomotive and electrified railroad operations at a test site--probably Pueblo. The result of the Phase I program will be a complete set of drawings prepared for fabrication and modification of equipment needed for a small-scale demonstration of the system.

The details of the proposed Phase I design and development program are presented below in the form of a series of task descriptions.

Dual-Mode Locomotive Design Study

The primary objective of the dual-mode design study is the determination of the practicality of modifying both new and existing diesel locomotives to the dual-mode configuration. As part of this study, the operation of the regenerative power converter to be used on the dual-mode locomotive along with its controls should be verified. The contractor will provide the necessary material, labor, facilities, and services to perform the following tasks:

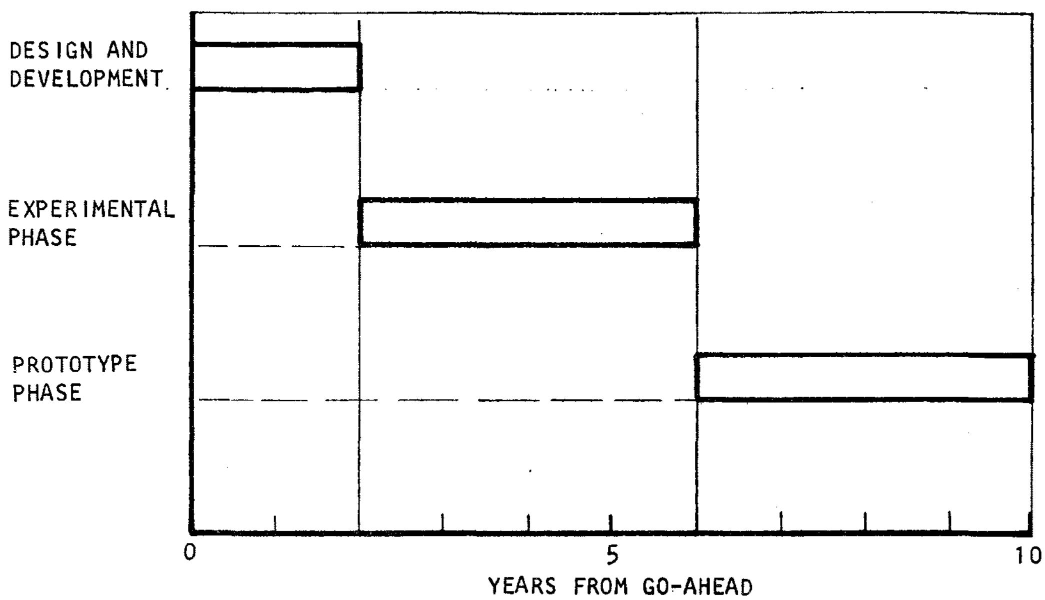


Figure 6-1. WESS Development Program Schedule

1. Task 1, Data Acquisition

Gather necessary diesel locomotive data required for dual-mode modification design from locomotive manufacturers, FRA, and operating railroads.

2. Task 2, Dual-Mode Modification Preparation Study

Determine the extent of preparations (removing or moving existing equipment) which must be accomplished to both a new and a typical used EMD SD40 locomotive to permit modification to a dual-mode configuration. Where it is found necessary to move existing equipment, the contractor will show that adequate space for relocation exists on the locomotive.

3. Task 3, Component Specifications

Prepare a set of specifications suitable for procurement or modification of the complete set of components required to modify a diesel locomotive to a dual-mode configuration. The required components as a minimum will include the following:

Pantograph

Lightning arrester

Vacuum/circuit breaker

Grounding switch

Main transformer

High-tension cable

Power converter

Smoothing choke

Traction motor (modification to separate excitation)

Traction motor field supply

Supply changeover switch

Oil/air heat exchanger

4. Task 4, Control Modifications

Define control requirements for regenerative electric operation in sufficient detail to permit necessary redesign of existing locomotive controls for diesel locomotives.

5. Task 5, Locomotive Structural Modifications

Prepare a set of drawings that define modifications to the locomotive structure required to accommodate the installation of the new dual-mode locomotive components.

6. Task 6, Installation Layouts

Prepare a set of layout drawings that define the installation of the components that constitute the dual-mode locomotive modification. These drawings will include all necessary details on piping and ducting required for the installation.

7. Task 7, Electrical Interconnection Drawings

Prepare a complete set of electrical interconnection drawings sufficient for the installation of the dual-mode modification into a diesel locomotive.

Regenerative Electric Locomotive Design Study

This study will be conducted to establish the practicality of modifying both new and existing electric locomotives to a full regenerative-electric configuration. The study will include the verification of the locomotive and its controls for regenerative operation. The contractor will provide the necessary material, labor, facilities, and services to perform the following tasks:

1. Task 1, Data Acquisition

Gather necessary electric locomotive data required for the regenerative modification design from locomotive manufacturers, FRA, and operating railroads.

2. Task 2, Modification Preparation Study

Determine the extent of preparations (removing or moving existing equipment) required to permit modification to a regenerative configuration for both a new and a typical used GE E60 locomotive. Where it is found necessary to move existing equipment, the contractor will show that adequate space for relocation exists on the locomotive.

3. Task 3, Component Specifications

Prepare a set of specifications suitable for procurement or modification of the complete set of components required to modify an electric locomotive to a regenerative configuration. The required modifications as a minimum will include the following:

Converter modifications

Control modifications

4. Task 4, Electrical Interconnection Drawings

Prepare a complete set of electrical interconnection drawings sufficient for the installation of the regenerative modification into an electric locomotive.

Wayside Station Design Study

This study will be conducted to establish the complete feasibility of the wayside flywheel station including all of its components and the tie-in to an electric utility and the railroad electrification. The contractor will provide the necessary material, labor, facilities, and services to perform the following tasks:

1. Task 1, Flywheel Study

Review candidate flywheel configurations suitable for full-scale WESS application. Select the most logical configuration and conduct finite-element stress analyses to verify flywheel integrity and cycle life.

2. Task 2, Flywheel Ancillary Study

Conduct design studies at the following flywheel ancillaries and accessories:

Hydrostatic bearing (bottom)

Roller bearing (top)

Seals

Evacuation system

Housing

3. Task 3, Installation Study

Determine the most economical and practical way to install the flywheel at a typical WESS station.

4. Task 4, Flywheel Machine Specification

Prepare a specification suitable for procurement of the flywheel machine.

5. Task 5, Converter Study

Review candidate power converter configurations suitable for the wayside flywheel station. Select the optimum converter configuration and prepare a complete specification suitable for procurement.

6. Task 6, Interface Study

Establish the suitability of electrification interfaces between the flywheel and electric utility, and between the flywheel and railroad.

Scale Model Flywheel Demonstration

The objective of this demonstration is to verify the design of the steel axial disc type of flywheel proposed for WESS by actually building and testing a scale model flywheel. The contractor will provide the necessary material, labor, facilities, and services to perform the following tasks:

1. Task 1, Flywheel Design

Design a 7.33-kwhr steel axial-disc flywheel rotor that operates at the same stress levels and energy density as a full-size WESS flywheel.

2. Task 2, Flywheel Fabrication

Fabricate the scale model flywheel rotor using similar techniques as proposed for large WESS flywheel.

3. Task 3, Flywheel Testing

Conduct a program of spin tests on the scale model flywheel rotor suitable to verify the power density, energy density, and cycle life predictions for the design.

4. Task 4, Test Data Analysis

Verify the suitability of the scale model flywheel design for the full-size WESS flywheel by analysis of the test data.

Dual-Mode Locomotive Detail Design

The objective of this task is to completely define the modification of either a new or typical used SD40 locomotive from its original diesel arrangement to a dual-mode configuration, making it suitable for operation either as a diesel locomotive or as a regenerative electric locomotive. The resulting drawing package will be suitable for the actual modification of locomotives that will take place during the Phase II program.

Regenerative Electric Locomotive Detail Design

In this task, the contractor will fully define the modifications to a new or existing GE E60 electric locomotive necessary to provide a full regenerative braking capability. The resulting drawing package will be suitable for the actual modification of locomotives, which will take place during the Phase II program.

Wayside Station Detail Design

The objective of this task is to fully define a flywheel wayside station that would be suitable for a WESS demonstration at Pueblo, adjacent to the high-voltage ac catenary electrified rail section. The drawing package will be suitable for the actual construction of the wayside station at Pueblo and will describe the design of a usable 1-Mwhr flywheel. All ancillaries and all equipment required for interface with the electric utility and the electrified railroad will be included.

The approximate cost of the entire Phase I Design and Development Program is $3 million (1977 dollars).

PHASE II, EXPERIMENTAL INSTALLATION

In this phase, a 1-Mwhr flywheel would be installed at the Pueblo Transportation Test Center. It would be linked to the 14-mile Railroad Test Track, which is currently being electrified at 12.5/25/50 kv, 60 Hz. Included in this experimental phase would be the purchase of an electric locomotive that would be modified to be fully regenerative.

To investigate the dual-mode locomotive, it is proposed to borrow from cooperating railroads five locomotives, which would then be modified in accordance with the dual-mode concept. After initial proving trials and system integration testing at Pueblo, these locomotives would be placed into service on an electrified railroad to accumulate a minimum of 1 million locomotive miles.

The estimated cost of Phase II is $12 million (1977 dollars).

PHASE III, PROTOTYPE INSTALLATION

This phase consists of a full demonstration program on an operating railroad. To minimize the cost of such a program, it would be advantageous if the program were to be carried out on an electrified railroad that is also a WESS candidate. At this moment, the only railroad meeting such criteria is Black Mesa and Lake Powell; however, within the timescale under consideration, it is possible that some major electrification will have taken place that would allow alternate sites to be considered.

The estimated cost of Phase III is $6.9 million (1977 dollars).

At the conclusion of Phase III, when all the major risk areas have been evaluated, sufficient information will be available to enable railroads to decide whether WESS operationally and economically fits into their long-term planning.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

The completion of the wayside energy storage study has resulted in the quantification of the costs involved and the benefits derived from the concept of recuperating braking energy from freight trains on long downgrades with storage in a wayside flywheel. On this basis, the deployment of WESS on actual routes of U.S. railraods has been found economically attractive. In addition, the technical feasibility of the concept has been determined and a set of plans has been generated to verify the operational suitability of WESS. The specific conclusions and recommendations of this 1-year WESS study are given below.

CONCLUSIONS

1. Thirty-four prime candidate sites for WESS were identified. These sites are located on the most heavily travelled U.S. railroads that operate over mountain ranges. In addition, it is estimated that another 40 to 50 potential WESS sites exist in the U.S.

2. Ten railroad routes between major classification yards have been found to be viable candidates for local WESS installations on their grades. The installation programs could take place gradually, continuing until all worthwhile grades are converted.

3. WESS is highly compatible with presently electrified railroads and can effect substantial economies by providing peak demand-shaving.

4. The WESS concept enhances the economics of railroad electrification and permits evolutionary electrification of complete routes.

5. The most practical system scenario for diesel railroads is the use of dual-mode locomotives on WESS routes; this would provide regenerative electric operation on grades and conventional diesel operation between grades.

6. The preferred electrification system for use with WESS is a high-voltage ac catenary system for the transmitting power between the wayside flywheel station and the dual-mode locomotives.

7. The application of WESS to actual railroad grades can reduce energy consumption by as much as 23 percent, depending on grade characteristics and locomotive operating techniques.

8. The flywheel technology required for WESS can be based on the state of the art for steel flywheels. (Units of similar size are currently being fabricated). Future improvements in composite flywheel fabrication techniques should reduce costs and make larger-capacity flywheels possible.

9. The use of dual-mode locomotives operating over WESS grades permits a reduction in the number of locomotives required for the same performance on most railroad routes.

10. A presently available control system can optimize WESS operations by use of train dispatching information, flywheel status, and electric utility demand constraints.

11. In providing make-up power for the WESS sites, an electric utility was found to be superior to auxiliary diesel or gas turbine power generating sets.

12. The study identified three areas of potential technical risk that should be addressed in the subsequent development program at a cost of $22 M. The areas of risk are:

> Large Flywheel--Although steel flywheels in the weight range of the WESS unit have been built and high energy density flywheels in smaller capacities have been built, the combination has not been demonstrated to date.
>
> Dual-Mode Locomotive--Although no problems are foreseen, the modification of an existing locomotive like the EMD Model SD-40 to a dual-mode configuration has not been previously accomplished.
>
> Regenerative Electric Locomotive Operation--With the exception of a few European locomotives, no extensive service demonstration has been conducted with fully regenerative electric locomotives.

13. Use of large flywheels for user level peak-shaving and optimization of cogeneration schemes has applications beyond WESS.

RECOMMENDATIONS

1. The Phase I design and development program should be promptly initiated. As a first stage of this program, it is suggested that two design studies be started immediately to directly address the three potential technical risk areas. These design studies and their objectives are as follows:

> Dual-Mode Locomotive Design Study--Confirm the physical and electrical feasibility of modifying an EMD Model SD-40 locomotive to a dual-mode configuration. In addition, determine the electrical characteristics of the regenerative converter and the alterations required on the locomotive control circuitry. (The last two objectives also can be used to reduce the technical risk associated with the regenerative electric locomotive operation).
>
> Scale Model Flywheel--Design, build, and test a 7.33-kwhr flywheel (0.1 percent of WESS flywheel energy) to verify the design of the axially stacked, bolted, flat, unpierced, disk flywheel proposed for actual WESS demonstrations.

2. Extend the application study of WESS to include Canadian railroads in light of the Memorandum of Understanding between DOT and Transport Canada. Three Canadian railroads appear to have attractive combinations of traffic and grades--Canadian Pacific, Quebec and North Shore Labrador, and Port Cartier.

3. The peak-shaving potentials of WESS should be evaluated on actual candidate electrified railroads like Black Mesa and Lake Powell and the North East Corridor (NEC), or on routes that may be electrified such as the Conrail Pittsburgh to Harrisburg run.

4. A seminar on the latest WESS program results should be held to inform operating railroads on the concept.

5. The results of the WESS program should be coordinated with cognizant representatives of the Department of Energy to facilitate technology transfer from WESS to other energy conservation programs such as:

- Peak-shaving at user level (similar to NEC)

- Optimization of cogeneration schemes (similar to WESS)

6. Extend the Location Study (Item I) beyond the contract limitation of nine railroads to identify more potential WESS locations. Additional railroads that could be considered include the Milwaukee Road, Western Pacific, Baltimore & Ohio, Chessie, Norfolk & Western, as well as the Canadian railroads.

7. Conduct a nationwide study of WESS application to the National Electrification Network for routes over 40 million gross trailing tons per year. This study would extend the WESS analysis to cover about 10,000 miles of electrified railroad.

SECTION 8

REFERENCES

1. Yao, N. P., "Advanced Secondary Batteries for Electric Vehicle Propulsion," Proceedings of 1978 Advanced Transit Association International Conference, April 1978.

2. Zimmerman, K. R., The Milwaukee Road Under Wire, Quadrant Press, New York, 1973.

3. Meyer, K., "Die Prototyplokomotiven der Serie Re 6/6 der Schweizerischen Bundesbahnen," Schweiz. Bauztg., Vol. 90, No. 48, 1972, pp 1227-1253.

4. Schlacher, R., "Regenerative Braking Equipment for Class Re 6/6 Locomotives of Swiss Federal Railways," Brown Boveri Review, Vol. 60, No. 12, 1973, pp. 572-576.

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

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

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

8. Cetinich, J. N., Fuel Efficiency Improvement in Rail Freight Tranportation. Final Report prepared by Emerson Consultants, Inc., under contract to DOT-TSC, December 1975.

9. Schwarm, E. G., Energy Costs for Railroad Electrification. Final Report prepared by A.D. Little, Inc., under contract to DOT-TSC, May 1977.

10. Swanson, C. G., et al., The Energy and Environmental Impact of Railroad Electrification. Final Report prepared by METREK Division of MITRE Corp., under contract to DOT-FRA, September 1977.

APPENDIX A

WAYSIDE STORAGE STUDY DUAL-MODE LOCOMOTIVE STATEMENT OF WORK

INTRODUCTION

The dual-mode locomotive for use in conjunction with WESS is to be based on the conversion of the SD40 locomotive (and its derivative, the SD40-2) since this locomotive is the most commonly used in freight service on U.S. railroads.

A general arrangement of the locomotive is shown in Figure A-1 and a simplified schematic is shown in Figure A-2.

PREPARATORY WORK

The following preparatory work is required before the installation of new equipment.

Ballast

Where possible, the locomotives selected for this modification will comprise the light underframe model with little or no ballast to be removed; however, as necessary, for heavy frame locomotives, ballast may need to be removed in order to meet axle load limitations. The weight of the transformer is estimated at eight tons and the converter and choke at two tons.

Sandboxes

The sandboxes at each end of the locomotive are to be repositioned on the guard rail (similar to the DD-40-X locomotive). The associated sand delivery pipes to each truck and pneumatic connections are to be rerouted and extended as necessary to be compatible with the repositioned sandboxes.

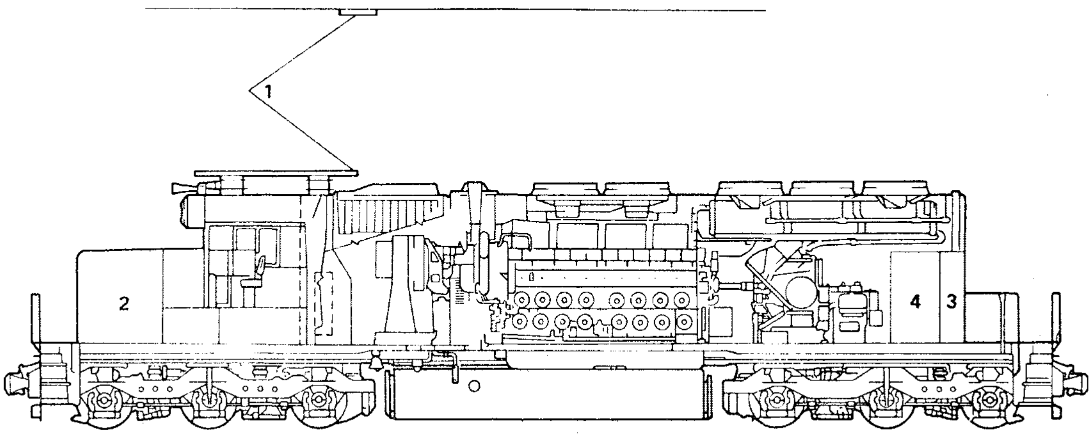
Electrical Connection Box

The electrical connection box, mounted inside the short hood, is to be repositioned so that access is available from outside the locomotive. Attention to adequate sealing against rain, snow, sand, etc. is imperative.

Short Hood

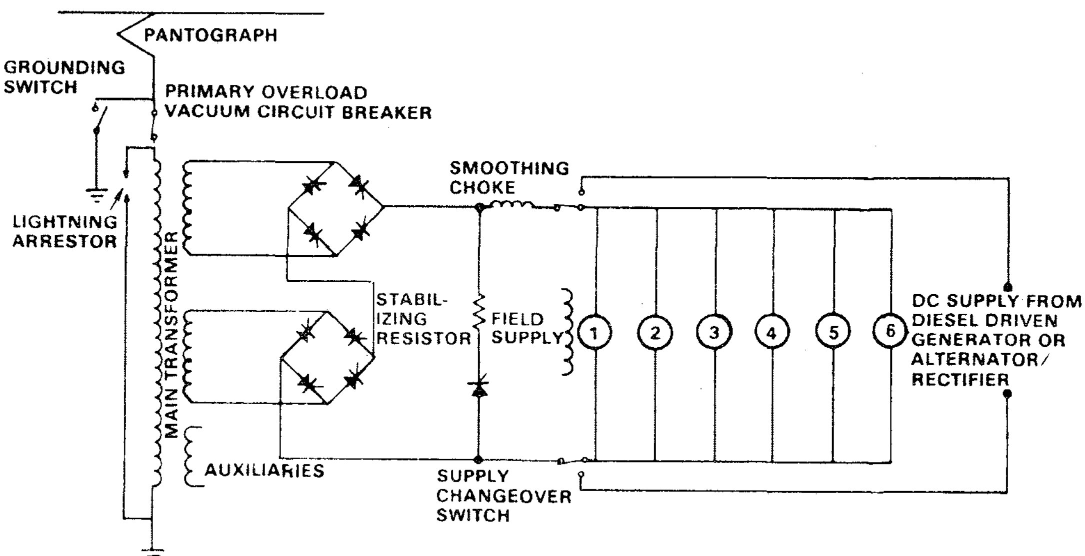
The short hood is to be removed and extended in length by approximately 12 in. The top section is to be removable to facilitate transformer removal and replacement.

Alternately, the transformer tank may form part of the front hood assembly, thus reducing the cooling requirement on the oil/air heat exchanger.



1 PANTOGRAPH
2 TRANSFORMER
3 CONVERTER
4 CHOKE

Figure A-1. Layout of Equipment



• EXISTING PROTECTION AND ISOLATION EQUIPMENT NOT SHOWN

Figure A-2. Secondary Mode Schematic

Cab Roof

The cab roof requires strengthening to provide adequate support for the roof equipment (pantograph, circuit breaker, etc.) and to afford protection for the crew in the event of a mishap involving damage to the pantograph. Reposition warning horns below roof line.

MAJOR ELECTRICAL EQUIPMENT

The following equipment will be supplied to the railroad for installation on the locomotive:

a. Roof equipment

b. HT cable

c. Transformer

d. Converter

e. Smoothing choke

f. Modified traction motors

g. Supply changeover switches

h. Traction motor field power supplies

i. Oil/air heat exchanger

j. Automatic power control equipment

ROOF EQUIPMENT

Install pantograph mounting feet insulators, roof through bushing and lightning arrester(s). Install pantograph and pneumatic air pipe to pantograph air system. Install vacuum circuit breaker.

HIGH TENSION (HT) CABLE

Install HT cable from roof through bushing in protective channel through cab area, under cab floor, and into transformer compartment.

MAIN TRANSFORMER

Install transformer mounting feet and mount transformer. Connect HT cable. Run four secondary cables in conduit or ducting from transformer to compressor compartment of locomotive. Cables to be rated at 3000 amps continuous. Transformer cooling oil pipes to be run to oil/air heat exchanger located in dynamic brake resistor cooling air stream or in traction motor cooling air duct. Rework front hood assembly as necessary.

COMPRESSOR COMPARTMENT

Install mountings for thyristor converter and choke and mount the equipment.

Provide cable connection between converter output and smoothing choke, rated at 6000 amp continuous.

Run cables from choke and output of converter to supply changeover switch located in electrical cabinet.

Run cables to dynamic brake grid compartment from stabilizing resistor thyristors and smoothing choke.

DYNAMIC BRAKE GRID COMPARTMENT

Install transformer oil/air heat exchanger above/below resistor grids and connect stabilizing resistor cables to existing dynamic brake grids. An alternative position for the heat exchanger is in the traction motor cooling air duct.

TRUCKS

Remove traction motors for reworking to separately excited traction motors. Refit after modification.

Weld automatic power control (APC) receiver mounting bracket to truck frame and mount APC receiver. Provide interface control wiring between APC receiver and pantograph control circuit.

WORK ASSOCIATED WITH SEPARATE EXCITATION OF TRACTION MOTORS

Run cables from alternator output terminals to traction motor field supply converter.

Install field control units in electrical cabinet and provide control wire interfaces with traction motor current monitoring devices (CMD) (to be installed in each motor leg), existing wheel slip/slide protection, converter logic, and dynamic brake demand.

CONTROL FUNCTIONS

Install supply changeover switch in electrical cabinet.

Provide cable to transmit throttle position from TH module to converter in compressor compartment.

Install pantograph control equipment.

Miscellaneous control system modifications are required to reduce engine speed to 700 rpm under power demand and inhibit dynamic brake when the pantograph is raised.

COMPLETED LOCOMOTIVE

Weigh locomotive to establish each wheel load and ballast as necessary.

APPENDIX B

WAYSIDE ENERGY STORAGE STUDY
DUAL-MODE LOCOMOTIVE COST ESTIMATE

TABLE B-1

MAN-HOUR COSTS

Cost Item	Cost, Man-hr
Preparatory work	
Remove ballast (where necessary)	80
Reposition sandboxes	32
Electrical connector box	48
Short hood	64
Strengthen cab roof	16
Reposition warning horns (if necessary)	8
Roof equipment	
Install roof insulators	16
Install pantograph	8
Install vacuum circuit breaker	8
Manufacture and install roof busbars	24
Connect air supplies and control wires	8
High-tension cable	
Installation and provision of channel	48
Main transformer	
Manufacture and install mountings	16
Install transformer	8
Connect cables to transformer	16
Install cooling oil pipes	32
Rework front hood	48
Compressor compartment	
Converter and choke mountings	24
Install converter and choke	12
Cable runs	16

TABLE B-1 (Continued)

Cost Item	Cost, Man-hr
Dynamic brake grid compartment	
Install heat exchanger	16
Connect cables	4
Connect oil pipes	2
Trucks	
Lift locomotive and remove trucks	20
Remove and replace traction motors	24
Automatic Power Control (APC) bracket	4
Mount APC equipment and control wiring	6
Retruck locomotive	24
Separately excited traction motors	
Cables to power supplies from alternator	24
Install field control units	48
Install current monitoring device in each motor leg	24
Control modifications	60
Control functions	
Supply changeover switch	8
Cable from TH module to converter	4
Pantograph control equipment	24
Miscellaneous control modifications	80
Completed locomotive	
Inspection and acceptance	150
Weigh locomotive	6
Fix ballast (when necessary)	16
TOTAL LABOR	1076 man-hr
TOTAL LABOR COST	$23,672

TABLE B-2

MATERIAL COSTS

Cost Item	Cost, $
Preparatory work	
Reposition sand boxes	100
Electrical connection box	50
Short hood	150
Strengthen cab roof	250
Reposition warning horns	20
Major electrical equipment	
Roof equipment	
Pantograph	6,000
Vacuum circuit breaker	3,000
Insulators	1,000
Grounding switch	500
Lightning arrestor	300
Main transformer	50,000
High-tension cable	500
Converter	60,000
Smoothing choke	10,000
Traction motor modification	18,000
Traction motor field supplies	5,000
Supply changeover switches	8,000
Oil/air heat exchanger	5,000
Automatic power control equipment	2,000
Roof equipment	
Air piping	100
High-tension cable	
Protective trunking	500
Main transformer	
Mounting pads	200
Conduit/ducting	500
Cooling pipes	2,000
Front hood	1,000

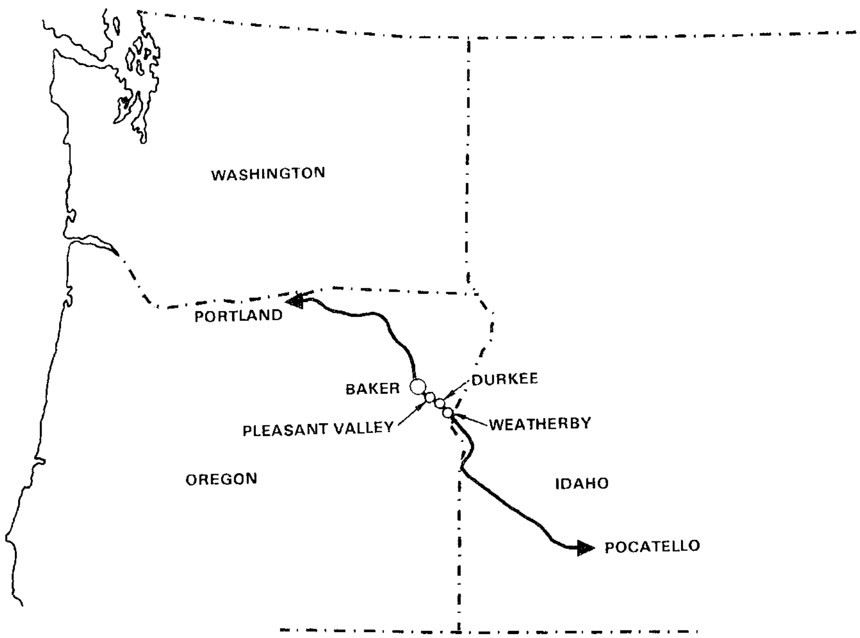
TABLE B-2 (Continued)

Cost Item	Cost, $
Compressor compartment	
Mounting pads	300
Dynamic brake grid compartment	
Oil/air heat exchanger mounting	100
Trucks	
APC mounting bracket	100
Complete locomotive	
Ballast (if required)	3,000
Cable cost (estimated)	10,000
TOTAL MATERIAL COST	$187,820
MODIFICATION COST	$211,492

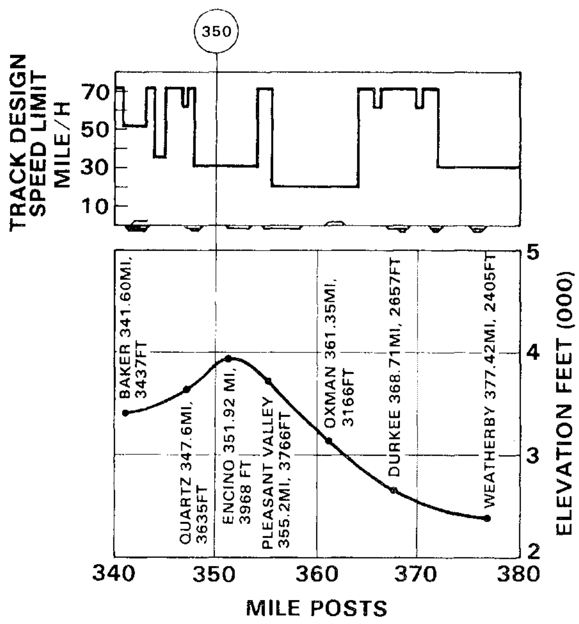
APPENDIX C

LOCATION STUDY DATA ON PRIME CANDIDATE GRADES

GRADE IDENTIFICATION NUMBER 035



GRADE IDENTIFICATION NUMBER 035



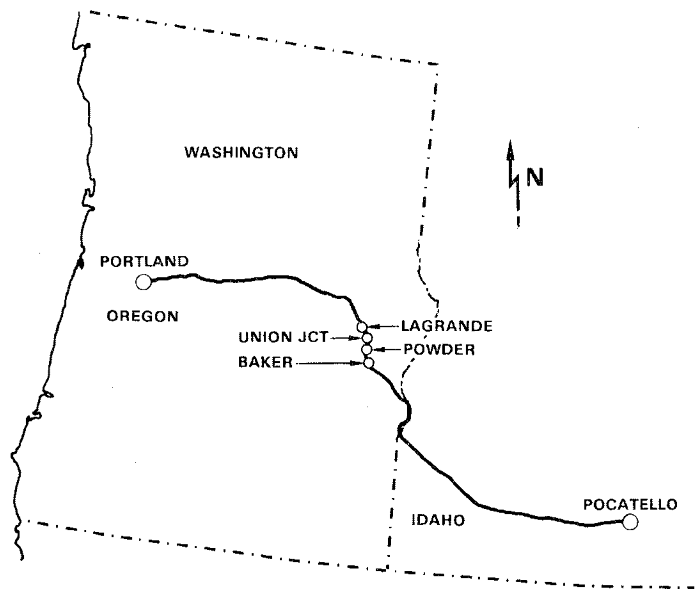
UNION PACIFIC RAILROAD

OREGON DIVISION

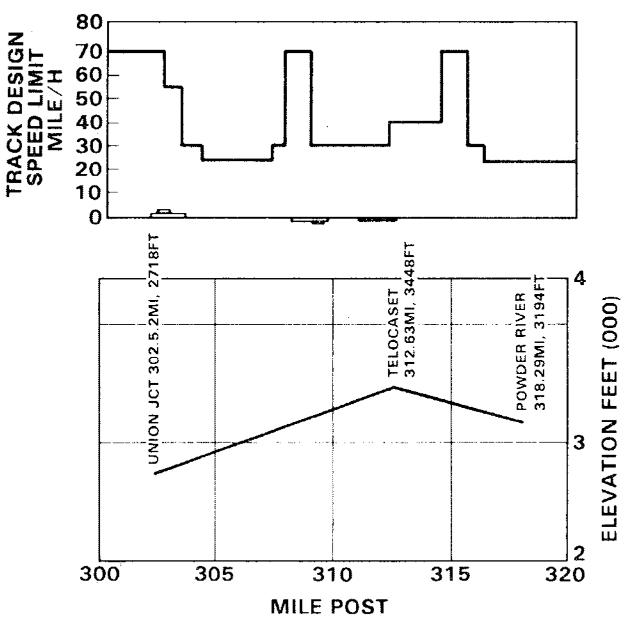
TRAFFIC DENSITY

EASTBOUND 19.2×10^6 TON/YEAR
WESTBOUND 14.1×10^6 TON/YEAR

GRADE IDENTIFICATION NUMBER 036



GRADE IDENTIFICATION NUMBER 036



UNION PACIFIC RAILROAD

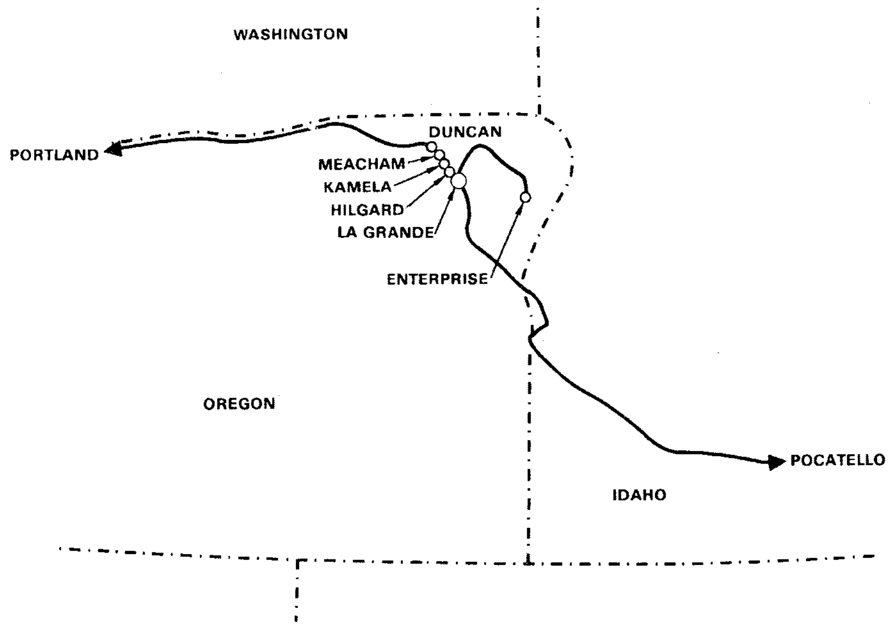
OREGON DIVISION

TRAFFIC DENSITY

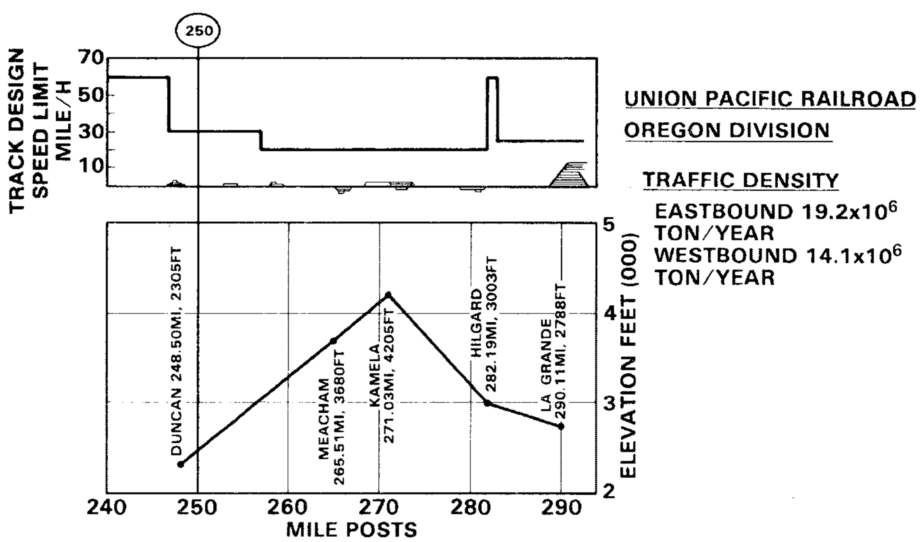
EASTBOUND 19.2×10^6 TON/YEAR

WESTBOUND 14.1×10^6 TON/YEAR

GRADE IDENTIFICATION NUMBER 037



GRADE IDENTIFICATION NUMBER 037



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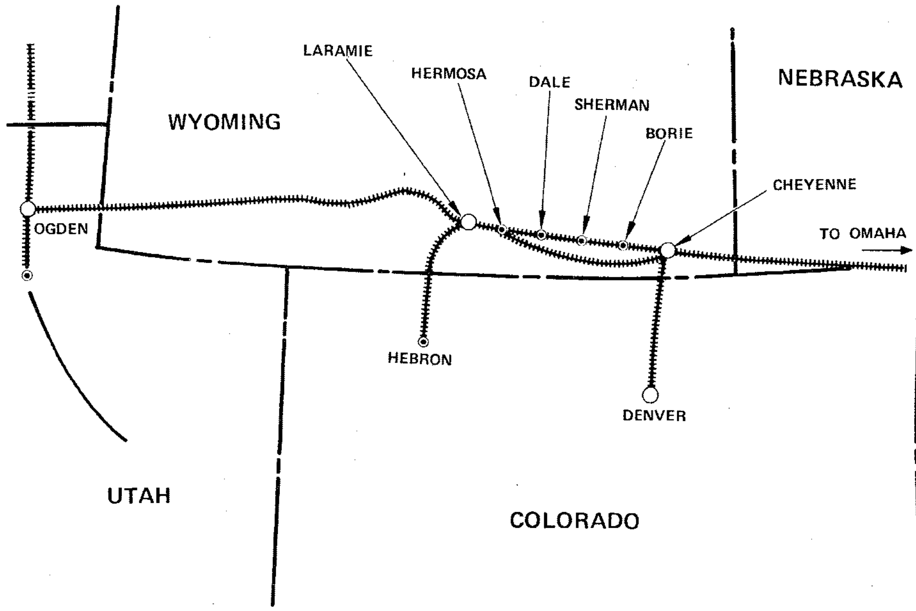

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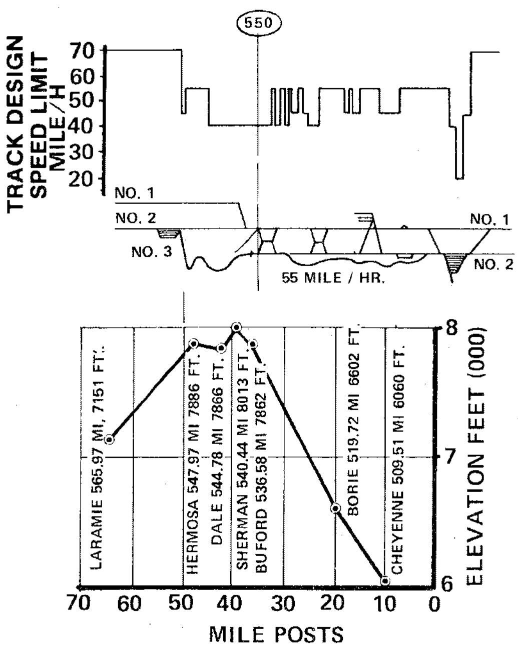


UNION PACIFIC RAILROAD

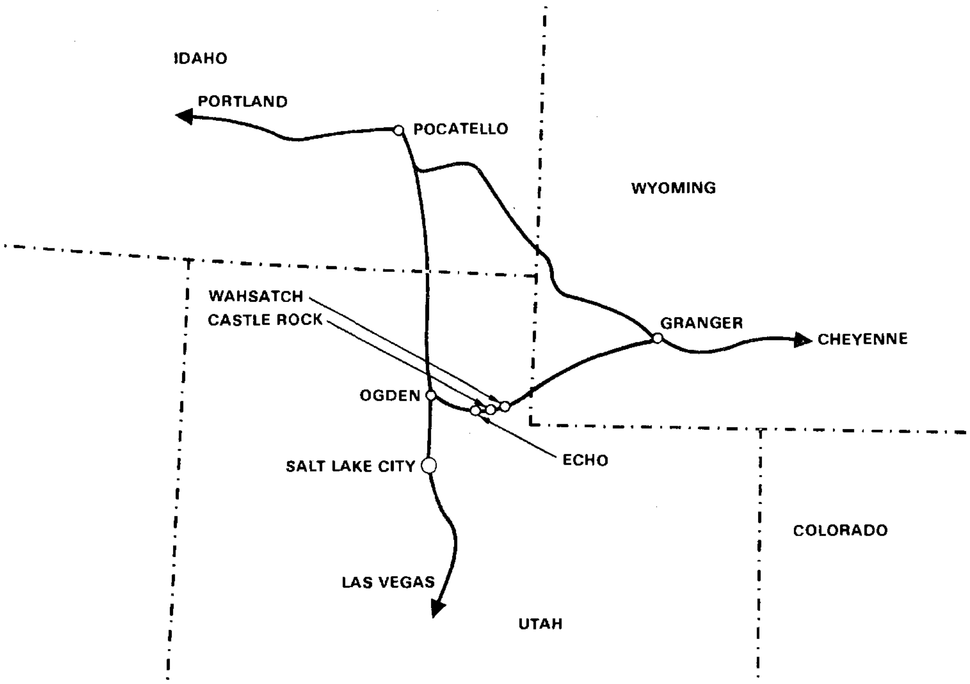
WYOMING DIVISION MAINLINE

TRAFFIC DENSITY

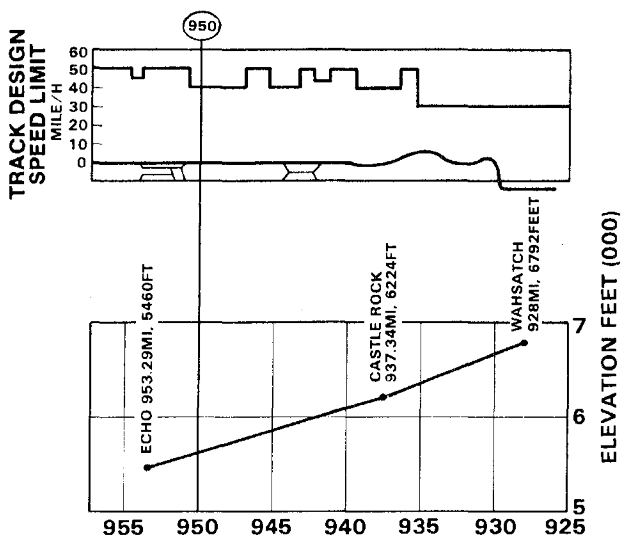
EASTBOUND 77×10^6 TON/YEAR

WESTBOUND 37×10^6 TON/YEAR

GRADE IDENTIFICATION NUMBER 061



GRADE IDENTIFICATION NUMBER 061



UNION PACIFIC RAILROAD

WYOMING DIVISION

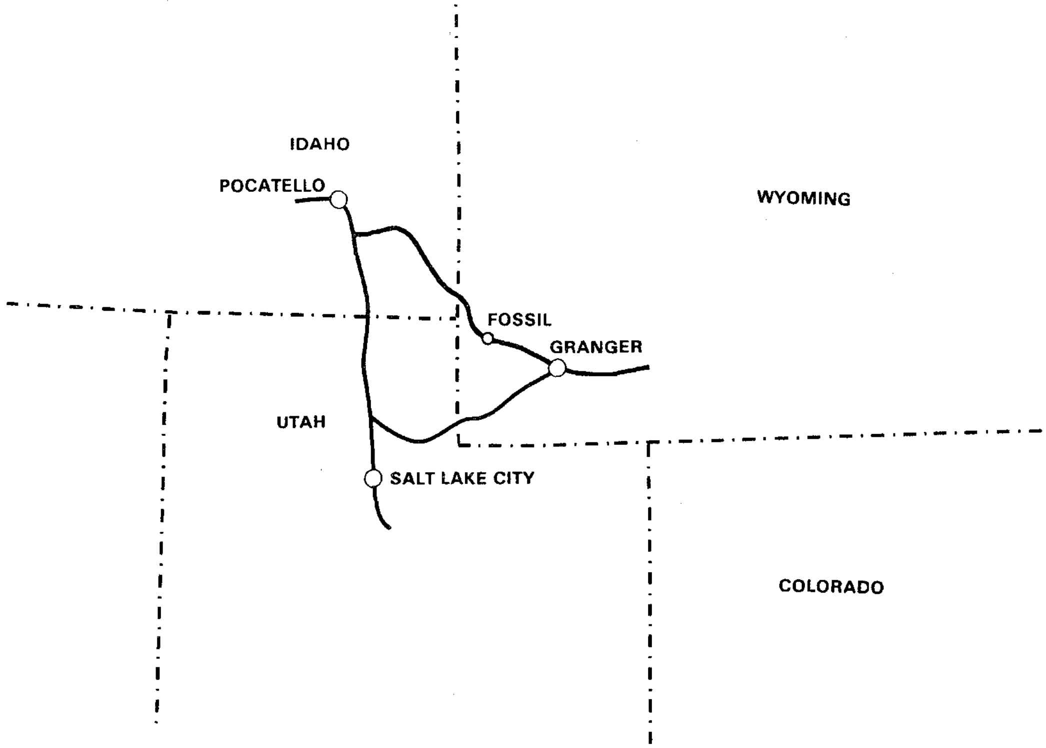
MAIN LINE

TRAFFIC DENSITY

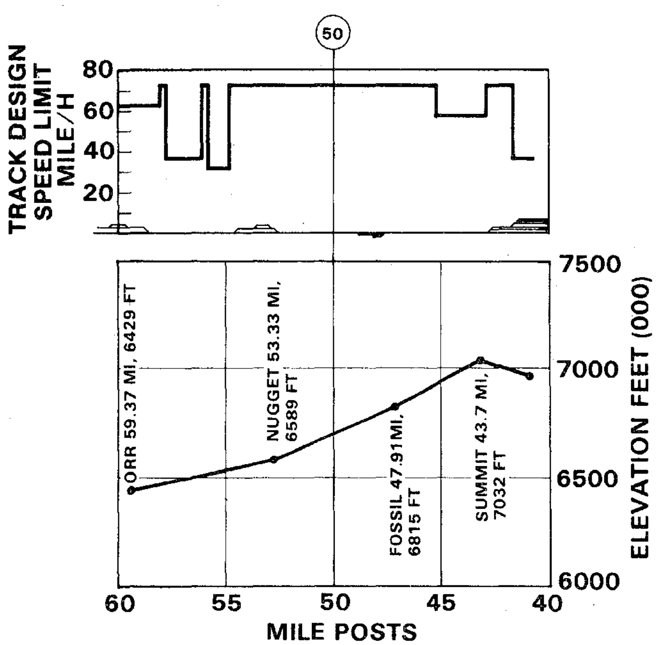
EASTBOUND $30.6x10^6$ TON/YEAR

WESTBOUND $28.8x10^6$ TON/YEAR

GRADE IDENTIFICATION NUMBER 063



GRADE IDENTIFICATION NUMBER 063



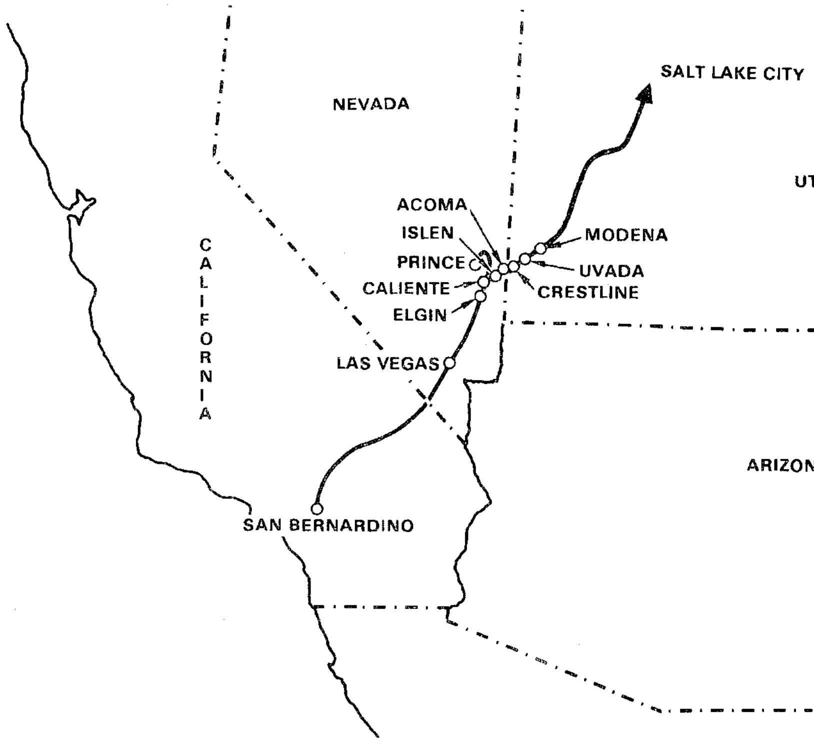
UNION PACIFIC RAILROAD

IDAHO DIVISION — MAINLINE

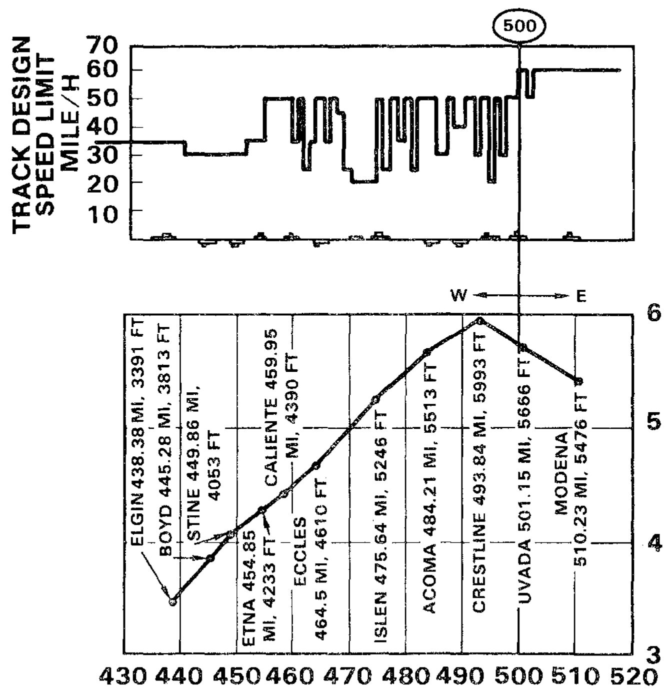
TRAFFIC DENSITY

IN EACH DIRECTION
22.5x10[6] TON/YEAR

GRADE IDENTIFICATION NUMBER 088



GRADE IDENTIFICATION NUMBER 088



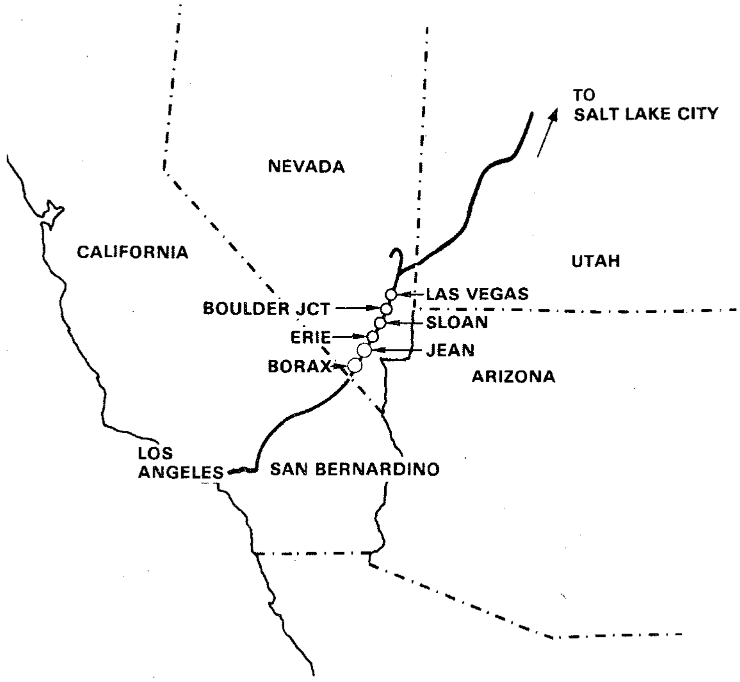
UNION PACIFIC RAILROAD

UTAH DIVISION MAINLINE

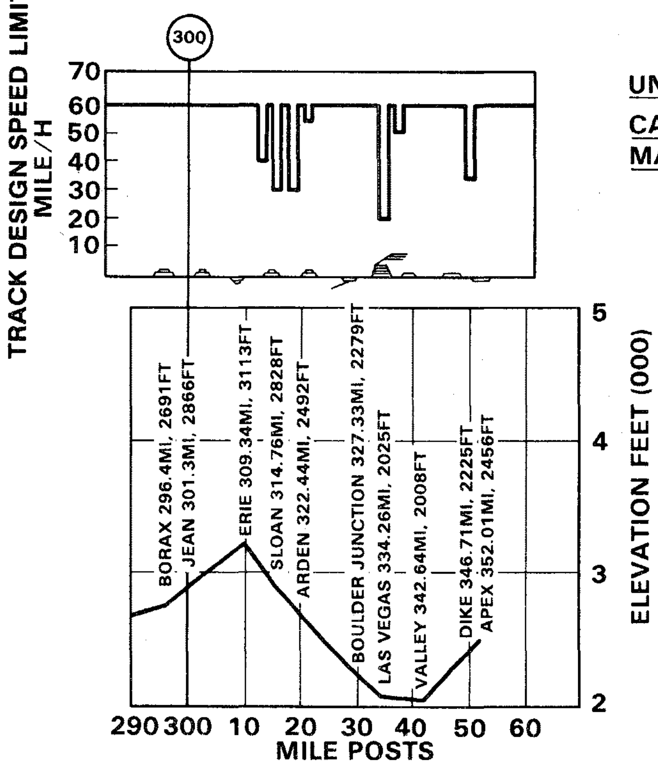
TRAFFIC DENSITY

EASTBOUND 10.6×10^6 TON/YEAR
WESTBOUND 17.9×10^6 TON/YEAR

GRADE IDENTIFICATION NUMBER 089



GRADE IDENTIFICATION NUMBER 089



UNION PACIFIC RAILROAD

CALIFORNIA/UTAH DIVISION

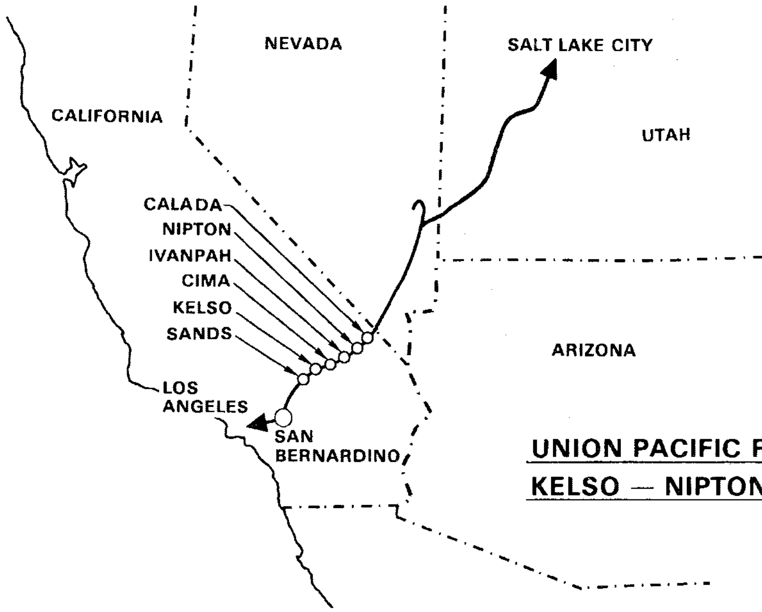
MAIN LINE

TRAFFIC DENSITY

EASTBOUND 14.9×10^6 TON/YEAR

WESTBOUND 13×10^6 TON/YEAR

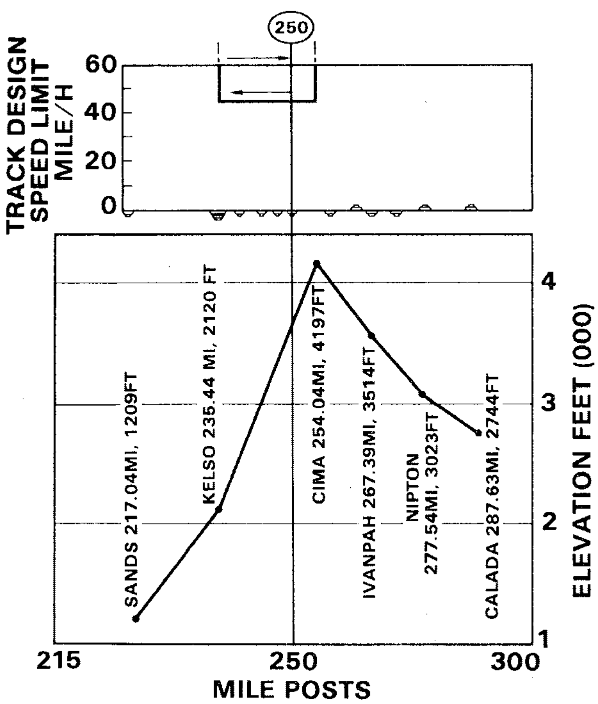
GRADE IDENTIFICATION NUMBER 090



UNION PACIFIC RAILROAD

KELSO — NIPTON

GRADE IDENTIFICATION NUMBER 090



UNION PACIFIC RAILROAD

CALIFORNIA DIVISION

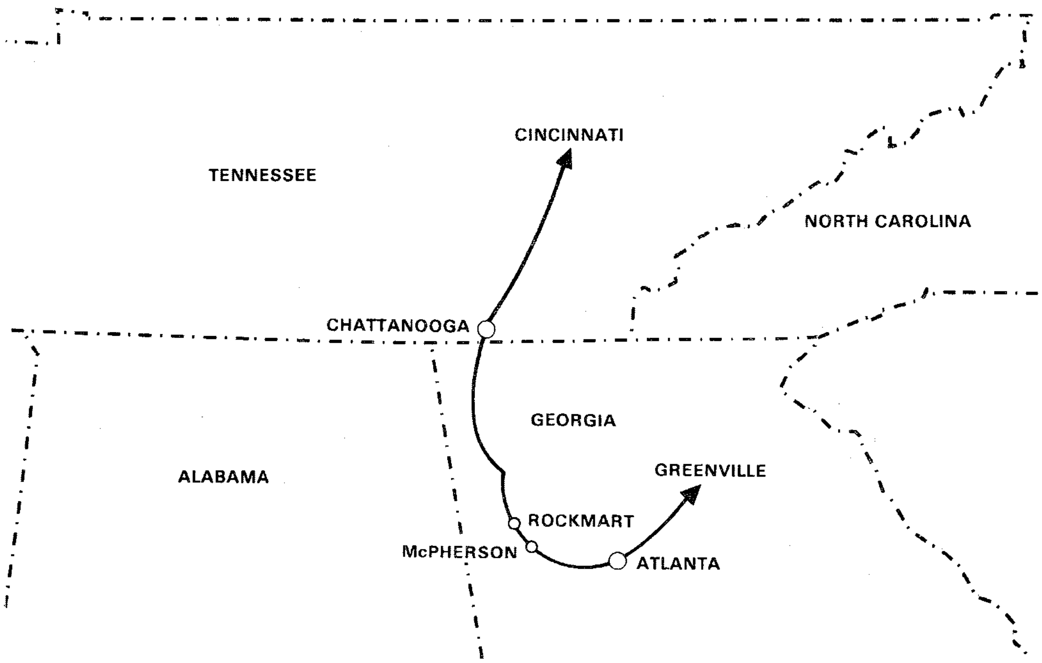
MAIN LINE

TRAFFIC DENSITY

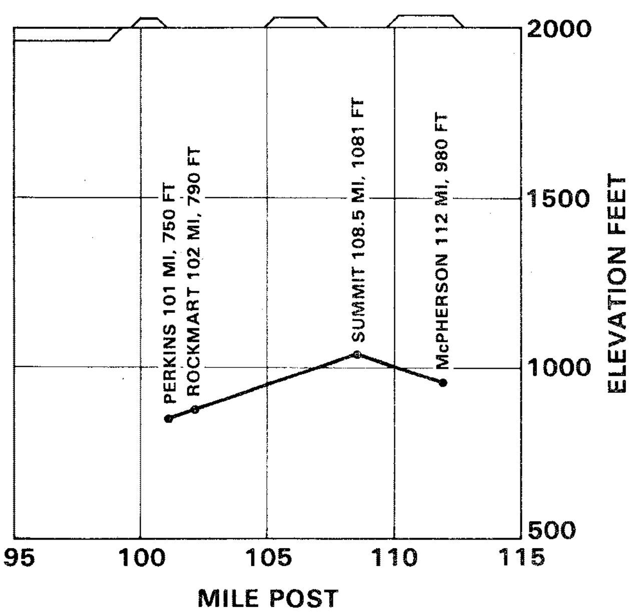
EASTBOUND $14.9x10^6$ TON/YEAR

WESTBOUND $13x10^6$ TON/YEAR

GRADE IDENTIFICATION NUMBER 121



GRADE IDENTIFICATION NUMBER 121



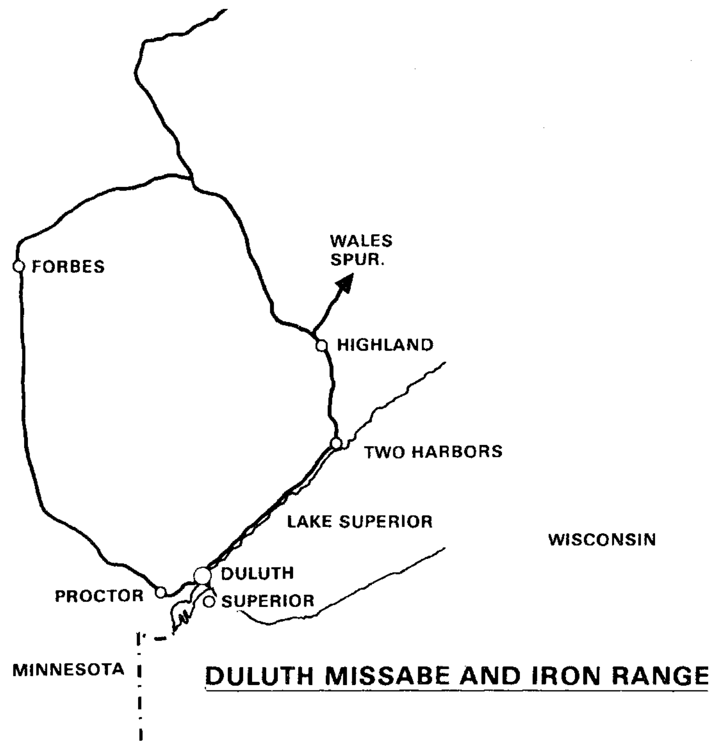
SOUTHERN RAILWAY

BRASWELL MOUNTAIN

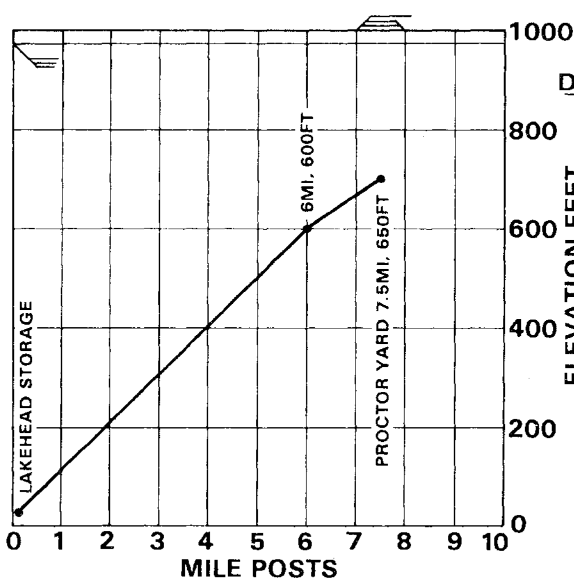
TRAFFIC DENSITY

NORTHBOUND 19×10^6 TON/YEAR
SOUTHBOUND 22×10^6 TON/YEAR

GRADE IDENTIFICATION NUMBER 145



GRADE IDENTIFICATION NUMBER 145



DULUTH MISSABE AND IRON RANGE

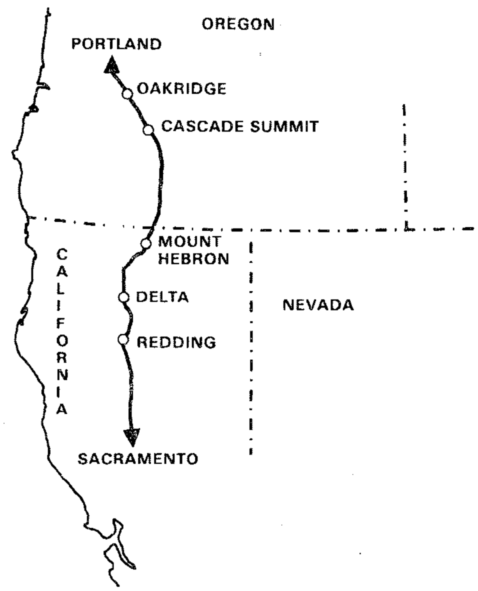
MISSABE DIVISION

TRAFFIC DENSITY

25.7 x10^6 TON/YEAR DOWNHILL

5.9 x10^6 TON/YEAR UPHILL

GRADE IDENTIFICATION NUMBER 175 AND 176



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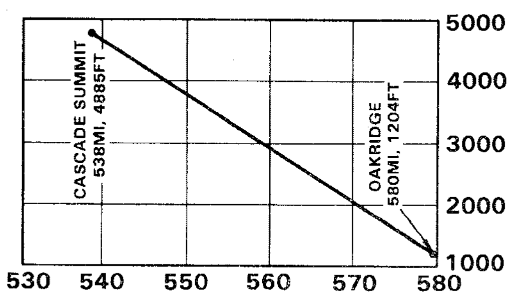


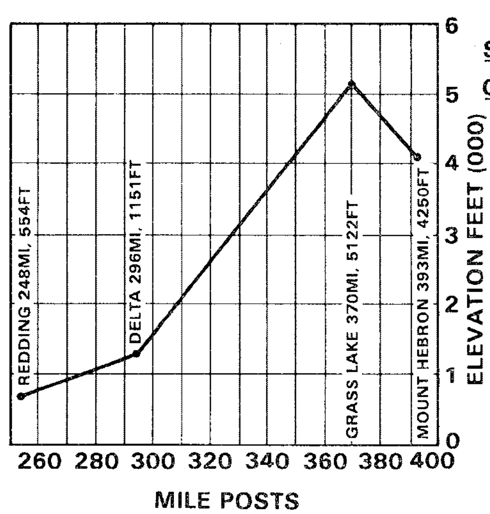
SOUTHERN PACIFIC RAILROAD

CASCADES II

TRAFFIC DENSITY

EASTBOUND 18.42×10^6 TON/YEAR
WESTBOUND 21.52×10^6 TON/YEAR

GRADE IDENTIFICATION NUMBER 176



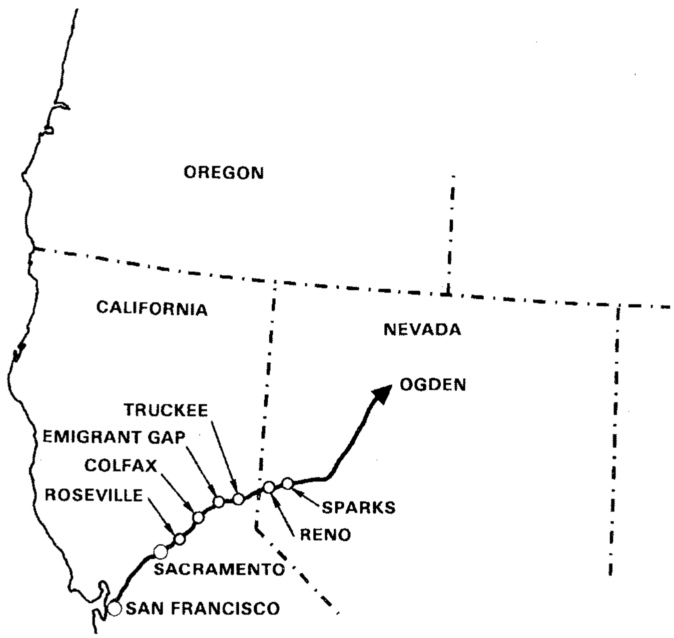
SOUTHERN PACIFIC RAILROAD

CASCADES I

TRAFFIC DENSITY

EASTBOUND 16.02×10^6 TON/YEAR
WESTBOUND 19.02×10^6 TON/YEAR

GRADE IDENTIFICATION NUMBER 183



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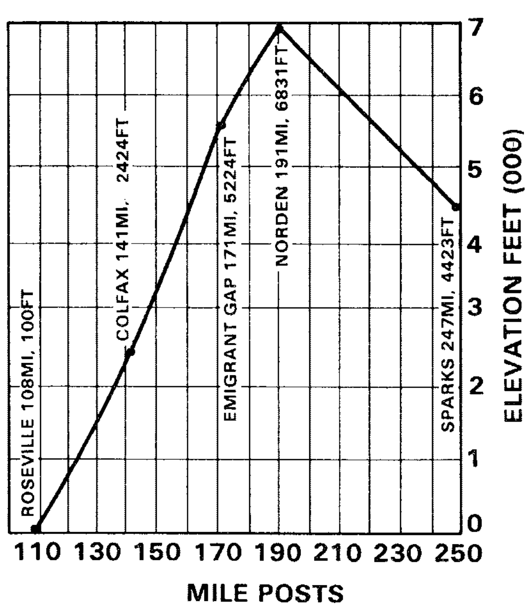


<u>SOUTHERN PACIFIC RAILROAD</u>

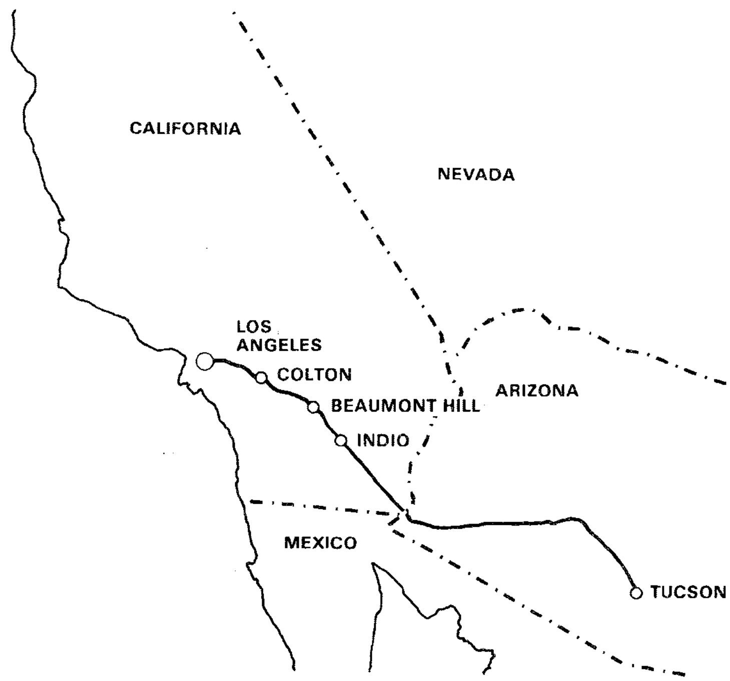
<u>SIERRAS</u>

<u>TRAFFIC DENSITY</u>

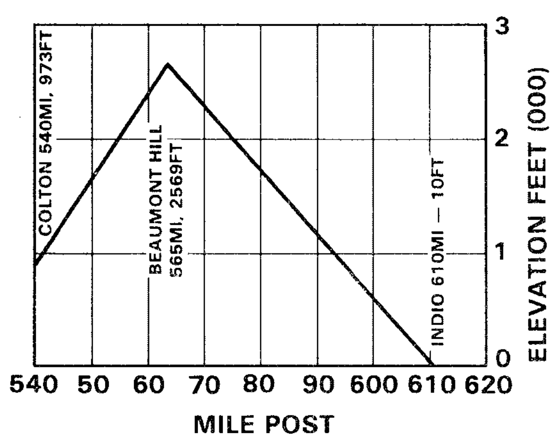
EASTBOUND 16.79 $\times 10^6$ TON/YEAR

WESTBOUND 20.25 $\times 10^6$ TON/YEAR

GRADE IDENTIFICATION NUMBER 195



GRADE IDENTIFICATION NUMBER 195



SOUTHERN PACIFIC RAILROAD

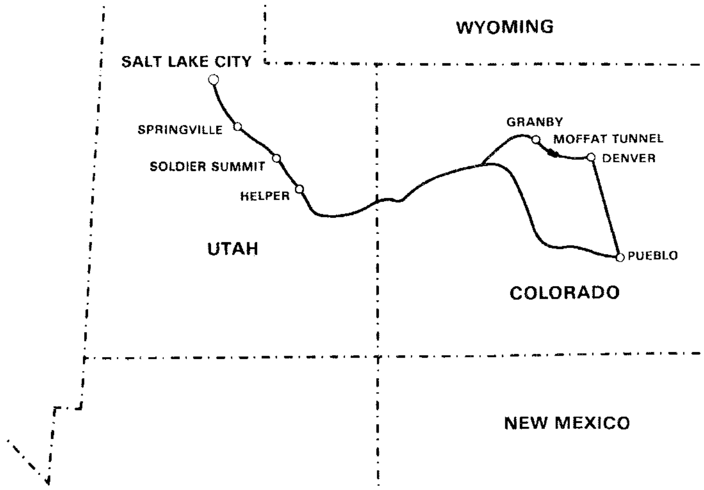
BEAUMONT HILL

TRAFFIC DENSITY

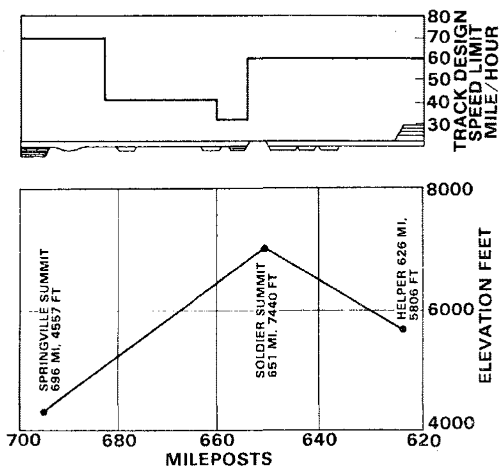
EAST BOUND 21.53×10^6 TON/YEAR

WESTBOUND 26.10×10^6 TON/YEAR

GRADE IDENTIFICATION NUMBERS 202, 206



GRADE IDENTIFICATION NUMBER 202



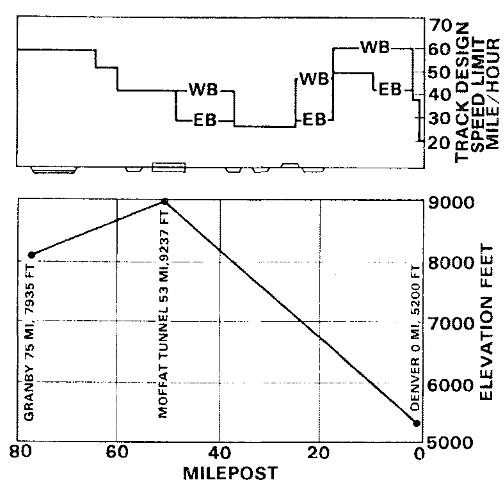
DENVER & RIO GRANDE WESTERN

HELPER — SPRINGVILLE

TRAFFIC DENSITY

17.5x10⁶ TON/YEAR IN EACH DIRECTION

GRADE IDENTIFICATION NUMBER 206



DENVER & RIO GRANDE WESTERN

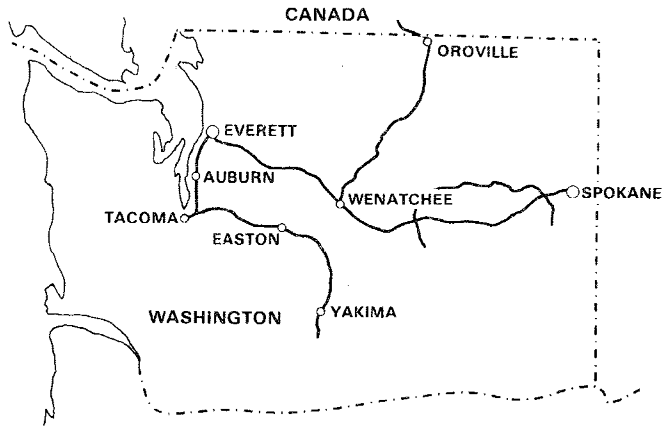
DENVER — GRANBY

TRAFFIC DENSITY

EASTBOUND
17x10⁶ TON/YEAR

WESTBOUND
14x10⁶ TON/YEAR

GRADE IDENTIFICATION NUMBERS 220, 222



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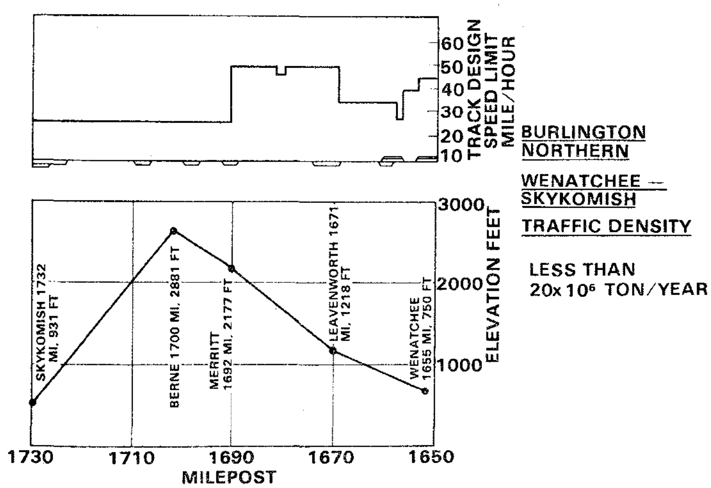
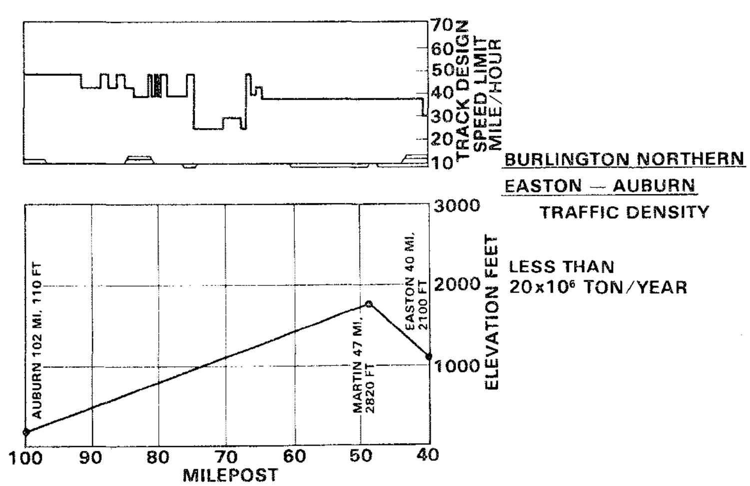
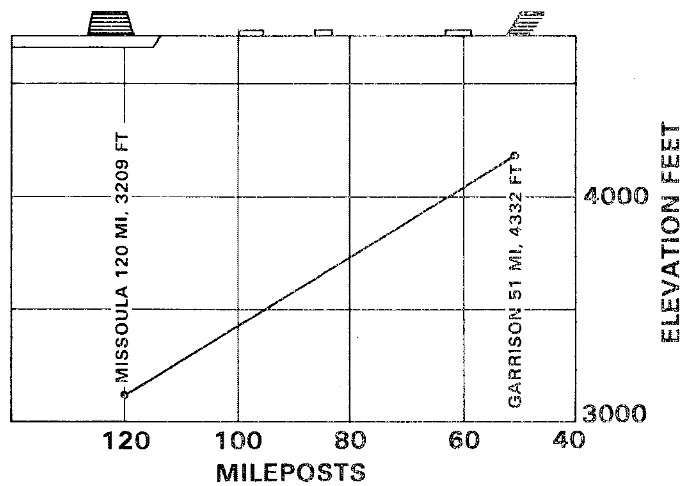


GRADE IDENTIFICATION NUMBER 222



GRADE IDENTIFICATION NUMBER 226

SPEED DATA NOT SUPPLIED



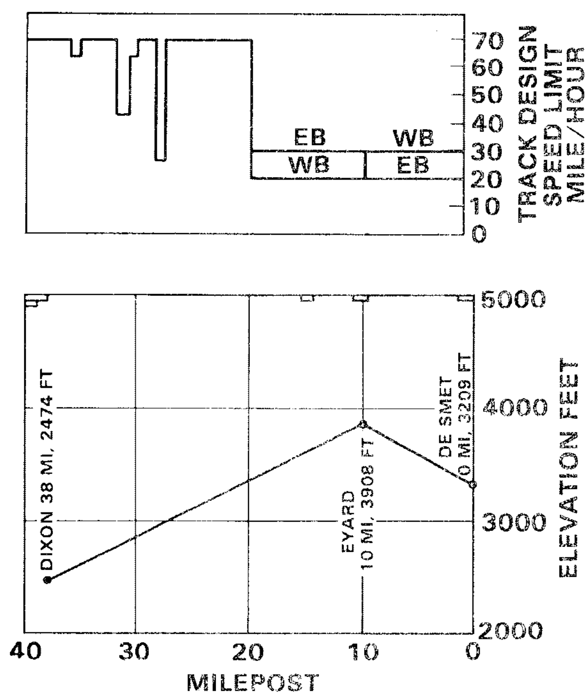
BURLINGTON NORTHERN

GARRISON — MISSOULA

TRAFFIC DENSITY

LESS THAN
20x10⁶ TON/YEAR

GRADE IDENTIFICATION NUMBER 227



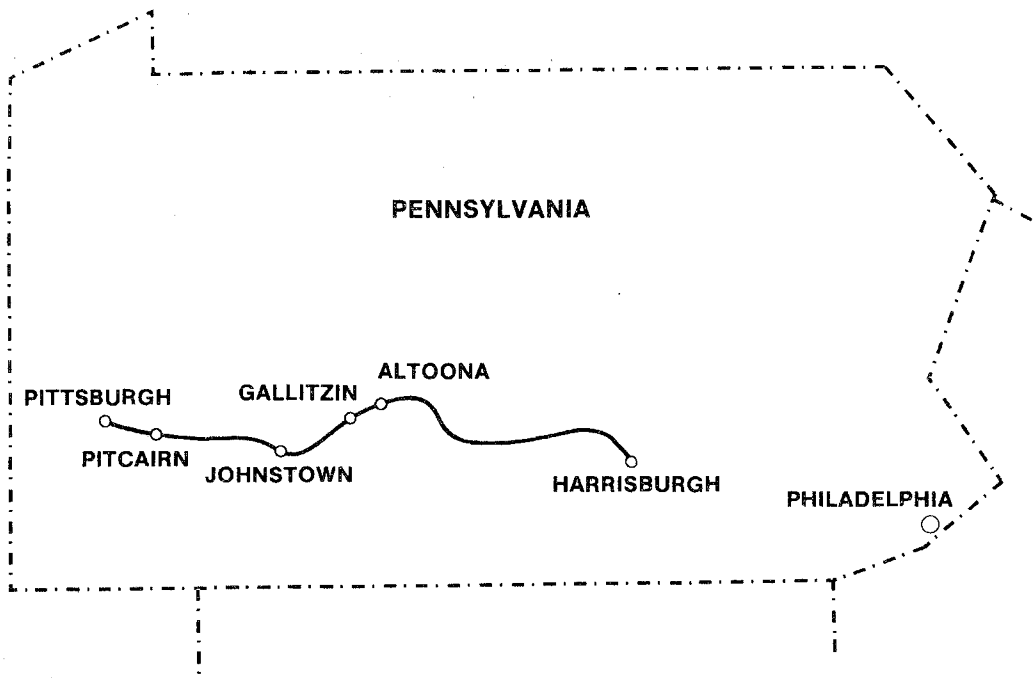
BURLINGTON NORTHERN

DE SMET — DIXON

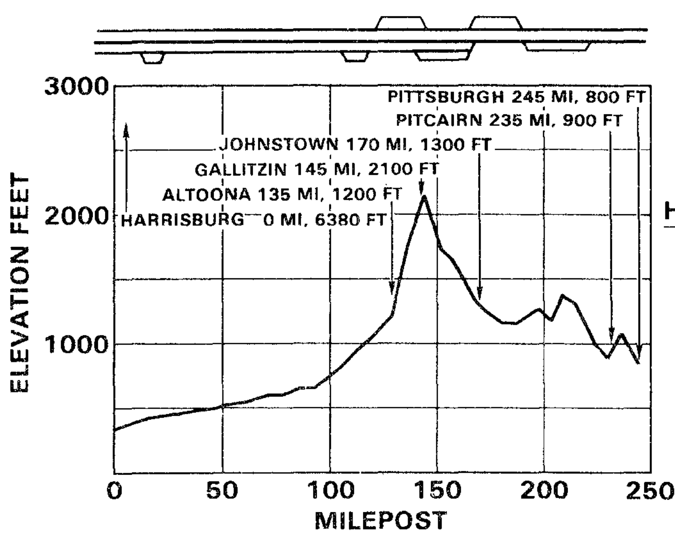
TRAFFIC DENSITY

LESS THAN
20x10⁶ TON/YEAR

GRADE IDENTIFICATION NUMBER 230



GRADE IDENTIFICATION NUMBER 230



CONSOLIDATED RAIL CORPORATION

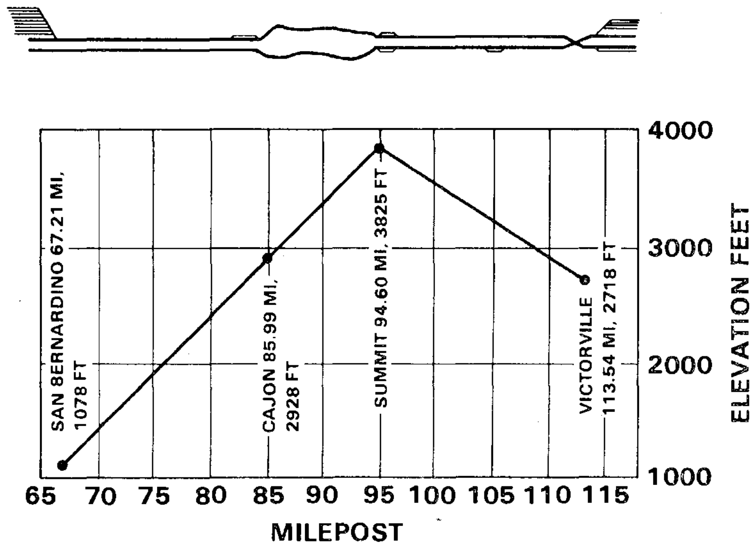
HARRISBURG — PITTSBURGH

TRAFFIC DENSITY
$56.8x10^6$ TON/YEAR
IN EACH DIRECTION

GRADE IDENTIFICATION NUMBER 240

GRADE IDENTIFICATION NUMBER 240

SPEED LIMITS SET BY AT&SF (NOT MADE AVAILABLE)



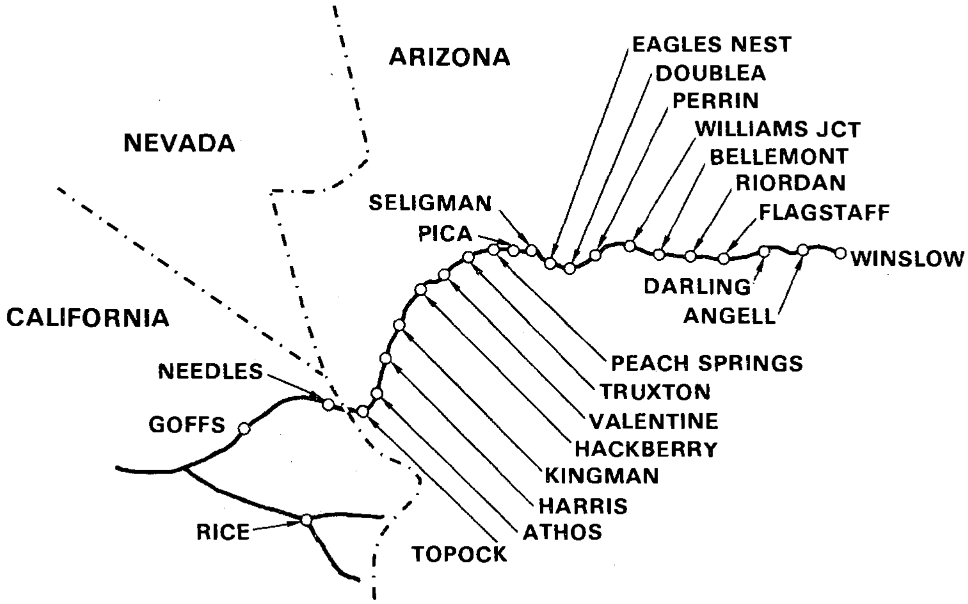
ATCHISON TOPEKA & SANTA FE UNION PACIFIC RAILROAD (LINES JOINTLY OPERATED) CAJON PASS

TOTAL TRAFFIC DENSITY

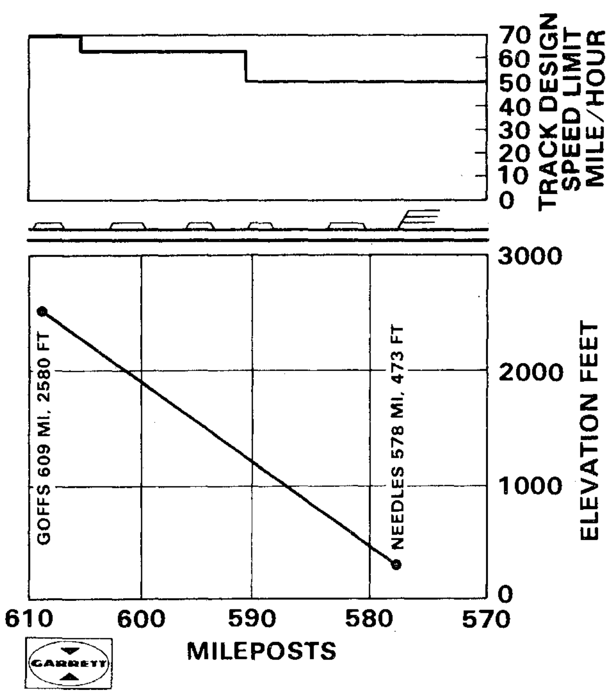
30.1×10^6 TON/YEAR EASTBOUND

41×10^6 TON/YEAR WESTBOUND

GRADE IDENTIFICATION NUMBERS 242, 243, 244, 246, 247, 248



GRADE IDENTIFICATION NUMBER 242



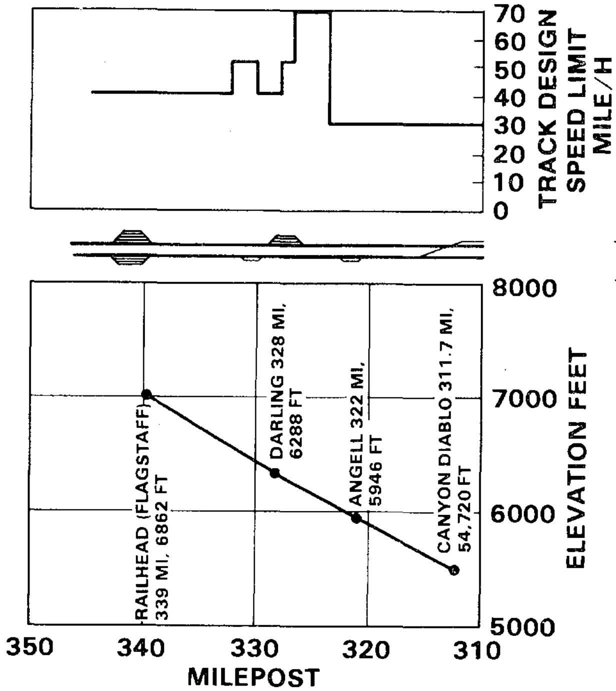
ATCHISON TOPEKA & SANTA FE

NEEDLES — GOFFS

TRAFFIC DENSITY

EASTBOUND $26x10^6$ TON/YEAR
WESTBOUND $32x10^6$ TON/YEAR

GRADE IDENTIFICATION NUMBER 243



ATCHISON TOPEKA & SANTA FE

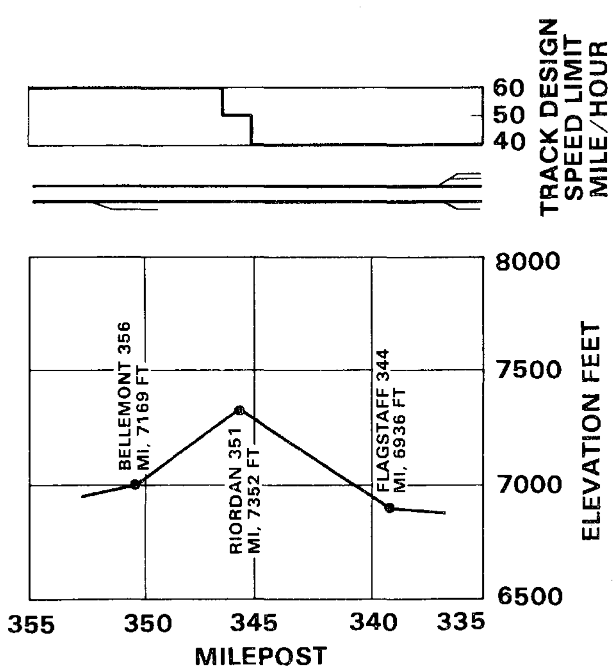
FLAGSTAFF — CANYON DIABLO

TRAFFIC DENSITY

EASTBOUND 28x10^{6} TON/YEAR

WESTBOUND 34x10^{6} TON/YEAR

GRADE IDENTIFICATION NUMBER 244



ATCHISON TOPEKA & SANTA FE

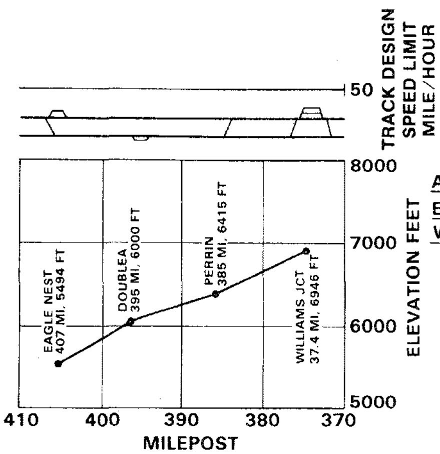
BELLEMONT — FLAGSTAFF

TRAFFIC DENSITY

EASTBOUND 28x10^{6} TON/YEAR

WESTBOUND 34x10^{6} TON/YEAR

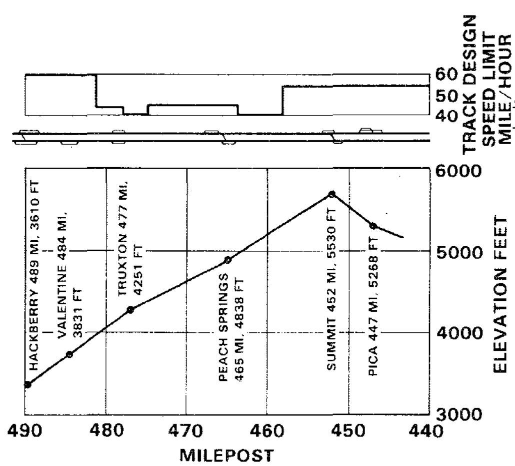
GRADE IDENTIFICATION NUMBER 246



ATCHISON TOPEKA & SANTA FE
EAGLE NEST —
WILLIAMS JUNCTION

TRAFFIC DENSITY
EASTBOUND
$26x10^6$ TON/YEAR
WESTBOUND
$32x10^6$ TON/YEAR

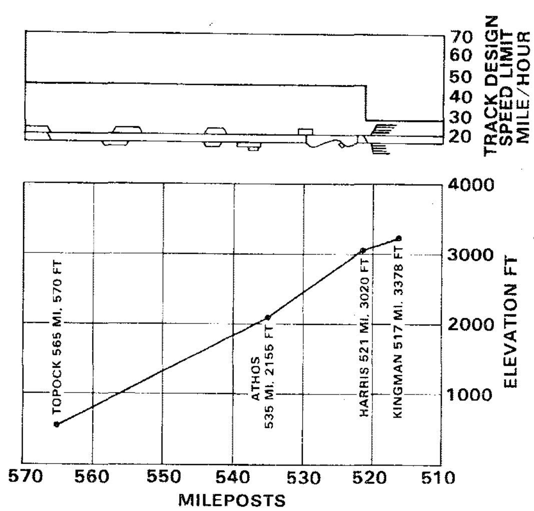
GRADE IDENTIFICATION NUMBER 247



ATCHISON TOPEKA
& SANTA FE
HACKBERRY — PICA

TRAFFIC DENSITY
EASTBOUND
$26x10^6$ TON/YEAR
WESTBOUND
$32x10^6$ TON/YEAR

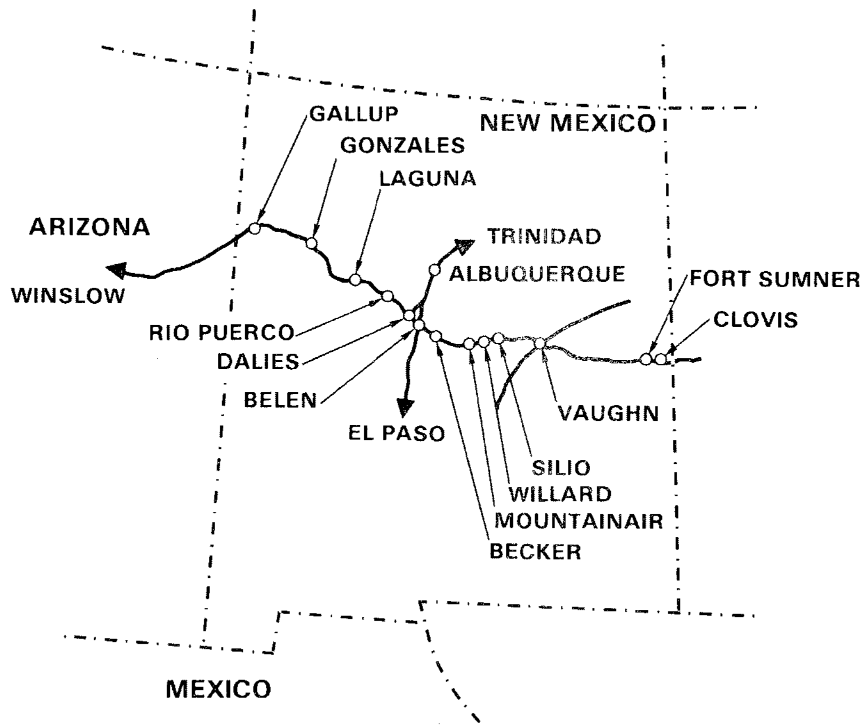
GRADE IDENTIFICATION NUMBER 248



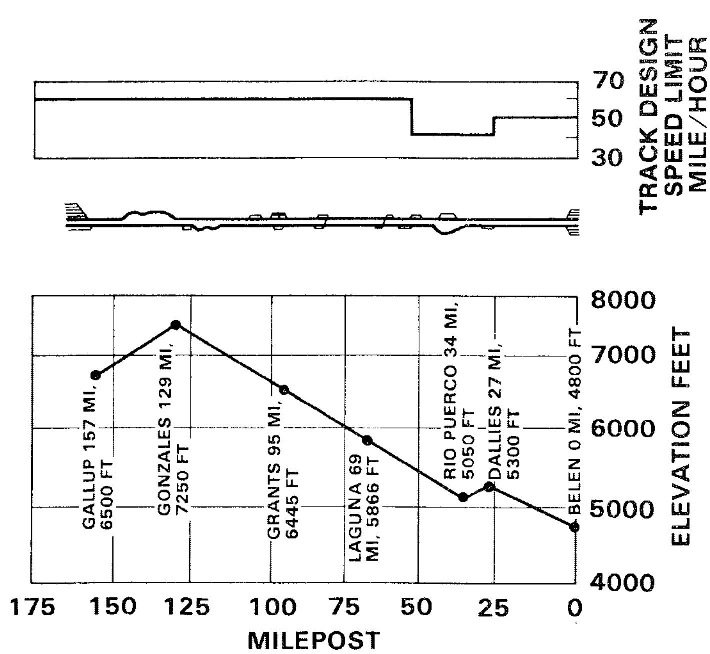
ATCHISON TOPEKA &
SANTA FE
TOPOCK — KINGMAN

TRAFFIC DENSITY
EASTBOUND
$26x10^6$ TON/YEAR
WESTBOUND
$32x10^6$ TON/YEAR

GRADE IDENTIFICATION NUMBERS 251, 252, 255



GRADE IDENTIFICATION NUMBER 251



ATCHISON TOPEKA & SANTA FE

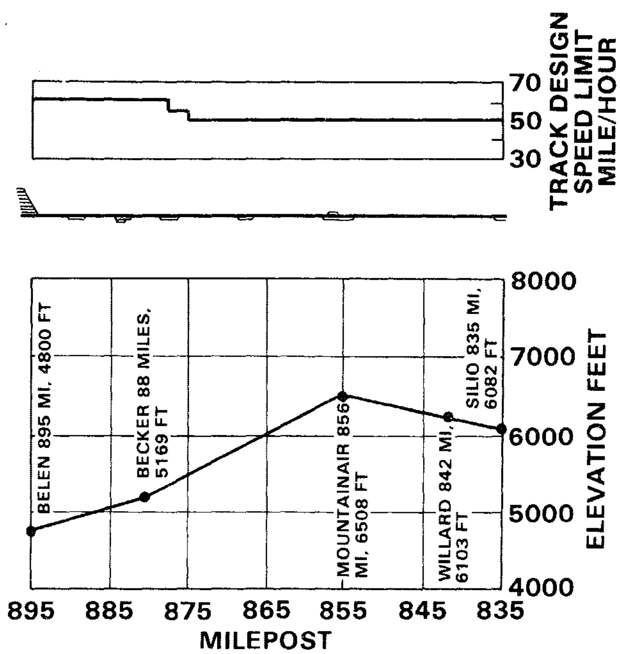
GALLUP — BELEN

TRAFFIC DENSITY

EASTBOUND
$27x10^6$ TON/YEAR

WESTBOUND
$32x10^6$ TON/YEAR

GRADE IDENTIFICATION NUMBER 252



ATCHISON TOPEKA & SANTA FE

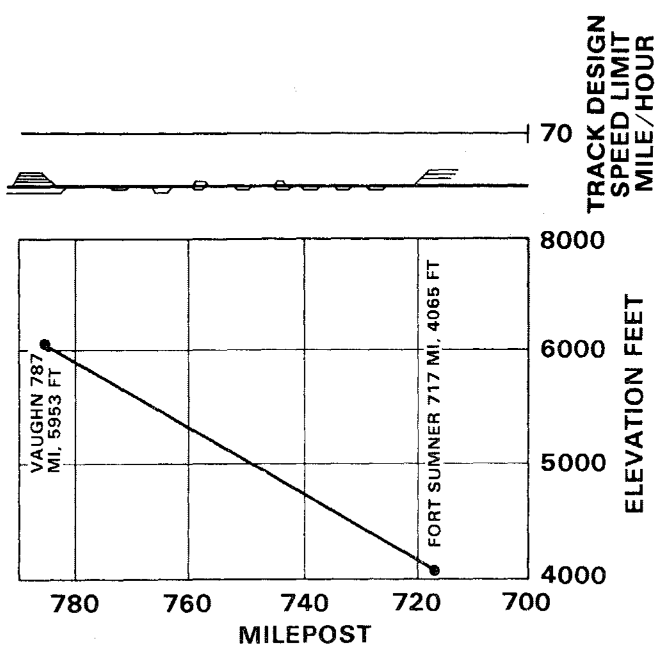
BELEN — SILIO

TRAFFIC DENSITY

EASTBOUND $26x10^6$ TON/YEAR

WESTBOUND $33x10^6$ TON/YEAR

GRADE IDENTIFICATION NUMBER 255



ATCHISON TOPEKA & SANTA FE

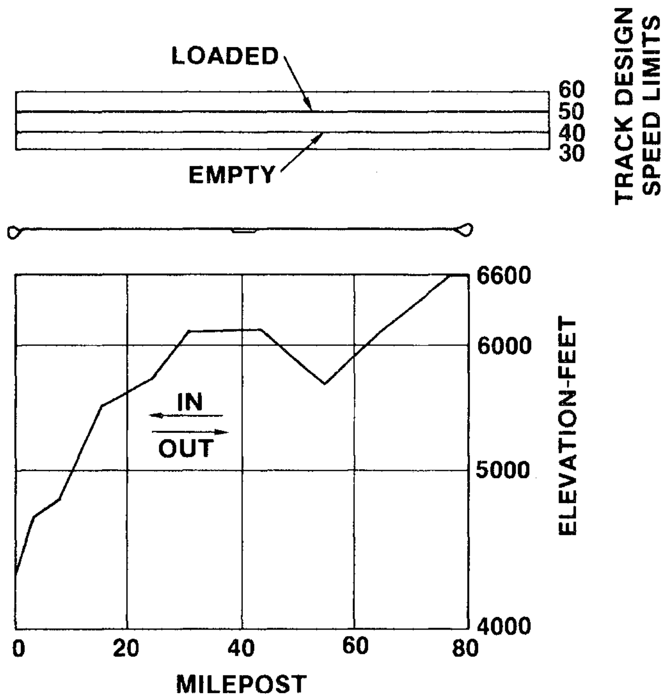
VAUGHN — FORT SUMNER

TRAFFIC DENSITY

EASTBOUND $26x10^6$ TON/YEAR

WESTBOUND $33x10^6$ TON/YEAR

GRADE IDENTIFICATION NUMBER 261



BLACK MESA AND LAKE POWELL RAILROAD (ARIZONA)

TRAFFIC DENSITY

IN — 44,000 GTT/DAY
OUT — 9840 GTT/DAY

APPENDIX D

WESS FLYWHEEL COST ANALYSIS

ASSUMPTIONS

The following are assumed in this WESS flywheel cost analysis:

Flywheel capacity	7.333 MWhr
Rotor material	Lukens Electro Slag Remelt 4340 Steel
Rotor weight	604.4 tons
Rotor diameter	13.5 ft
Rotor length	17.28 ft
Rotor material cost	\$0.60/lb
Material scrap value	\$0.15/lb

ROTOR MATERIAL COST

Based on through hardenability of 3 in.,

$$\text{No. of rotor plates} = \frac{17.28}{0.25}\ 69$$

because the top and bottom plates are forgings. Also allow 0.25 in. for machining top and bottom plate surfaces; also allow 1 in. on the radius. Then,

Material weight = $(13.667)^2(12)^2(3.5)(0.283)(67)$ = 1,785,000 lb

Material cost = (1,785,000)(0.6) = \$1,071,000

Actual material required = $(13.5)^2(12)^2(3)(.283)(67)\pi/4$ = 1,172,472 lb

Scrap value = (0.15)(612,528) = \$91,872

Total material cost = \$979,121

TOP AND BOTTOM FORGING MATERIAL COST

$$\text{Useful weight} = \frac{2.12}{69.12}(604.4)(2000) = 37,075 \text{ lb}$$

But, assume that twice useful material is required for forging:

Material weight = 74,151 lb

Scrap weight = 37,075 lb

Material cost = (74,151)(0.6) - (37,075)(0.15) = $38,929

ROTOR PLATE PREPARATION COST

Labor hours for rotor plate preparation are as follows:

Process	Labor Hr/Plate
Flame cut to 13.67 ft diameter	4
Mill both sides to reach 3.1 in. thickness	8
Blanchard grind both sides 0.050 in.	16
Bore twenty-four 6-in. holes	12
Finish machine diameter to 13.5 ft	16
Heat treat	8
Inspection	6
Total	70 hr

Assume labor cost at $22/hr. Then,

Plate preparation cost = (67)(70)(22) = $103,180

TOP AND BOTTOM FORGING PREPARATION COST

Labor hours for top and bottom forging preparation are as follows:

Process	Labor Hr/Plate
Heating and handling	24
Rough forging	80
Final forging	40
Bore twenty-four 6-in. holes	24
Final machining	160
Heat treat	12
Inspection	24
Total	374 hr

Total forging preparation cost = (2)(374)(22) = $16,456

THROUGH-BOLT COST

Assume machining from 6.5-in. rod.

Material weight = $(24)(20)(12)6.5)^2(.283)\pi/4$ = 54,091 lb.

Material cost (4340 steel) = (54,091)(0.6) = \$32,455

Cost to fabricate:

Process		Labor Hr/Bolt
Turn to diameter		16
Cut threads (both ends)		16
Heat treat		4
Inspection		4
	Total	40 hr

Total fabrication cost = (24)(40)(22) = \$21,120

Through-bolt cost totals:

Material		\$32,455
Fabrication		21,120
Nuts (48)		7,200
	Total Cost	\$60,775

HOUSING MATERIAL COST

Housing material cost analysis is based on a 2-in.-thick conformal housing with reinforced top and bottom fabricated from 1020 grade steel (cost \$0.20/lb). Housing height is 20 feet with an inside diameter of 13.7 ft.

Weight of cylinder = $(14,033^2 - 13.7^2)(12)^2(20)(12)(.283)\pi = 71,012$ lb

Weight of top and bottom = $(2)(14.033)^2(12)^2(2)(.283) = 32,100$ lb

Total material cost = (0.2)(103.112) = \$20,622

HOUSING FABRICATION COST

Labor hours for housing fabrication are as follows:

Process		Labor Hr
Roll cylinder		160
Weld cylinder		80
Machine cylinder ends		80
Flame cut top and bottom		16
Reinforce top and bottom		80
Machine top and bottom		240
Inspection		64
	Total	720 hr

Housing fabrication cost = (720)(22) = \$15,840

TOP AND BOTTOM BEARING AND SEAL ASSEMBLY COST

Labor hours for top and bottom bearing and seal assembly are as follows:

Process		Labor Hr
Machine top assembly		960
Machine bottom assembly		1200
Inspection		216
	Total	2376 hr

Total fabrication cost = (2376)(22) = $52,272

Material including seals and bearings = $10,000

Total bearing and seal assembly cost = $62,272

ANCILLARIES AND ASSEMBLY MATERIAL COST

The cost for ancillaries and assembly material is:

2	High-pressure lube pumps	$ 4000
2	Low-pressure lube pumps	1000
2	Vacuum pumps	3000
2	Heat exchanger systems	2000
2	Sumps	800
1	Air compressor	500
1	Air reservoir and controls	1500
6	Hydraulic jacks	6000
1	Set misc. assembly material	20000
	Total Ancillary Cost	$38,000

FLYWHEEL SHIPMENT COST

Assuming a rail shipment of 2500 miles, the quotation for flywheel shipment from ATSF and Conrail is $49,776.

FLYWHEEL ASSEMBLY AND TEST COST

Labor hours for flywheel assembly and test are as follows:

Process	Labor Hr
Install bottom housing and bearing	480
Stack flywheel discs	690
Assemble housing and top support	720
Install ancillaries	640
Install flywheel machine	480
Test rotating system	240
Disassemble and balance rotor	480
Reassemble	240
Conduct system tests	960
Total	4930 hr

Flywheel assembly and test cost = (4930)(22) = $108,460

COST SUMMARY

The preceding costs can be summarized as follows:

Element	Cost
Rotor material	$1,071,000
Top and bottom forging material	38,929
Rotor plate preparation	103,180
Top and bottom forging preparation	16,456
Through-bolt	60,775
Housing material	20,622
Housing fabrication	15,840
Top and bottom bearing and seal assemblies	62,272
Ancillaries and assembly material	38,800
Flywheel shipment	49,776
Flywheel assembly and test	108,460
Total Cost	$1,586,110

Then,

Cost/Kwhr = $216.29

Assume general and administrative cost plus profit of 25 percent.

Final Cost/Kwhr of flywheel = $270

APPENDIX E

WESS ECONOMICS PROGRAM LISTING

```
@FOR,S   WESS
FOR 003E-05/15/78-13:22:34 (0,)

   MAIN PROGRAM

   STORAGE USED: CODE(1) 000055; DATA(0) 000014; BLANK COMMON(2) 003321

    COMMON BLOCKS:

    0003    AAAAAA 001230
    0004    BBBBBB 000070
    0005    EEEEEE 000135

   EXTERNAL REFERENCES (BLOCK, NAME)

    0006    NINTRO
    0007    INPUT
    0010    DETAIL
    0011    NINTR$
    0012    XPRR
    0013    NSTOP$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000026 10L     0001    000045 1346    0002    002727 ADDLAB  0002    003320 ACDLA9  0002    002117 ADLABR
    0002    003161 ADLAB9  0002    002273 BENFCR  0005    000071 BEN2    0002    001505 CILMCS  0004    000067 CONST
    0002    001347 COSEND  0002    002777 COSEN9  0002    001323 COSMOD  0002    001313 COSNEW  0002    001333 COSTRA
    0002    001535 DFSIPG  0002    001525 DFSMPG  0003    000703 DISCON  0002 I  002473 EHCREW  0002    001545 EHELPM
    0002    003137 EHELP9  0002    002603 ELECHI  0002    003111 ELECH9  0002    002723 ELEENE  0002    003317 ELEEN9
    0002 I  002363 ELEHEL  0002    001655 EMAINT  0002    003203 EMAIN9  0002    001515 EMATPM  0002    000710 ESAVMP
    0002    001765 ESRRMP  0002    003225 ESRRM9  0005 I  000001 FIX     0002    002361 FLYCOS  0002    001130 FLYSC
    0002    000204 FLYWCV  0002    000162 FLYWMA  0002    000140 FLYWS   0003    001206 FNPV    0002 I  000050 GTTONS
    0000 I  000000 I       0002    001274 IANANO  0002 I  002737 IFLAG   0004    000044 IIIIII  0002    001276 ILUSE
    0003    001205 IPR     0002    002337 IRANK   0004    000022 IRANKK  0002    000000 IRNAME  0002 I  001275 IROUTE
    0002    000020 IRROAD  0002    002750 ISEN    0002 I  000360 ISITES  0004    000045 ISUB    0003    001204 KSTART
    0002 F  000120 LOCFMI  0002    001307 LOCTRA  0002    000060 LOCTYP  0002 R  000100 LOCUSE  0002 L  002742 LSCEN1
    0002 L  002743 LSCEN2  0002 L  002744 LSCEN3  0002 L  002745 LSCEN4  0004    000000 MDUMY   0002    000470 MILEPF
    0002    000600 MILEPT  0002    001303 MODLOC  0005    000045 MSUB    0003 R  000062 NAS     0002    001277 NEWLOC
    0002    002747 NH      0002    002746 NL      0005    000000 NOFIX   0002    000054 NOLOC   0002 I  002736 NOSITE
    0002 I  000034 NOSITT  0002    002362 NUSUSE  0003 R  000000 NPV     0002 I  002751 NSUB    0005    000023 NSUB3
    0003    000702 NYRCON  0002    002315 RBEN    0005    000113 RBEN2   0002    001020 REGPL   0002 I  000030 RMILES
    0003    001074 ROI     0003    000764 ROTPER  0002    001343 ROUTEE  0002    002776 ROUTE9  0002    002007 RPEAKD
    0002    003247 RPEAK9  0002 R  002733 R13A6   0002 R  002734 R13A7   0002 R  002735 R13A8   0002 R  002740 R135A7
    0002 R  002741 R135A8  0002    003271 SACC90  0002    003272 SACPS9  0002    002713 SAVLRP  0002 I  001240 SCENIO
    0002    002751 SDCOSI  0002    002227 SUSAVA  0002    003066 SIIV90  0002    001353 SITELE  0002    003022 SITEL9
    0002    000226 STABLD  0002    003067 SUMIV9  0002    001511 TCILMC  0002    003133 TCILM9  0002    000336 TCOSFS
    0002    003000 TCOSF9  0002    000040 TDENER  0002    000044 TDENWB  0002    003136 TDFSI9  0002    003135 TDFSM9
    0002    001541 TDFSTI  0002    001531 TDFSTM  0002    001521 TEMTPM  0002    003134 TEMTP9  0002    001327 TOTMOD
    0002    002774 TOTM09  0002    001317 TOTNEW  0002    002773 TOTNE9  0002    001337 TOTTRA  0002    002775 TOTTR9
    0002    002717 TSAVLR  0002    003316 TSAVL9  0002    001463 TSITEC  0002    003044 TSITE9  0003    000704 XIR
    0005    000070 ZUMACC  0005    000067 ZUMINV


00100      1*     C * * WAYSIDE ENERGY STORAGE STUDY  BY LEN COOK X-2126 AIRESEARCH CALIF          000000
00100      2*     C * *  CO.,TORRANCE,CALIF  MARCH 1978                                             000000
00101      3*           INCLUDE COM1                                                                 000000
```

```
00121      4*            CALL NINTRO(1.E-30,13)                                  000001
00122      5*            R13A6=1.06**13                                          000005
00123      6*            R13A7=1.07**13                                          000007
00124      7*            R13A8=1.08**13                                          000011
00125      8*            R135A7=1.07**13.5                                       000013
00126      9*            R135A6=1.06**13.5                                       000020
00127     10*         10 CONTINUE                                                000026
00130     11*            IFLAG=1                                                 000026
00131     12*            CALL INPUT                                              000027
00132     13*            NOSITE=NOSITT(IROUTE)                                   000031
00133     14*            DO 12 I=1,NOSITE                                        000037
00136     15*         12 NSUB(I)=ISITES(I,IROUTE)                                000045
00140     16*            CALL DETAIL                                             000047
00141     17*            GO TO 10                                                000051
00142     18*            END                                                     000054

       END OF COMPILATION:          NO DIAGNOSTICS.
```

```
#FOR,S   BLKDAT
FOR 003E-05/15/78-13:22:38 (0,)

  BLOCK DATA

  STORAGE USED: CODE(1) 000000; DATA(0) 000000; BLANK COMMON(2) 003321

   COMMON BLOCKS:

   0003     AAAAAA 001230
   0004     BBBBBB 000070
   0005     EEEEEE 000135


  STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

   0002 R 002727 ADDLAB    0002   003320 ADDLA9    0002 R 002117 ADLABR    0002   003161 ADLAB9    0002   002273 BENFCR
   0005   000071 BEN2      0002 R 001505 CILMCS    0004 R 000067 CONST     0002 R 001347 COSEND    0002   002777 COSEN9
   0002 R 001323 COSMOD    0002 R 001313 COSNEW    0002   001333 COSTRA    0002 R 001535 DFSIPG    0002 R 001525 DFSMPG
   0003 R 000703 DISCON    0002 I 002473 EHCREW    0002 R 001545 EHELPM    0002   003137 EHELP9    0002 R 002603 ELECHI
   0002   003111 ELECH9    0002   002723 ELEENE    0002   003317 ELEEN9    0002 I 002363 ELEHEL    0002   001655 EMAINT
   0002   003203 EMAIN9    0002 R 001515 EMATPM    0002 R 000710 ESAVMP    0002 R 001765 ESRRMP    0002   003225 ESRRM9
   0005 I 000001 FIX       0002 R 002361 FLYCOS    0002 R 001130 FLYSC     0002   000204 FLYWCV    0002   000162 FLYWMA
   0002   000140 FLYWS     0003   001206 FNPV      0002 I 000050 GTTONS    0002 I 001274 IANANO    0002   002737 IFLAG
   0004   000044 IIIIII    0002 I 001276 ILUSE     0003 I 001205 IPR       0002   002337 IRANK     0004   000022 IRANKK
   0002 I 000000 IRNAME    0002 I 001275 IROUTE    0002 I 000020 IRROAD    0002   002750 ISEN      0002 I 000360 ISITES
   0004   000045 ISUB      0003 I 001204 KSTART    0002 R 000120 LOCFMI    0002   001307 LOCTRA    0002 I 000060 LOCTYP
   0002 R 000100 LOCUSE    0002 L 002742 LSCEN1    0002 L 002743 LSCEN2    0002 L 002744 LSCEN3    0002 L 002745 LSCEN4
   0004   000000 MDUMY     0002 I 000470 MILEPF    0002 I 000600 MILEPT    0002 I 001303 MODLOC    0005   000045 MSUB
   0003 R 000062 NAS       0002 I 001277 NEWLOC    0002   002747 NH        0002   002746 NL        0005   000000 NOFIX
   0002 I 000054 NOLOC     0002   002736 NOSITE    0002 I 000034 NOSITT    0002   002362 NOSUSE    0003 R 000000 NPV
   0002   002751 NSUB      0005   000023 NSUB3     0003 I 000702 NYRCON    0002   002315 RBEN      0005   000113 RBEN2
   0002 R 001020 REGPL     0002 I 000030 RMILES    0003   001074 ROI       0003   000764 ROIPER    0002 R 001343 ROUTEE
   0002   002776 ROUTE9    0002 R 002007 RPEAKD    0002   003247 RPEAK9    0002   002733 R13A6     0002   002734 R13A7
   0002   002735 R13A8     0002   002740 R135A7    0002   002741 R135A8    0002   003271 SACC90    0002   003272 SACPS9
   0002 R 002713 SAVLRP    0002 I 001240 SCENIO    0002   002251 SDCOSI    0002   002227 SDSAVA    0002   003066 SIIV90
   0002 R 001353 SITELE    0002   003022 SITEL9    0002 R 000226 STABLD    0002   003067 SUMIV9    0002 R 001511 TCILMC
   0002   003133 TCILM9    0002   000336 TCOSFS    0002   003000 TCOSF9    0002 R 000040 TDENEB    0002 R 000044 TDENWB
   0002   003136 TDFSI9    0002   003135 TDFSM9    0002 R 001541 TDFSTI    0002 R 001531 TDFSTM    0002 R 001521 TEMTPM
   0002   003134 TEMTP9    0002   001327 TOTMOD    0002   002774 TOTMO9    0002   001317 TOTNEW    0002   002773 TOTNE9
   0002   001337 TOTTRA    0002   002775 TOTTR9    0002 R 002717 TSAVLR    0002   003316 TSAVL9    0002   001463 TSITEC
   0002   003044 TSITE9    0003 R 000704 XIR       0005   000070 ZUMACC    0005   000067 ZUMINV


00101      1*           BLOCK DATA                                                                         000000
00102      2*           INCLUDE COM1,LIST                                                                  000000
00102      2*      COM1   PROC                                                                             000000
00103      2*           PARAMETER NP1=4,NP2=16,NP3=18,NP4=1,NP5=50                                         000000
00104      2*           LOGICAL LSCEN1,LSCEN2,LSCEN3,LSCEN4                                                000000
00105      2*           REAL LOCUSE,LOCFMI                                                                 000000
00106      2*           REAL NPV,NAS                                                                       000000
00107      2*           INTEGER SCENIO,RMILES,GTTONS,ELEHEL,EHCREW,FIX                                     000000
00107      2*      C * * BLANK COMMON                                                                      000000
00110      2*           COMMON                                                                             000000
00110      2*          1 IRNAME(4,NP1),IRROAD(2,NP1),RMILES(NP1),NOSITT(NP1)  ,                            000000
00110      2*          2 TDENEB(NP1),TDENWB(NP1), GTTONS(NP1), NOLOC(NP1),                                 000000
00110      2*          3 LOCTYP(4,NP1), LOCUSE(NP2),LOCFMI(NP2), FLYWS(NP3),                               000000
00110      2*          4 FLYWMA(NP3),      FLYWCV(NP3),      STABLD(NP3,NP1),TCOSFS(NP3)   ,               000000
```

```
00110    2*        5 ISITES(NP3,NP1),MILEPF(NP3,NP1),MILEPT(NP3,NP1),ESAVMP(NP3,NP1),        000000
00110    2*        6 PEGPL(NP3,NP1),FLYSC(NP3,NP1),SCENIO(7,NP1), IANANO , IROUTE,            000000
00110    2*        7 ILUSE,NEWLOC(NP1),MODLOC(NP1),LOCTRA(NP1),COSNEW(NP1),                   000000
00110    2*        8 TOTNEW(NP1), COSMOD(NP1),TOTMOD(NP1), COSTRA(NP1),TOTTRA(NP1),           000000
00110    2*        9 ROUTEE(NP1),COSEND(NP1), SITELE(NP3,NP1),TSITEC(NP3),                    000000
00110    2*        A CILMCS(NP1),TCILMC(NP1),                          EMATPM(NP1),           000000
00110    2*        B TEMTPM(NP1), DFSMPG(NP1),TDFSTM(NP1), DFSIPG(NP1),TDFSTI(NP1),           000000
00110    2*    C * * SITE DEPENDENT (*)                                                       000000
00110    2*        D EHELPM(NP3,NP1), EMAINT(NP3,NP1), ESRRMP(NP3),                           000000
00110    2*        E RPEAKD(NP3,NP1), ADLARR(NP3,NP1),                                        000000
00110    2*        F SDSAVA(NP3),SDCOST(NP3),BENFCR(NP3),RBEN(NP3),IRANK(NP3)                 000000
00110    2*    C * * FLYWHEEL COST                                                            000000
00111    2*         COMMON FLYCOS                                                             000000
00112    2*         COMMON                                                                    000000
00112    2*        G LOSUSE,ELEHEL(NP1,NP3),EHCHEW(NP1,NP3),ELECHI(NP1,NP3),                  000000
00112    2*        H SAVLRP(NP1),TSAVLR(NP1),ELEENE(NP1),ADDLAR(NP1)                          000000
00112    2*    C                                                                              000000
00113    2*         COMMON R13A6,R13A7,R13A8,NOSITE,IFLAG,R135A7,R135A8                       000000
00113    2*        1,LSCEN1,LSCEN2,LSCEN3,LSCEN4,NL,NH,ISEN,NSUB(NP3)                         000000
00113    2*    C * * COMMON     INITIAL INVESTMENTS 1990 DOLLARS                              000000
00114    2*         COMMON                                                                    000000
00114    2*        1 TOTNE9   ,  TOTMO9   ,  TOTTR9  ,   ROUTE9  ,   COSEN9    ,            000000
00114    2*        2 TCOSF9(NP3)     ,SITEL9(NP3)     , TSITE9(NP3)     ,SIIV90               000000
00114    2*        3,SUMIV9(NP3)     ,FLECH9(NP3)                                             000000
00115    2*         COMMON       *  ANNUAL COST AND CREDITS 1990 DOLLARS.                     000000
00115    2*        1 TCILM9,TEMTP9,TDFSM9,TDFSI9                                              000000
00115    2*        2              ,EHELP9(NP3)     ,ADLAB9(NP3)     ,EMAIN9(NP3),             000000
00115    2*        3 ESRRM9(NP3)     ,RPEAK9(NP3)     ,SACC90,SACPS9(20)                      000000
00115    2*        4, TSAVL9,ELEEN9,ADDLA9                                                    000000
00116    2*         COMMON/AAAAAA/NPV(NP5),     NAS(100,NP1),NYRCON,DISCON,XIR(12,4),         000000
00116    2*        1 ROIPER(4,NP3),ROI(4,NP3),KSTART,IPR,FNPV(NP3)                            000000
00117    2*         COMMON/BBBBBB/MDUMY(NP3),IRANKK(NP3),IIIIII ,ISUR(NP3),CONST              000000
00120    2*         COMMON/EEEEEE/NUFIX,FIX(NP3),NSUB3(NP3),MSUB(NP3),ZUMINV,ZUMACC           000000
00120    2*        1,REN2(NP3),RREN2(NP3)                                                     000000
00120    2*      END                                                                          000000
00121    3*         DATA IRNAME/                                                              000000
00121    4*        1 24HLOS ANGELES-RELEN                  ,                                  000000
00121    5*        2 24H                                   ,                                  000000
00121    6*        3 24H                                   ,                                  000000
00121    7*        4 24H                                   /                                  000000
00123    8*         DATA IANANO/ '3/1      '       /                                          000000
00125    9*         DATA SCENIO/                                                              000000
00125   10*        1 42HDUAL MODE                                                             000000
00125   11*        2,42HELECTRIC HELPER                                                       000000
00125   12*        3,42HELECTRIC RAILROAD                                                     000000
00125   13*        4,42HCONCURRENT ELECT. & WESS                                              000000
00125   14*        5/                                                                         000000
00127   15*         DATA IRROAD/                                                              000000
00127   16*        1 12HAT&SF         ,                                                       000000
00127   17*        2 12H              ,                                                       000000
00127   18*        3 12H              ,                                                       000000
00127   19*        4 12H              /                                                       000000
00131   20*         DATA RMILES/ 900, 3*0/                                                    000000
00133   21*         DATA TDENER/32.3 ,3*0.0/                                                  000000
00135   22*         DATA TDENWB/32.3, 3*0.0/                                                  000000
00137   23*         DATA GTTONS/4600 , 3*0/                                                   000000
00141   24*         DATA NOLOC /3,3*0/                                                        000000
00143   25*         DATA LOCTYP/                                                              000000
00143   26*        124HC C ELECTRIC                        ,                                  000000
00143   27*        224H                                    ,                                  000000
```

```
00143    28*       324H                                  ,                        000000
00143    29*       424H                                  /                        000000
00145    30*        DATA LOCUSE/16*3.6/                                           000000
00147    31*        DATA LOCFMI/16*29.34/                                         000000
00151    32*        DATA ISITES/                                                  000000
00151    33*       11,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,                 000000
00151    34*       21,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,                 000000
00151    35*       31,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,                 000000
00151    36*       41,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18/                 000000
00153    37*        DATA MILEPF/                                                  000000
00153    38*       10,27,   115,145,291,316,361,373,451,483,494,507,577,670,694,707,   000000
00153    39*       A791,848,                                                      000000
00153    40*       218*0,18*0,18*0/                                               000000
00155    41*        DATA MILEPT/                                                  000000
00155    42*       1 11, 48,140,161,306,353,367,411,475,490,501,566,651,686,702,715,   000000
00155    43*       A842,857,                                                      000000
00155    44*       218*0,18*0,18*0/                                               000000
00157    45*        DATA ESAVMP/                                                  000000
00157    46*       1 1154.,700., 935., 702., 672., 4233., 858., 2974., 1835.,     000000
00157    47*       2 482.,  503., 6400.,7411., 2247., 681., 563.,  8710., 444.,   000000
00157    48*       3 54*0.0/                                                      000000
00161    49*        DATA REGPL/                                                   000000
00161    50*       111.76, 3.02,11.76,11.76,11.25,11.48, 3.15, 5.91,11.30,11.30, 7.55,   000000
00161    51*       A11.76,11.76,11.69, 6.10,11.76, 7.34,11.76,                    000000
00161    52*       218*0.0,18*0.0,18*0.0/                                         000000
00163    53*        DATA FLYSC/                                                   000000
00163    54*       12.0,2.0,2.0,1.5,1.5,10., 2.,6.0,5.0,1.0,1.0,15.,15.,5.0,1.5,1.5,   000000
00163    55*       A 12.9, 1.0 ,                                                  000000
00163    56*       2 54*0.0/                                                      000000
00165    57*        DATA STABLD/5*0.06, .12,5*0.05, 2*.18,3*0.06,.12,.06,  54*0.0/   000000
00167    58*        DATA ILUSE/1/                                                 000000
00171    59*        DATA IROUTF/1/                                                000000
00173    60*        DATA NOSITT/4*18/                                             000000
00175    61*        DATA LSCEN1,LSCEN2,LSCEN3,LSCEN4/ 2*.FALSE. ,.TRUE. ,.FALSE./   000000
00202    62*        DATA SITELF/72*0.0/                                           000000
00204    63*        DATA NEWLOC/4*0/                                              000000
00206    64*        DATA COSNEW/4*0.0/                                            000000
00210    65*        DATA MODLOC/209, 3*0/                                         000000
00212    66*        DATA COSMOD/0.06  , 3*0.0/                                    000000
00214    67*        DATA ROUTEE/4*0.0/                                            000000
00216    68*        DATA COSEND/4*0.0/                                            000000
00220    69*        DATA CILMCS/4*0.0/                                            000000
00222    70*        DATA TCILMC/4*0.0/                                            000000
00224    71*        DATA EMATPM/4*0.0/                                            000000
00226    72*        DATA TEMTPM/4*0.0/                                            000000
00230    73*        DATA DFSMPG/4*0.0/                                            000000
00232    74*        DATA TDFSTM/4*.0/                                             000000
00234    75*        DATA DFSIPG/4*0.0/                                            000000
00236    76*        DATA TDFSTI/4*.0/                                             000000
00240    77*        DATA EHELPM/72*0.0/                                           000000
00242    78*        DATA ADLABR/72*0.0/                                           000000
00244    79*        DATA ESRAMP/18*0.0/                                           000000
00246    80*        DATA PPEAKD/18*0.39 , 54*0.0/                                 000000
00250    81*        DATA NYRCON/30/                                               000000
00252    82*        DATA DISCON/.1/                                               000000
00254    83*        DATA KSTART/1/                                                000000
00254    84*     C * * INFLATION RATES USED FOR ANNUAL COSTS(AFTER 1990)          000000
00256    85*        DATA XIR/0.000001,2*0.02, 0.01,5*0.02,   2*0.01, 0.02,        000000
00256    86*       1 12*0.000001,                                                 000000
00256    87*       2 0.06,2*0.08,      0.07,   5*0.08, 2*0.07, 0.08,              000000
```

```
00256           3 0.06,2*0.08,      0.07,   2*0.10,  0.08,2*0.08, 0.10, .07, .08/                    000000
00260            DATA ADDLAB/ 4*0.0/                                                                 000000
00262            DATA TSAVLR/.0,  3*0.0          /                                                   000000
00264            DATA SAVLRP/ 300000., 3*0.0/                                                        000000
00266            DATA IPR/1/                                                                         000000
00270            DATA CONST/.01/                                                                     000000
00270      C     DATA CONST/.01/ CONST FACTOR FOR ESRRMP, CAN BE INPUT VIA NAMELIST                  000000
00272            DATA ELEHEL/ 18*0,  54*0/                                                           000000
00274            DATA EHCREW/ 18*0,  54*0/                                                           000000
00276            DATA ELECHI/ 18*0., 54*0./                                                          000000
00300            DATA FLYCOS/0.216/                                                                  000000
00302            END                                                                                 000000

        END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,S   INPUT
FOR 003E-05/15/78-13:22:42 (0,)

   SUBROUTINE INPUT     ENTRY POINT 000242

   STORAGE USED: CODE(1) 000245; DATA(0) 003667; BLANK COMMON(2) 003321

    COMMON BLOCKS:

    0003    AAAAAA 001230
    0004    BBBBBB 000070
    0005    EEEEEE 000135

   EXTERNAL REFERENCES (BLOCK, NAME)

    0006    NRNL$
    0007    NWNL$
    0010    NWDU$
    0011    NI02$
    0012    NSTOP$
    0013    NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000    000344 1000F     0001    000223 999L      0002 R 002727 ADDLAB    0002    003320 ADDLA9    0002 R 002117 ADLABR
    0002    003161 ADLAB9    0000    000246 ANNUAL    0002    002273 BENFCR    0005    000071 BEN2      0002 R 001505 CILMCS
    0004 R 000067 CONST     0002 R 001347 COSEND    0002    002777 COSEN9    0002 R 001323 COSMOD    0002 R 001313 COSNEW
    0002 R 001333 COSTRA    0002 R 001535 DFSIPG    0002 R 001525 DFSMPG    0003 R 000703 DISCON    0002 I 002473 EHCREW
    0002 R 001545 EHELPM    0002    003137 EHELP9    0002 R 002603 ELECHI    0002    003111 ELECH9    0002 R 002723 ELEENE
    0002    003317 ELEEN9    0002 I 002363 FLEHEL    0002 R 001655 EMAINT    0002    003203 EMAIN9    0002 R 001515 EMATPM
    0002 R 000710 ESAVMP    0002 R 001765 ESRRMP    0002    003225 ESRRM9    0005 I 000001 FIX       0002 R 002361 FLYCOS
    0002 R 001130 FLYSC     0002    000204 FLYWCV    0002    000162 FLYWMA    0002    000140 FLYWS     0003    001206 FNPV
    0002 I 000050 GTIONS    0002 I 001274 IANANO    0002    002737 IFLAG     0004    000044 IIIIII    0002 I 001276 ILUSE
    0000    000361 INJP$     0000    000174 INVEST    0003 I 001205 IPR       0002    002337 IRANK     0004    000022 IRANKK
    0002 I 000000 IRNAME    0002 I 001275 IROUTE    0002 I 000020 IRROAD    0002 I 002750 ISEN      0002 I 000360 ISITES
    0004    000045 ISUB      0003 I 001204 KSTART    0002 R 000120 LOCFMI    0002 I 001307 LOCTRA    0002 I 000060 LOCTYP
    0002 R 000100 LOCUSE    0002 L 002742 LSCEN1    0002 L 002743 LSCEN2    0002 L 002744 LSCEN3    0002 L 002745 LSCEN4
    0004    000000 MDUMY     0002 I 000470 MILEPF    0002 I 000600 MILEPT    0002 I 001303 MODLOC    0005    000045 MSUB
    0003 R 000062 NAS       0002 I 001277 NEWLOC    0002 I 002747 NH        0002 I 002746 NL        0005 I 000000 NOFIX
    0002 I 000054 NCLOC     0002    002736 NOSITE    0002 I 000034 NOSITT    0002    002362 NOSUSE    0003 R 000000 NPV
    0002    002751 NSUR      0005    000023 NSUB3     0003 I 000702 NYRCON    0000    000010 ONE       0002    002315 RBEN
    0005    000113 RBEN2     0002 R 001020 REGPL     0002 I 000030 RMILES    0003    001074 ROI       0003    000764 ROIPER
    0002 R 001343 ROUTEE    0002    002776 ROUTE9    0002 R 002007 RPEAKD    0002    003247 RPEAK9    0002    002733 R13A6
    0002    002734 R13A7     0002    002735 R13A8     0002    002740 R135A7    0002    002741 R135A8    0002    003271 SACC90
    0002    003272 SACPS9    0002 R 002713 SAVLRP    0002 I 001240 SCENIO    0002    002251 SDCOSI    0002    002227 SDSAVA
    0002    003066 SIIV90    0002 R 001353 SITELE    0002    003022 SITEL9    0002 R 000226 STABLD    0002    003067 SUMIV9
    0002 R 001511 TCILMC    0002    003133 TCILM9    0002    000336 TCOSFS    0002    003000 TCOSF9    0002 R 000040 TDENEB
    0002 R 000044 TDENWB    0002    003136 TDFSI9    0002    003135 TDFSM9    0002 R 001541 TDFSTI    0002 R 001531 TDFSTM
    0002 R 001521 TEMTPM    0002    003134 TEMTP9    0002    001327 TOTMOD    0002    002774 TOTMO9    0002    001317 TOTNEW
    0002    002773 TOTNE9    0002    001337 TOTTRA    0002    002775 TOTTR9    0002 R 002717 TSAVLR    0002    003316 TSAVL9
    0002    001463 TSITEC    0002    003044 TSITE9    0000    000133 TWO       0003 R 000704 XIR       0005    000070 ZUMACC
    0005    000067 ZUMINV
```

```
00101     1*         SUBROUTINE INPUT                                                  000000
00103     2*         INCLUDE COM1,LIST                                                 000000
00103     2*   COM1     PROC                                                           000000
00104     2*         PARAMETER NP1=4,NP2=16,NP3=18,NP4=1,NP5=50                        000000
00105     2*         LOGICAL LSCEN1,LSCEN2,LSCEN3,LSCEN4                               000000
00106     2*         REAL LOCUSE,LOCFMI                                                000000
00107     2*         REAL NPV,NAS                                                      000000
00110     2*         INTEGER SCENIO,RMILES,GTTONS,ELEHEL,EHCREW,FIX                    000000
00110     2*   C * * BLANK COMMON                                                      000000
00111     2*         COMMON                                                            000000
00111     2*        1 IRNAME(4,NP1),IRROAD(2,NP1),RMILES(NP1),NOSITT(NP1)  ,           000000
00111     2*        2 TDENEB(NP1),TDENWB(NP1), GTTONS(NP1), NOLOC(NP1),                000000
00111     2*        3 LOCTYP(4,NP1), LOCUSE(NP2),LOCFMI(NP2), FLYWS(NP3),              000000
00111     2*        4 FLYWMA(NP3),      FLYWCV(NP3),      STABLD(NP3,NP1),TCOSFS(NP3)   ,  000000
00111     2*        5 ISITES(NP3,NP1),MILEPF(NP3,NP1),MILEPT(NP3,NP1),ESAVMP(NP3,NP1),  000000
00111     2*        6 REGPL(NP3,NP1),FLYSC(NP3,NP1),SCENIO(7,NP1), IANANO , IROUTE,    000000
00111     2*        7 ILUSE,NEWLOC(NP1),MODLOC(NP1),LOCTRA(NP1),COSNEW(NP1),           000000
00111     2*        8 TOTNEW(NP1), COSMOD(NP1),TOTMOD(NP1), COSTRA(NP1),TOTTRA(NP1),   000000
00111     2*        9 ROUTEE(NP1),COSEND(NP1), SITELE(NP3,NP1),TSITEC(NP3),            000000
00111     2*        A CILMCS(NP1),TCILMC(NP1),                          EMATPM(NP1),   000000
00111     2*        B TEMTPM(NP1), DFSMPG(NP1),TDFSTM(NP1), DFSIPG(NP1),TDFSTI(NP1),   000000
00111     2*   C * * SITE DEPENDENT ($)                                                000000
00111     2*        D EHELPM(NP3,NP1), EMAINT(NP3,NP1), ESRRMP(NP3),                   000000
00111     2*        E RPEAKD(NP3,NP1), ADLABR(NP3,NP1),                                000000
00111     2*        F SDSAVA(NP3),SDCOSI(NP3),BENFCR(NP3),RBEN(NP3),IRANK(NP3)         000000
00111     2*   C * * FLYWHEEL COST                                                     000000
00112     2*         COMMON FLYCOS                                                     000000
00113     2*         COMMON                                                            000000
00113     2*        G NOSUSE,ELEHEL(NP1,NP3),EHCREW(NP1,NP3),ELECHI(NP1,NP3),          000000
00113     2*        H SAVLRP(NP1),TSAVLR(NP1),ELEENE(NP1),ADDLAB(NP1)                  000000
00113     2*   C                                                                       000000
00114     2*         COMMON R13A6,R13A7,R13A8,NOSITE,IFLAG,R135A7,R135A8               000000
00114     2*        1,LSCEN1,LSCEN2,LSCEN3,LSCEN4,NL,NH,ISEN,NSUB(NP3)                 000000
00114     2*   C * * COMMON      INITIAL INVESTMENTS 1990 DOLLARS                      000000
00115     2*         COMMON                                                            000000
00115     2*        1 TOTNE9    ,  TOTMO9    ,  TOTTR9   ,   ROUTE9   ,    COSEN9    ,  000000
00115     2*        2 TCOSF9(NP3)      ,SITEL9(NP3)      , TSITE9(NP3)      ,SIIV90   000000
00115     2*        3,SUMIV9(NP3)      ,ELECH9(NP3)                                    000000
00116     2*         COMMON       *  ANNUAL COST AND CREDITS 1990 DOLLARS.             000000
00116     2*        1 TCILM9,TEMTP9,TDFSM9,TDFSI9                                      000000
00116     2*        2                ,EHELP9(NP3)      ,ADLAB9(NP3)      ,EMAIN9(NP3),  000000
00116     2*        3 ESRRM9(NP3)      ,RPEAK9(NP3)      ,SACC90,SACPS9(20)             000000
00116     2*        4, TSAVL9,ELEEN9,ADDLA9                                            000000
00117     2*         COMMON/AAAAAA/NPV(NP5),      NAS(100,NP1),NYRCON,DISCON,XIR(12,4),  000000
00117     2*        1 ROIPER(4,NP3),ROI(4,NP3),KSTART,IPR,FNPV(NP3)                    000000
00120     2*         COMMON/BBBBBB/MDUMY(NP3),IRANKK(NP3),IIIIII ,ISUB(NP3),CONST      000000
00121     2*         COMMON/EEEEEE/NOFIX,FIX(NP3),NSUB3(NP3),MSUB(NP3),ZUMINV,ZUMACC   000000
00121     2*        1,BEN2(NP3),RBEN2(NP3)                                             000000
00121     2*    END                                                                    000000
00122     3*         NAMELIST/ONE/IROUTE,ISEN,IANANO,NOSITT,KSTART,RMILES,             000000
00122     4*        1 TDENEB,TDENWB,GTTONS,NOLOC,LOCTYP,LOCUSE,LOCFMI,                 000000
00122     5*        2 SCENIO,IRNAME,IRROAD,IPR   ,     ILUSE,FLYCOS                    000000
00122     6*        3,FIX,NOFIX                                                        000000
00123     7*         NAMELIST/TWO/ISITES,MILEPF,MILEPT,ESAVMP,REGPL,FLYSC,STABLD       000000
00123     8*        1,ELEHEL,EHCREW                                                    000000
00124     9*         NAMELIST/INVEST/NEWLOC,COSNEW,MODLOC,COSMOD,LOCTRA,COSTRA,        000000
00124    10*        1 ROUTEE,COSEND ,SITELE,ELECHI                                     000000
00125    11*         NAMELIST/ANNUAL/CILMCS,TCILMC,EMATPM,TEMTPM,DFSMPG,TDFSTM,        000000
00125    12*        1 DFSIPG,TDFSTI,EHELPM,ADLABR,EMAINT,ESRRMP,RPEAKD                 000000
00125    13*        2 ,NYRCON,DISCON,XIR                                               000000
```

```
00125          3,SAVLRP,TSAVLH,ELEENE,ADDLAB                                    000000
00126           CONST=0.01                                                       000000
00127           IROUTE=1                                                         000001
00130           NL=1                                                             000003
00131           NH=18                                                            000004
00132           KSTART=1                                                         000006
00133           ISEN=1                                                           000007
00134           NOFIX=0                                                          000010
00135           READ(5,ONE,END=999)                                              000011
00140           LSCEN1=.FALSE.                                                   000016
00141           LSCEN2=.FALSE.                                                   000017
00142           LSCEN3=.FALSE.                                                   000020
00143           LSCEN4=.FALSE.                                                   000021
00144           IF(ISEN.EQ.1)LSCEN1=.TRUE.                                       000022
00146           IF(ISEN.EQ.2)LSCEN2=.TRUE.                                       000031
00150           IF(ISEN.EQ.3)LSCEN3=.TRUE.                                       000036
00152           IF(ISEN.EQ.4)LSCEN4=.TRUE.                                       000043
00154           IF((LSCEN1).OR.(LSCEN2))XIR(10,1)=0.02                           000050
00156           IF((LSCEN1).OR.(LSCEN2))XIR(10,3)=0.08                           000055
00160           IF((LSCEN1).OR.(LSCEN2))XIR(10,4)=0.10                           000062
00162           IF((LSCEN3).OR.(LSCEN4))XIR(10,1)=0.01                           000067
00164           IF((LSCEN3).OR.(LSCEN4))XIR(10,3)=0.07                           000074
00166           IF((LSCEN3).OR.(LSCEN4))XIR(10,4)=0.07                           000101
00170           IF((LSCEN1).OR.(LSCEN2))XIR(11,1)=0.000001                       000106
00172           IF((LSCEN1).OR.(LSCEN2))XIR(11,3)=0.000001                       000113
00174           IF((LSCEN1).OR.(LSCEN2))XIR(11,4)=0.000001                       000120
00176           IF((LSCEN3).OR.(LSCEN4))XIR(11,1)=0.01                           000125
00200           IF((LSCEN3).OR.(LSCEN4))XIR(11,3)=0.07                           000132
00202           IF((LSCEN3).OR.(LSCEN4))XIR(11,4)=0.07                           000137
00204           NH=NOSITT(IROUTE)                                                000144
00204     C * * NH=NOSITE   , ORIGINALLY NH WAS TO BE USED TO RUN JUST PART      000144
00204     C * *                 OF THE SITES, BUT THIS PROBABLY IS NOT NECESSARY. 000144
00205           IF(KSTART.LT.NOFIX)  KSTART=NOFIX                                000147
00207           IF(KSTART.LT.1)KSTART=1                                          000155
00211           WRITE(6,ONE)                                                     000163
00214           READ(5,TWO)                                                      000167
00217           WRITE(6,TWO)                                                     000173
00222           READ(5,INVEST)                                                   000177
00225           WRITE(6,INVEST)                                                  000203
00230           READ(5,ANNUAL)                                                   000207
00233           WRITE(6,ANNUAL)                                                  000213
00236           RETURN                                                           000217
00237       999 WRITE(6,1000)                                                    000223
00241      1000 FORMAT('1NORMAL END INPUT')                                      000227
00242           STOP                                                             000227
00243           E N D                                                            000244

     END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@AFOR,S   DETAIL
ATHENA EXTENDED FORTRAN 24I-05 (14 APR 77)
COMPILATION DONE ON 15 MAY 78 AT 13:43:01

     *SUBROUTINE  DETAIL        ENTRY POINT 00623    SEQ 000102

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001     *CODE           000642
         0000     *CONST+TEMP     000054
         0002     *SIMPLE VAR     000017
         0004     *ARRAYS         000066
         0005     N$BLNK   003321
         0006     AAAAAA   001230
         0007     BBBBBB   000070
         0010     EEEEEE   000135

   EXTERNAL REFERENCES

         0011     TREE
         0012     REPORT
         0013     G1990D
         0014     SUM90
         0015     NPVNAS
         0016     NWDU$
         0017     NIO2$
         0020     NERIO$

STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0002 R 000010 AAANUM     0005 R 002727 ADDLAB     0005   003320 ADDLA9     0005 R 002117 ADLABR     0005   003161 ADLAB9
    0002 R 000011 BBBDEN     0005 R 002273 BENFCH     0010 R 000071 BEN2       0005   001505 CILMCS     0007 R 000067 CONST
    0005   001347 COSEND     0005   002777 COSEN9     0005 R 001323 COSMOD     0005 R 001313 COSNEW     0005 R 001333 COSTRA
    0002 R 000014 CURSD      0002 R 000013 CURSN      0005   001535 DFSIPG     0005   001525 DFSMPG     0006   000703 DISCON
    0005 I 002473 EHCREW     0005 R 001545 EHELPM     0005   003137 EHELP9     0005 R 002603 ELECHI     0005   003111 ELECH9
    0005 R 002723 ELEENE     0005   003317 ELEEN9     0005 I 002363 ELEHEL     0005 R 001655 EMAINT     0005   003203 EMAIN9
    0005   001515 EMATPM     0005 R 000710 ESAVMP     0005 R 001765 ESRRMP     0005   003225 ESRRM9     0010 I 000001 FIX
    0005 R 002361 FLYCOS     0005 R 001130 FLYSC      0005 R 000204 FLYWCV     0005 R 000162 FLYWMA     0005 R 000140 FLYWS
    0006   001206 FNPV       0005 I 000050 GTTONS     0002 I 000004 I          0005   001274 IANANO     0005 I 002737 IFLAG
    0002 I 000003 II         0007 I 000044 IIIIII     0005   001276 ILUSE      0006   001205 IPR        0005 I 002337 IRANK
    0007 I 000022 IRANKK     0005   000000 IRNAME     0005 I 001275 IROUTE     0005   000020 IRROAD     0005   002750 ISEN
    0005   000360 ISITES     0007 I 000045 ISUB       0002 I 000001 J          0002 I 000007 K          0002 I 000006 KK
    0006 I 001204 KSTART     0005 R 000120 LOCFMI     0005 I 001307 LOCTRA     0005   000060 LOCTYP     0005 R 000100 LOCUSE
    0005 L 002742 LSCEN1     0005 L 002743 LSCEN2     0005 L 002744 LSCEN3     0005 L 002745 LSCEN4     0007   000000 MDUMY
    0005   000470 MILEPF     0005   000600 MILEPT     0005 I 001303 MODLOC     0010 I 000045 MSUB       0002 I 000002 N
    0006 R 000062 NAS        0002 I 000016 NDUM       0005 I 001277 NEWLOC     0005   002747 NH         0005   002746 NL
    0010 I 000000 NOFIX      0005   000054 NOLOC      0005 I 002736 NOSITE     0005 I 000034 NOSITT     0002 I 000012 NOSTEM
    0005 I 002362 NOSUSE     0006 R 000000 NPV        0005 I 002751 NSUB       0004 I 000000 NSUB2      0010 I 000023 NSUB3
    0004 I 000044 NSUB4      0006   000702 NYRCON     0005 R 002315 RBEN       0010 R 000113 RBEN2      0004 R 000022 RDUM
    0005 R 001020 REGPL      0005 I 000030 RMILES     0006   001074 ROI        0006   000764 ROIPER     0005 R 001343 ROUTEE
    0005   002776 ROUTE9     0005 R 002007 RPEAKD     0005   003247 RPEAK9     0005 R 002733 R13A6      0005 R 002734 R13A7
    0005 R 002735 R13A8      0005   002740 R135A7     0005   002741 R135A8     0005   003271 SACC90     0005   003272 SACPS9
    0005   002713 SAVLRP     0005 I 001240 SCENIO     0005 R 002251 SDCOST     0005 R 002227 SDSAVA     0002 R 000000 SIGN
    0005 R 003066 SIIV90     0005 R 001353 SITELE     0005   003022 SITEL9     0005 R 000226 STABLD     0005 R 003067 SUMIV9
    0005 R 001511 TCILMC     0005   003133 TCILM9     0005 R 000336 TCOSFS     0005   003000 TCOSF9     0005 R 000040 TDENEB
    0005 R 000044 TDENWB     0005   003136 TDFSI9     0005   003135 TDFSM9     0005 R 001541 TDFSTI     0005 R 001531 TDFSTM
    0005 R 001521 TEMTPM     0005   003134 TEMTP9     0005 R 001327 TOTMOD     0005   002774 TOTMO9     0005 R 001317 TOTNEW
    0005   002773 TOTNE9     0005 R 001337 TOTTRA     0005   002775 TOTTR9     0002 R 000005 TRAFF      0005 R 002717 TSAVLR
    0005   003316 TSAVL9     0005 R 001463 TSITEC     0005   003044 TSITE9     0002 R 000015 XDEM       0006   000704 XIR
    0010 R 000070 ZUMACC     0010 R 000067 ZUMINV     0001   000034 130G       0001   000100 145G       0001   000137 160G
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0001   000152 165I    0001   000160 167I    0001   000240 206I    0001   000252 211I    0001   000265 220G
0001   000307 231G    0001   000333 241G    0001   000346 252G    0001   000355 260G    0001   000360 263G
0000   000000 298F    0001   000252 299L    0001   000421 306G    0001   000441 315I    0001   000462 324G
0001   000511 335G    0001   000375 342L    0001   000377 343L    0001   000405 350L    0001   000543 352G
0001   000556 361G    0001   000537 370L

00101   1*        SUBROUTINE DETAIL                                                              1 00001
00101   2*    C * * MAIN SUBROUTINE - THIS SUBROUTINE DOES THE WORK.                             2
00103   3*          INCLUDE  COM1,LIST                                                           3
00104   3*          PARAMETER NP1=4,NP2=16,NP3=18,NP4=1,NP5=50
00105   3*          LOGICAL LSCEN1,LSCEN2,LSCEN3,LSCEN4
00106   3*          REAL LOCUSE,LOCFMI
00107   3*          REAL NPV,NAS
00110   3*          INTEGER SCENIO,RMILES,GTTONS,ELEHEL,EHCREW,FIX
00110   3*    C * * BLANK COMMON
00111   3*          COMMON
00111   3*         1 IRNAME(4,NP1),IRROAD(2,NP1),RMILES(NP1),NOSITT(NP1)  ,
00111   3*         2 TDENEB(NP1),TDENWB(NP1), GTTONS(NP1), NOLOC(NP1),
00111   3*         3 LOCTYP(4,NP1), LOCUSE(NP2),LOCFMI(NP2), FLYWS(NP3),
00111   3*         4 FLYWMA(NP3),      FLYWCV(NP3),     STABLD(NP3,NP1),TCOSFS(NP3)   ,
00111   3*         5 ISITES(NP3,NP1),MILEPF(NP3,NP1),MILEPT(NP3,NP1),ESAVMP(NP3,NP1),
00111   3*         6 REGPL(NP3,NP1),FLYSC(NP3,NP1),SCENIO(7,NP1), IANANO , IROUTE,
00111   3*         7 ILUSE,NEWLOC(NP1),MODLOC(NP1),LOCTRA(NP1),COSNEW(NP1),
00111   3*         8 TOTNEW(NP1), COSMOD(NP1),TOTMOD(NP1), COSTRA(NP1),TOTTRA(NP1),
00111   3*         9 ROUTFE(NP1),COSEND(NP1), SITELE(NP3,NP1),TSITEC(NP3),
00111   3*         A CILMCS(NP1),TCILMC(NP1),                              EMATPM(NP1),
00111   3*         B TEMTPM(NP1), DFSMPG(NP1),TDFSTM(NP1), DFSIPG(NP1),TDFSTI(NP1),
00111   3*    C * * SITE DEPENDENT ($)
00111   3*         D EHELPM(NP3,NP1), EMAINT(NP3,NP1), ESRRMP(NP3),
00111   3*         E RPEAKD(NP3,NP1), ADLABR(NP3,NP1),
00111   3*         F SDSAVA(NP3),SDCOSI(NP3),BENFCR(NP3),RBEN(NP3),IRANK(NP3)
00111   3*    C * * FLYWHEEL COST
00112   3*          COMMON FLYCOS
00113   3*          COMMON
00113   3*         G NOSUSE,ELEHEL(NP1,NP3),EHCREW(NP1,NP3),ELECHI(NP1,NP3),
00113   3*         H SAVLRP(NP1),TSAVLR(NP1),ELEENE(NP1),ADDLAB(NP1)
00113   3*    C
00114   3*          COMMON R13A6,R13A7,R13A8,NOSITE,IFLAG,R135A7,R135A8
00114   3*         1,LSCEN1,LSCEN2,LSCEN3,LSCEN4,NL,NH,ISEN,NSUB(NP3)
00114   3*    C * * COMMON      INITIAL INVESTMENTS 1990 DOLLARS
00115   3*          COMMON
00115   3*         1 TOTNE9   ,  TOTMO9   ,  TOTTR9   ,   ROUTE9   ,   COSEN9    ,
00115   3*         2 TCOSF9(NP3)     ,SITEL9(NP3)     , TSITE9(NP3)     ,SIIV90
00115   3*         3,SUMIV9(NP3)    ,ELECH9(NP3)
00116   3*          COMMON        *  ANNUAL COST AND CREDITS 1990 DOLLARS,
00116   3*         1 TCILM9,TEMTP9,TDFSM9,TDFSI9
00116   3*         2              ,EHELP9(NP3)      ,ADLAB9(NP3)      ,EMAIN9(NP3),
00116   3*         3 ESRRM9(NP3)       ,RPEAK9(NP3)      ,SACC90,SACPS9(20)
00116   3*         4, TSAVL9,ELEEN9,ADDLA9
00117   3*          COMMON/AAAAAA/NPV(NP5),      NAS(100,NP1),NYRCON,DISCON,XIR(12,4),
00117   3*         1 ROIPER(4,NP3),ROI(4,NP3),KSTART,IPR,FNPV(NP3)
00120   3*          COMMON/BBBBBB/MDUMY(NP3),IRANKK(NP3),IIIIII ,ISUB(NP3),CONST
00121   3*          COMMON/EEEEEE/NOFIX,FIX(NP3),NSUB3(NP3),MSUB(NP3),ZUMINV,ZUMACC
00121   3*         1,BEN2(NP3),RBEN2(NP3)
00122   3*          END
00123   4*          DIMENSION NSUB2(NP3)                                                         4
00124   5*          DIMENSION RDUM(NP3),NSUB4(NP3)                                               5
00125   6*          J=1                                                                          6
00126   7*          N=NOSITT(IROUTE)                                                             7 00010
```

```
00127          DO 100 II=1,N                                                      00012
00132          I=NSUB(II)                                                         00035
00133          FLYWS(I)   =FLYSC(I,IROUTE)+ FLYCOS                                00042
00134          FLYWMA(I)   = REGPL(I,IROUTE)* 0.06                                00045
00135          FLYWCV(I   )= REGPL(I,IROUTE)*0.03                                 00050
00136          TCOSFS(I )  =FLYWS(I )  +FLYWMA(I )  +FLYWCV(I)   +STABLD(I,IROUTE) 00053
00137      100 CONTINUE                                                           00060
00137    C * * DETAIL * * CALC INITIAL INVESTMENT
00141          TOTNEW(IROUTE)=NEWLOC(IROUTE) *  COSNEW(IROUTE)
00142          TOTMOD(IROUTE)=MODLOC(IROUTE) *  COSMOD(IROUTE)                    00065
00143          TOTTRA(IROUTE)=LOCTRA(IROUTE) *  COSTRA(IROUTE)                    00072
00144          DO 200 II=1,NOSITE                                                 00101
00147          I=NSUB(II)
00150          TSITEC(I )        =SITELE(I,IROUTE) +  TCOSFS(I)                   00104
00150         1  + ELECHI(I,IROUTE)
00151      200 CONTINUE                                                           00115
00151    C * * ANNUAL COSTS & CREDITS (1977 $M)
00151    C * * ROUTE DEPENDENT
00151    C * * DETAIL * * SITE RANKING * *
00151    C * * SUM ANNUAL COST & CREDITS ROUTE DEPENDENT.
00153          ZUMACC=TSAVLR(IROUTE)+ TCILMC(IROUTE) + TEMTPM(IROUTE) +
00153         1 ELEENE(IROUTE) + TDFSTM(IROUTE)+ TDFSTI(IROUTE) + ADDLAB(IROUTE)
00154          ZUMACC=ZUMACC*R13A6                                                00125
00154    C * * SUM INITIAL INVEST.COSTS ROUTE DEPENDENT.
00155          ZUMINV=TOTNEW(IROUTE)+TOTMOD(IROUTE)+TOTTRA(IROUTE)+ROUTEE(IROUTE) 00127
00156          ZUMINV=ZUMINV*R13A6                                                00134
00157          DO 300 II=1,NOSITE                                                 00140
00162          I=NSUB(II)
00162    C * * CALC NET ANNUAL SITE SAVINGS MILLIONS OF DOLLARS ( SDSAVA(I))
00162    C     ESRRMP(I,IROUTE)=ESAVMP(I,IROUTE)*0.02/(2*1000)*TDENEB(IROUTE)
00162    C    1          /GTTONS(IROUTE)        *1000000.
00163          CONST=0.19                                                         00145
00164          IF(LSCEN3)CONST=0.01                                               00147
00166          IF(LSCEN3.AND.(IROUTE.EQ.4))CONST=0.001985                         00155
00170          TRAFF=     (TDENEB(IROUTE)+TDENWB(IROUTE))                         00161
00171          ESRRMP(I   )        =ESAVMP(I,IROUTE)*CONST* TRAFF/GTTONS(IROUTE)  00163
00172          SDSAVA(I)=ESRRMP(I )        *R13A7+RPEAKD(I,IROUTE)*R13A7          00172
00172         1+EHELPM(I,IROUTE)*R13A8+EMAINT(I,IROUTE)*R13A8+ADLABR(I,IROUTE)*
00172         2          R13A6
00172    C * * CALC INITAIL SITE DEPENDENT COSTS $M = SDCOSI(I)
00173          SDCOSI(I)=TCOSFS(I )        *R13A6 + SITELE(I,IROUTE)*R13A6        00210
00174          IF(ABS(SDCOSI(I)).GT.1.E-13) GO TO 299                             00216
00176          WRITE(6,298)I,SDCOSI(I)                                            00222
00203      298 FORMAT(/' SDCOSI(',I2,')=',E18.8//)                                00231
00204          SIGN=1.0
00205          IF(SDCOSI(I).LT.0.0)SIGN=-1.0                                      00233
00207          SDCOSI(I)=SIGN*1.E-13                                              00241
00210          IF(ABS(SDSAVA(I)).LT.1.E-13)SDSAVA(I)=1.E-13                       00245
00212      299 CONTINUE                                                           00253
00213          BENFCR(I)=SDSAVA(I)/SDCOSI(I)                                      00254
00214          RBEN(I)=1.0/BENFCR(I)                                              00257
00215      300 CONTINUE                                                           00267
00215    C * * SORT SITE RANKINGS
00217          DO 314 I=1,NOSITE
00222          NSUB2(I)=NSUB(I)
00223          MSUB(I)=NSUB(I)                                                    00271
00224          IRANKK(I)=I                                                        00272
00225      314 IRANK(I)= I                                                        00274
00225    C 314 IRANK(I)=NSUB(I)
00227          CALL TREE(RBEN,IRANK,NOSITE)                                       00277
```

```
00230    68*         DO 316 I=1,NOSITE                                               68 00304
00233    69*     316 ISUB(I)=IRANK(I)                                                69 00310
00235    70*         CALL TREE(ISUB,IRANKK,NOSITE)                                   70 00313
00236    71*         IFLAG=1                                                         71 00320
00237    72*         CALL REPORT                                                     72 00322
00240    73*         DO 318 I=1,NOSITE                                               73 00334
00243    74*         NSUB(I)=NSUB2(IRANK(I))                                         74 00335
00244    75*      32 NSUB3(I)=NSUB(I)                                                75 00337
00245    76*     318 CONTINUE                                                        76 00341
00245    77*   C * * NEW RANK TECHNIQUE  4 MAY 1978 PER L. COOK                      77
00247    78*         IF(NOFIX.LE.0)GO TO 343                                         78
00247    79*   C * *LOAD FIXED  SITES INTO NSUB3(I)                                  79
00251    80*         DO 333 I=1,NOFIX                                                80 00347
00254    81*     333 NSUB3(I)=FIX(I)                                                 81
00254    82*   C * * LOAD SORTED SITES( EXCLUDING FIXED  OF COURSE) INTO REMAINING   82
00254    83*   C * * NSUB3(I) ARRAYS CELLS UP TO NSITE CELLS.                        83
00256    84*         KK=NOFIX                                                        84 00352
00257    85*         DO 342 J=1,NOSITE                                               85 00362
00262    86*         DO 341 K=1,NOFIX                                                86
00265    87*         IF(NSUB(J).EQ.FIX(K))GO TO 342                                  87
00267    88*     341 CONTINUE                                                        88 00370
00271    89*         KK=KK+1                                                         89
00272    90*         NSUB3(KK)=NSUB(J)                                               90 00373
00273    91*     342 CONTINUE                                                        91 00400
00275    92*     343 CONTINUE                                                        92
00276    93*         AAANUM=ZUMACC                                                   93
00277    94*         BBBDEN=ZUMINV                                                   94 00402
00300    95*         NOSTEM=NOFIX                                                    95 00404
00301    96*     350 CONTINUE                                                        96 00406
00302    97*         NOSTEM=NOSTEM+1                                                 97
00303    98*         IF(NOSTEM.EQ.NOSITE) GO TO 370                                  98 00412
00305    99*         DO 360 II=NOSTEM,NOSITE                                         99 00416
00310   100*         I=NSUB3(II)                                                    100 00422
00311   101*         CURSN=AAANUM+SDSAVA(I)                                         101 00425
00312   102*         CURSD=BBBDEN + SDCOSI(I)                                       102 00430
00313   103*         XDEM=CURSD                                                     103 00433
00314   104*         IF(ABS(XDEM).LT.1.E-13)XDEM=1.E-13                             104 00434
00316   105*         BEN2(I)=CURSN/ XDEM                                            105 00443
00317   106*         RBEN2(I)=1./BEN2(I)                                            106 00447
00320   107*     360 CONTINUE                                                       107 00454
00322   108*         NDUM=NOSITE -NOSTEM+1                                          108
00323   109*         DO 362 J=1,NDUM                                                109 00460
00326   110*         II=J+NOSTEM-1                                                  110 00464
00327   111*         I=NSUB3(II)                                                    111 00470
00330   112*         RDUM(J)=RBEN2(I)                                               112 00473
00331   113*     362 NSUB4(J)=I                                                     113 00476
00333   114*         CALL TREE(RDUM,NSUB4,NDUM)                                     114 00501
00333   115*   C * * RELOAD NSUB3 & RBEN(I)                                         115
00334   116*         DO 364 J=1,NDUM                                                116 00506
00337   117*         II=J+NOSTEM-1                                                  117 00513
00340   118*         I=NSUB4(J)                                                     118 00517
00341   119*         NSUB3(II)=I                                                    119 00521
00342   120*         RBEN(I)=RDUM(J)                                                120 00523
00343   121*     364 CONTINUE                                                       121 00530
00345   122*         AAANUM=AAANUM+SDSAVA(NSUB3(NOSTEM))                            122
00346   123*         BBBDEN=BBBDEN+SDCOSI(NSUB3(NOSTEM))                            123 00534
00347   124*         GO TO 350                                                      124 00537
00350   125*     370 CONTINUE                                                       125 00540
00351   126*         DO 380 I=1,NOSITE                                              126
00354   127*     380 NSUB(I)=NSUB3(I)                                               127 00544
```

```
00356   128*         IFLAG=2                                    128 00547
00357   129*         CALL G1990D                                129 00551
00360   130*         DO 320 I=KSTART,NOSITE                     130 00553
00363   131*         NOSUSE=NOSITE+KSTART-I                     131 00560
00364   132*         IIIIII=I+1-KSTART                          132 00564
00365   133*         CALL SUM90                                 133 00570
00366   134*         SUMIV9(IIIIII)=SIIV90                      134 00572
00367   135*         CALL NPVNAS                                135 00575
00370   136*     320 CONTINUE                                   136 00601
00372   137*         CALL REPORT                                137
00373   138*         RETURN                                     138 00603
00374   139*         END                                        139 00643

    0 DIAGNOSTICS

CPU13.253   CTP1.096   SUPS110.670
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@FOR,S   TREE
FOR 003E-05/15/78-13:22:51 (0,)

   SUBROUTINE TREE        ENTRY POINT 000172

   STORAGE USED: CODE(1) 000204; DATA(0) 000023; BLANK COMMON(2) 000000

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001   000026 20L       0001   000041 40L       0001   000054 50L       0001   000072 60L       0001   000113 80L
    0001   000121 90L       0000 I 000000 I         0000   000007 INJP$     0000 I 000006 J         0000 I 000003 K
    0000 I 000004 LT        0000 I 000005 LTSUB     0000 I 000001 M         0000 I 000002 NFLAG


00101      1*         SUBROUTINE TREE(L,LSUB,N)                                           000007
00103      2*         DIMENSION L(N),LSUB(N)                                              000007
00103      3*    C * * TREE SORTING SCHEME.                                               000007
00104      4*         IF(N.LE.1)RETURN                                                    000007
00106      5*         I=N/2                                                               000016
00107      6*         M=N                                                                 000021
00110      7*         NFLAG=0                                                             000023
00111      8*         GO TO 40                                                            000024
00112      9*      20 I=I-1                                                               000026
00113     10*         IF(I.GT.1)GO TO 40                                                  000030
00115     11*         I=1                                                                 000033
00116     12*         M=N                                                                 000035
00117     13*         NFLAG=1                                                             000037
00120     14*      40 K=I                                                                 000041
00121     15*         LT=L(K)                                                             000042
00122     16*         LTSUB=LSUB(K)                                                       000046
00123     17*         GO TO 60                                                            000052
00124     18*      50 L(K)=L(J)                                                           000054
00125     19*         LSUB(K)=LSUB(J)                                                     000061
00126     20*         K=J                                                                 000067
00127     21*      60 J=2*K                                                               000072
00130     22*         IF(J-M)70,80,90                                                     000074
00133     23*      70 IF(L(J+1).LE.L(J))GO TO 80                                          000077
00135     24*         J=J+1                                                               000107
00136     25*      80 IF(L(J).GT.LT)GO TO 50                                              000113
00140     26*      90 L(K)=LT                                                             000121
00141     27*         LSUB(K)=LTSUB                                                       000124
00142     28*         IF(NFLAG.EQ.0)GO TO 20                                              000130
00144     29*         LT=L(1)                                                             000132
00145     30*         L(1)=L(M)                                                           000134
00146     31*         L(M)=LT                                                             000140
00147     32*         LTSUB=LSUB(1)                                                       000141
00150     33*         LSUB(1)=LSUB(M)                                                     000143
00151     34*         LSUB(M)=LTSUB                                                       000147
00152     35*         M=M-1                                                               000150
00153     36*         IF(M.GT.1)GO TO 40                                                  000153
00155     37*         RETURN                                                              000156
00156     38*         END                                                                 000203

       END OF COMPILATION:        NO  DIAGNOSTICS.
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@FOR,S   G1990D
FOR 003E-05/15/78-13:22:54 (0,)

   SUBROUTINE G1990D     ENTRY POINT 000201

   STORAGE USED: CODE(1) 000215; DATA(0) 000126; BLANK COMMON(2) 003321

    COMMON BLOCKS:

    0003   AAAAAA 001230
    0004   BBBBBB 000070
    0005   EEEEEE 000135

   EXTERNAL REFERENCES (BLOCK, NAME)

    0006   XPRR
    0007   NWNLS
    0010   NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001   000051 132G     0001   000117 152G     0002 R 002727 ADDLAB   0002 R 003320 ADDLA9   0002 R 002117 ADLABR
    0002 R 003161 ADLAB9   0002   002273 BENFCR   0005   000071 BEN2     0002   001505 CILMCS   0004   000067 CONST
    0002 R 001347 COSEND   0002 R 002777 COSEN9   0002   001323 COSMOD   0002   001313 COSNEW   0002   001333 COSTRA
    0002   001535 DFSIPG   0002   001525 DFSMPG   0003   000703 DISCON   0002 I 002473 EHCREW   0002 R 001545 EHELPM
    0002 R 003137 EHELP9   0002 R 002603 ELECHI   0002 R 003111 ELECH9   0002 R 002723 ELEENE   0002 R 003317 ELEEN9
    0002 I 002363 ELEHEL   0002 R 001655 EMAINT   0002 R 003203 EMAIN9   0002   001515 EMATPM   0002   000710 ESAVMP
    0002 R 001765 ESRRMP   0002 R 003225 ESRRM9   0005 I 000001 FIX      0002   002361 FLYCOS   0002   001130 FLYSC
    0002   000204 FLYWCV   0002   000162 FLYWMA   0002   000140 FLYWS    0003   001206 FNPV     0002 I 000050 GTTONS
    0000   000002 G90DOL   0000 I 000001 I        0002   001274 IANANO   0002   002737 IFLAG    0004   000044 IIIIII
    0002   001276 ILUSE    0000   000077 INJP$    0003 I 001205 IPR      0002   002337 IRANK    0004   000022 IRANKK
    0002   000000 IRNAME   0002 I 001275 IROUTE   0002   000020 IRROAD   0002   002750 ISEN     0002   000360 ISITES
    0004   000045 ISUB     0003   001204 KSTART   0002 R 000120 LOCFMI   0002   001307 LOCTRA   0002   000060 LOCTYP
    0002 R 000100 LOCUSE   0002 L 002742 LSCEN1   0002 L 002743 LSCEN2   0002 L 002744 LSCEN3   0002 L 002745 LSCEN4
    0004   000000 MDUMY    0002   000470 MILEPF   0002   000600 MILEPT   0002   001303 MODLOC   0005   000045 MSUB
    0003 R 000062 NAS      0002   001277 NEWLOC   0002   002747 NH       0002   002746 NL       0005   000000 NOFIX
    0002   000054 NOLOC    0002   002736 NOSITE   0002   000034 NOSITT   0002 I 002362 NOSUSE   0003 R 000000 NPV
    0002   002751 NSUB     0005   000023 NSUB3    0003   000702 NYRCON   0002   002315 RBEN     0005   000113 RBEN2
    0002   001020 REGPL    0002 I 000030 RMILES   0003   001074 ROI      0003   000764 ROIPER   0002 R 001343 ROUTEE
    0002 R 002776 ROUTE9   0002 R 002007 RPEAKD   0002 R 003247 RPEAK9   0002 R 002733 R13A6    0002   002734 R13A7
    0002   002735 R13A8    0000 R 000000 R135A6   0002 R 002740 R135A7   0002 R 002741 R135A8   0002   003271 SACC90
    0002   003272 SACPS9   0002   002713 SAVLRP   0002 I 001240 SCENIO   0002   002251 SDCOSI   0002   002227 SDSAVA
    0002   003066 SIIV90   0002 R 001353 SITELE   0002 R 003022 SITEL9   0002   000226 STABLD   0002   003067 SUMIV9
    0002 R 001511 TCILMC   0002 R 003133 TCILM9   0002 R 000336 TCOSFS   0002 R 003000 TCOSF9   0002   000040 TDENEB
    0002   000044 TDENWB   0002 R 003136 TDFSI9   0002 R 003135 TDFSM9   0002 R 001541 TDFSTI   0002 R 001531 TDFSTM
    0002 R 001521 TEMTPM   0002 R 003134 TEMTP9   0002 R 001327 TOTMOD   0002 R 002774 TOTMO9   0002 R 001317 TOTNEW
    0002 R 002773 TOTNE9   0002 R 001337 TOTTRA   0002 R 002775 TOTTR9   0002 R 002717 TSAVLR   0002 R 003316 TSAVL9
    0002 R 001463 TSITEC   0002 R 003044 TSITE9   0003   000704 XIR      0005   000070 ZUMACC   0005   000067 ZUMINV


00101      1*          SUBROUTINE G1990D                                                          000006
00101      2*     C * * THIS SUBR CONVERTS 1977$ TO 1990$                                          000006
00103      3*          INCLUDE COM1,LIST                                                          000006
00103      3*     COM1   PROC                                                                     000006
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00104    3*        PARAMETER NP1=4,NP2=16,NP3=18,NP4=1,NP5=50                                    000006
00105    3*        LOGICAL LSCEN1,LSCEN2,LSCEN3,LSCEN4                                           000006
00106    3*        REAL LOCUSE,LOCFMI                                                            000006
00107    3*        REAL NPV,NAS                                                                  000006
00110    3*        INTEGER SCENIO,RMILES,GTTONS,ELEHEL,EHCREW,FIX                                000006
00110    3*    C * * BLANK COMMON                                                                000006
00111    3*        COMMON                                                                        000006
00111    3*       1 IRNAME(4,NP1),IRROAD(2,NP1),RMILES(NP1),NOSITT(NP1)  ,                       000006
00111    3*       2 TDENEB(NP1),TDENWB(NP1), GTTONS(NP1), NOLOC(NP1),                            000006
00111    3*       3 LOCTYP(4,NP1), LOCUSE(NP2),LOCFMI(NP2), FLYWS(NP3),                          000006
00111    3*       4 FLYWMA(NP3),      FLYWCV(NP3),     STABLD(NP3,NP1),TCOSFS(NP3)   ,           000006
00111    3*       5 ISITES(NP3,NP1),MILEPF(NP3,NP1),MILEPT(NP3,NP1),ESAVMP(NP3,NP1),             000006
00111    3*       6 REGPL(NP3,NP1),FLYSC(NP3,NP1),SCENIO(7,NP1), IANANO , IROUTE,                000006
00111    3*       7 ILUSE,NEWLOC(NP1),MODLOC(NP1),LOCTRA(NP1),COSNEW(NP1),                       000006
00111    3*       8 TOTNEW(NP1), COSMOD(NP1),TOTMOD(NP1), COSTRA(NP1),TOTTRA(NP1),               000006
00111    3*       9 ROUTEE(NP1),COSEND(NP1), SITELE(NP3,NP1),TSITEC(NP3),                        000006
00111    3*       A CILMCS(NP1),TCILMC(NP1),                              EMATPM(NP1),           000006
00111    3*       B TEMTPM(NP1), DFSMPG(NP1),TDFSTM(NP1), DFSIPG(NP1),TDFSTI(NP1),               000006
00111    3*    C * * SITE DEPENDENT ($)                                                          000006
00111    3*       D EHELPM(NP3,NP1), EMAINT(NP3,NP1), ESRRMP(NP3),                               000006
00111    3*       E RPEAKD(NP3,NP1), ADLABR(NP3,NP1),                                            000006
00111    3*       F SDSAVA(NP3),SDCOSI(NP3),BENFCR(NP3),RBEN(NP3),IRANK(NP3)                     000006
00111    3*    C * * FLYWHEEL COST                                                               000006
00112    3*        COMMON FLYCOS                                                                 000006
00113    3*        COMMON                                                                        000006
00113    3*       G NOSUSE,ELEHEL(NP1,NP3),EHCREW(NP1,NP3),ELECHI(NP1,NP3),                      000006
00113    3*       H SAVLRP(NP1),TSAVLR(NP1),ELEENE(NP1),ADDLAB(NP1)                              000006
00113    3*    C                                                                                 000006
00114    3*        COMMON R13A6,R13A7,R13A8,NOSITE,IFLAG,R135A7,R135A8                           000006
00114    3*       1,LSCEN1,LSCEN2,LSCEN3,LSCEN4,NL,NH,ISEN,NSUB(NP3)                             000006
00114    3*    C * * COMMON      INITIAL INVESTMENTS 1990 DOLLARS                                000006
00115    3*        COMMON                                                                        000006
00115    3*       1 TOTNE9    ,  TOTMO9    ,  TOTTR9   ,   ROUTE9   ,   COSEN9    ,               000006
00115    3*       2 TCOSF9(NP3)     ,SITEL9(NP3)     , TSITE9(NP3)     ,SIIV90                   000006
00115    3*       3,SUMIV9(NP3)    ,ELECH9(NP3)                                                  000006
00116    3*        COMMON        $  ANNUAL COST AND CREDITS 1990 DOLLARS.                        000006
00116    3*       1 TCILM9,TEMTP9,TDFSM9,TDFSI9                                                  000006
00116    3*       2               ,EHELP9(NP3)      ,ADLAB9(NP3)      ,EMAIN9(NP3),              000006
00116    3*       3 ESRRM9(NP3)      ,RPEAK9(NP3)      ,SACC90,SACPS9(20)                        000006
00116    3*       4, TSAVL9,ELEEN9,ADDLA9                                                        000006
00117    3*        COMMON/AAAAAA/NPV(NP5),     NAS(100,NP1),NYRCON,DISCON,XIR(12,4),             000006
00117    3*       1 ROIPER(4,NP3),ROI(4,NP3),KSTART,IPR,FNPV(NP3)                                000006
00120    3*        COMMON/HBBBBB/MDUMY(NP3),IRANKK(NP3),IIIIII ,ISUB(NP3),CONST                  000006
00121    3*        COMMON/EEEEEE/NOFIX,FIX(NP3),NSUB3(NP3),MSUB(NP3),ZUMINV,ZUMACC               000006
00121    3*       1,BEN2(NP3),RBEN2(NP3)                                                         000006
00121    3*     END                                                                              000006
00122    4*        NAMELIST/G90DOL/NOSUSE,TOTMO9,TOTTR9,ROUTE9,COSEN9,TCOSF9,SITEL9,             000006
00122    5*       1TSITE9,TOTNE9,                                                                000006
00122    6*       2 TCILM9,TEMTP9,TDFSM9,TDFSI9,EHELP9,ADLAB9,EMAIN9,ESRRM9,RPEAK9               000006
00122    7*    C                                                                                 000006
00123    8*        R135A6=(1.060)**13.50                                                         000010
00123    9*    C                                                                                 000010
00123   10*    C * * CONVERT INITIAL INVESTMENTS INTO 1990 DOLLARS                               000010
00124   11*        TOTNE9        =TOTNEW(IROUTE)*R13A6                                           000015
00125   12*        TOTMO9        =TOTMOD(IROUTE)*R13A6                                           000020
00126   13*        TOTTR9        =TOTTRA(IROUTE)*R13A6                                           000023
00127   14*        ROUTE9        =ROUTEE(IROUTE)*R13A6                                           000026
00130   15*        COSEN9        =COSEND(IROUTE)*R13A6                                           000031
00131   16*        DO 100 I=1,NP3                                                                000051
00134   17*        ELECH9(I)=ELECHI(I,IROUTE)*R13A6                                              000051
```

```
00135      18*          TCOSF9(I )       =TCOSFS(I)*R13A6                                                000053
00136      19*          SITEL9(I )       =SITELE(I,IROUTE)*R13A6                                         000056
00137      20*          TSITE9(I   )     =TSITEC(I   ) * R13A6                                           000061
00140      21*      100 CONTINUE                                                                         000065
00140      22*     C                                                                                     000065
00140      23*     C * * ANNUAL COSTS & CREDITS 1990 DOLLARS.                                            000065
00142      24*          TSAVL9=TSAVLR(IROUTE)*R135A6                                                     000065
00143      25*          TCILM9        =TCILMC(IROUTE)*R135A8                                             000070
00144      26*          TEMTP9        =TEMTPM(IROUTE)*R135A8                                             000073
00145      27*          ELEEN9=ELEENE(IROUTE)*R135A7                                                     000076
00146      28*          TDFSM9        =TDFSTM(IROUTE)*R135A8                                             000101
00147      29*          TDFSI9        =TDFSTI(IROUTE)*R135A8                                             000104
00150      30*          ADDLA9=ADDLAB(IROUTE)*R135A8                                                     000107
00151      31*          DO 200 I=1,NP3                                                                   000117
00154      32*          EHELP9(I )       =EHELPM(I,IROUTE)*R135A8                                        000117
00155      33*          ADLAB9(I )       =ADLABR(I,IROUTE)*R135A8        * SCNARIO # 2 ONLY              000121
00156      34*          IF((LSCEN1).OR.(LSCEN2))ESRRM9(I     )   =ESRRMP(I)*R135A8                       000124
00160      35*          IF((LSCEN3).OR.(LSCEN4))ESRRM9(I)        =ESRRMP(I)*R135A7                       000131
00162      36*          IF((LSCEN3).OR.(LSCEN4))RPEAK9(I )   =   RPEAKD(I,IROUTE)*R135A7                 000136
00164      37*          EMAIN9(I   )     =EMAINT(I,IROUTE)*R135A8                                        000144
00165      38*      200 CONTINUE                                                                         000150
00167      39*          IF(IPR.EQ.2)WRITE(6,G900OL)                                                      000150
00173      40*          RETURN                                                                           000157
00174      41*          E N D                                                                            000214
```

END OF COMPILATION: NO DIAGNOSTICS.

```
@FOR,S   SUM90
FOR 003E-05/15/78-13:22:59 (0,)

   SUBROUTINE SUM90     ENTRY POINT 000223

   STORAGE USED: CODE(1) 000231; DATA(0) 001071; BLANK COMMON(2) 003321

    COMMON BLOCKS:

    0003    AAAAAA 001230
    0004    BBBBBB 000070
    0005    EEEEEE 000135

   EXTERNAL REFERENCES (BLOCK, NAME)

    0006    NWNL$
    0007    NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000042 135G      0001    000055 145G      0001    000115 170G      0002    002727 ADDLAB    0002 R 003320 ADDLA9
    0002    002117 ADLABR    0002 R 003161 ADLAB9    0002    002273 BENFCR    0005    000071 BEN2      0002   001505 CILMCS
    0004    000067 CONST     0002   001347 COSEND    0002    002777 COSEN9    0002    001323 COSMOD    0002   001313 COSNEW
    0002    001333 COSTRA    0002   001535 DFSIPG    0002    001525 DFSMPG    0003    000703 DISCON    0002 I 002473 EHCREW
    0002    001545 EHELPM    0002 R 003137 EHELP9    0002    002603 ELECHI    0002 R 003111 ELECH9    0002   002723 ELEENE
    0002 R  003317 ELEEN9    0002 I 002363 ELEHEL    0002    001655 EMAINT    0002 R 003203 EMAIN9    0002   001515 EMATPM
    0002    000710 ESAVMP    0002   001765 ESRRMP    0002 R  003225 ESRRM9    0005 I 000001 FIX       0002   002361 FLYCOS
    0002    001130 FLYSC     0002   000204 FLYWCV    0002    000162 FLYWMA    0002    000140 FLYWS     0003   001206 FNPV
    0002 I  000050 GTTONS    0000 I 000001 I         0002    001274 IANANO    0002    002737 IFLAG     0004   000044 IIIIII
    0002    001276 ILUSE     0000   000073 INJP$     0003 I  001205 IPR       0002    002337 IRANK     0004   000022 IRANKK
    0002    000000 IRNAME    0002   001275 IROUTE    0002    000020 IRROAD    0000 I 000000 IS        0002   002750 ISEN
    0002    000360 ISITES    0004   000045 ISUB      0003    001204 KSTART    0002 R 000120 LOCFMI    0002   001307 LOCTRA
    0002    000060 LOCTYP    0002 R 000100 LOCUSE    0002 L  002742 LSCEN1    0002 L 002743 LSCEN2    0002 L 002744 LSCEN3
    0002 L  002745 LSCEN4    0004   000000 MDUMY     0002    000470 MILEPF    0002    000600 MILEPT    0002   001303 MODLOC
    0005    000045 MSUB      0003 R 000062 NAS       0002    001277 NEWLOC    0002    002747 NH        0002   002746 NL
    0005    000000 NOFIX     0002   000054 NOLOC     0002    002736 NOSITE    0002    000034 NOSITT    0002 I 002362 NOSUSE
    0003 R  000000 NPV       0002 I 002751 NSUB      0005    000023 NSUB3     0003    000702 NYRCON    0002   002315 RBEN
    0005    000113 RBEN2     0002   001020 REGPL     0002 I  000030 RMILES    0003    001074 ROI       0003   000764 ROIPER
    0002    001343 ROUTEE    0002 R 002776 ROUTE9    0002    002007 RPEAKD    0002 R 003247 RPEAK9    0002   002733 R13A6
    0002    002734 R13A7     0002   002735 R13A8     0002    002740 R135A7    0002    002741 R135A8    0002 R 003271 SACC90
    0002 R  003272 SACPS9    0002   002713 SAVLRP    0002 I  001240 SCENIO    0002    002251 SUCOSI    0002   002227 SDSAVA
    0002 R  003066 SIIV90    0002   001353 SITELE    0002    003022 SITEL9    0002    000226 STABLD    0002   003067 SUMIV9
    0000    000004 SUM90D    0002   001511 TCILMC    0002 R  003133 TCILM9    0002    000336 TCOSFS    0002   003000 TCOSF9
    0002    000040 TDENEB    0002   000044 TDENWB    0002 R  003136 TDFSI9    0002 R 003135 TDFSM9    0002   001541 TDFSTI
    0002    001531 TDFSTM    0002   001521 TEMTPM    0002 R  003134 TEMTP9    0002    001327 TOTMOD    0002 R 002774 TOTMO9
    0002    001317 TOTNEW    0002 R 002773 TOTNE9    0002    001337 TOTTRA    0002 R 002775 TOTTR9    0002   002717 TSAVLR
    0002 R  003316 TSAVL9    0002   001463 TSITEC    0002 R  003044 TSITE9    0003 R 000704 XIR       0005   000070 ZUMACC
    0005    000067 ZUMINV


00101      1*          SUBROUTINE SUM90                                                                   000001
00101      2*       C * * THIS SUBR SUMS INITIAL INVESTMENTS(1990 DOLLARS) AND ANNUAL COSTS               000001
00101      3*       C * * AND CREDITS(1990 DOLLARS).                                                      000001
00103      4*          INCLUDE COM1,LIST                                                                  000001
```

```
00103    4*    CUM1     PROC                                                              000001
00104    4*          PARAMETER NP1=4,NP2=16,NP3=18,NP4=1,NP5=50                          000001
00105    4*          LOGICAL LSCEN1,LSCEN2,LSCEN3,LSCEN4                                 000001
00106    4*          REAL LOCUSE,LOCFMI                                                  000001
00107    4*          REAL NPV,NAS                                                        000001
00110    4*          INTEGER SCENIO,RMILES,GTTONS,ELEHEL,EHCREW,FIX                      000001
00110    4*    C * * BLANK COMMON                                                        000001
00111    4*          COMMON                                                              000001
00111    4*         1 IRNAME(4,NP1),IRROAD(2,NP1),RMILES(NP1),NOSITT(NP1) ,              000001
00111    4*         2 TDENEB(NP1),TDENWB(NP1), GTTONS(NP1), NOLOC(NP1),                  000001
00111    4*         3 LOCTYP(4,NP1), LOCUSE(NP2),LOCFMI(NP2), FLYWS(NP3),                000001
00111    4*         4 FLYWMA(NP3),      FLYWCV(NP3),     STABLD(NP3,NP1),TCOSFS(NP3)   , 000001
00111    4*         5 ISITES(NP3,NP1),MILEPF(NP3,NP1),MILEPT(NP3,NP1),ESAVMP(NP3,NP1),   000001
00111    4*         6 REGPL(NP3,NP1),FLYSC(NP3,NP1),SCENIO(7,NP1), IANANO , IROUTE,      000001
00111    4*         7 ILUSE,NEWLOC(NP1),MODLOC(NP1),LOCTRA(NP1),COSNEW(NP1),             000001
00111    4*         8 TOTNEW(NP1), COSMOD(NP1),TOTMOD(NP1), COSTRA(NP1),TOTTRA(NP1),     000001
00111    4*         9 ROUTEE(NP1),COSEND(NP1), SITELE(NP3,NP1),TSITEC(NP3),              000001
00111    4*         A CILMCS(NP1),TCILMC(NP1),                          EMATPM(NP1),     000001
00111    4*         B TEMTPM(NP1), DFSMPG(NP1),TDFSTM(NP1), DFSIPG(NP1),TDFSTI(NP1),     000001
00111    4*    C * * SITE DEPENDENT ($)                                                  000001
00111    4*         D EHELPM(NP3,NP1), EMAINT(NP3,NP1), ESRRMP(NP3),                     000001
00111    4*         E RPEAKD(NP3,NP1), ADLABR(NP3,NP1),                                  000001
00111    4*         F SDSAVA(NP3),SDCOSI(NP3),BENFCR(NP3),RBEN(NP3),IRANK(NP3)           000001
00111    4*    C * * FLYWHEEL COST                                                       000001
00112    4*          COMMON FLYCOS                                                       000001
00113    4*          COMMON                                                              000001
00113    4*         G NOSUSE,ELEHEL(NP1,NP3),EHCREW(NP1,NP3),ELECHI(NP1,NP3),            000001
00113    4*         H SAVLRP(NP1),TSAVLR(NP1),ELEENE(NP1),ADDLAB(NP1)                    000001
00113    4*    C                                                                         000001
00114    4*          COMMON R13A6,R13A7,R13A8,NOSITE,IFLAG,R135A7,R135A8                 000001
00114    4*         1,LSCEN1,LSCEN2,LSCEN3,LSCEN4,NL,NH,ISEN,NSUB(NP3)                   000001
00114    4*    C * * COMMON      INITIAL INVESTMENTS 1990 DOLLARS                        000001
00115    4*          COMMON                                                              000001
00115    4*         1 TOTNE9    ,  TOTMO9    ,  TOTTR9    ,   ROUTE9   ,    COSEN9    ,  000001
00115    4*         2 TCOSF9(NP3)      ,SITEL9(NP3)     , TSITE9(NP3)     ,SIIV90        000001
00115    4*         3,SUMIV9(NP3)    ,ELECH9(NP3)                                        000001
00116    4*          COMMON         *  ANNUAL COST AND CREDITS 1990 DOLLARS.             000001
00116    4*         1 TCILM9,TEMTP9,TDFSM9,TDFSI9                                        000001
00116    4*         2              ,EHELP9(NP3)     ,ADLAB9(NP3)     ,EMAIN9(NP3),       000001
00116    4*         3 ESRRM9(NP3)      ,RPEAK9(NP3)      ,SACC90,SACPS9(20)              000001
00116    4*         4, TSAVL9,ELEEN9,ADDLA9                                              000001
00117    4*          COMMON/AAAAAA/NPV(NP5),      NAS(100,NP1),NYRCON,DISCON,XIR(12,6),  000001
00117    4*         1 ROIPER(4,NP3),ROI(4,NP3),KSTART,IPR,FNPV(NP3)                      000001
00120    4*          COMMON/BBBBBB/MDUMY(NP3),IRANKK(NP3),IIIIII ,ISUB(NP3),CONST        000001
00121    4*          COMMON/EEEEEE/NOFIX,FIX(NP3),NSUB3(NP3),MSUB(NP3),ZUMINV,ZUMACC     000001
00121    4*         1,BEN2(NP3),RBEN2(NP3)                                               000001
00121    4*     END                                                                      000001
00122    5*          NAMELIST/SUM90D/SIIV90,SACC90,SACPS9,TCILM9,TEMTP9,TDFSM9,TDFSI9,   000001
00122    6*         1 ADLAB9,EMAIN9,ESRRM9,RPEAK9,XIR,NSUB                               000001
00122    7*         2, ELECH9,TSAVL9,ELEEN9,ADDLA9                                       000001
00122    8*    C * * SIIV90 =SUM OF INITIAL INVESTMENTS 1990 DOLLARS.                    000001
00123    9*          SIIV90 =0                                                           000002
00124   10*          IF((LSCEN2),OR,(LSCEN4))SIIV90=SIIV90+TOTNE9                        000003
00126   11*          IF((LSCEN1),OR,(LSCEN3))SIIV90=SIIV90+TOTMO9                        000011
00130   12*          IF((LSCEN1),OR,(LSCEN2),OR,(LSCEN4))SIIV90=SIIV90+TOTTR9            000017
00132   13*          IF(LSCEN4)SIIV90=SIIV90+ROUTE9                                      000027
00132   14*    C     SIIV90=SIIV90+COSEN9(IROUTE)   *THIS SOULD NOT HAVE BEEB HERE.      000027
00132   15*    C * * NOSUSE= NO. OF SITES CONSIDERED IN IMMEDIATE ANALYSIS.              000027
00134   16*          DO 350 IS=1,NOSUSE                                                  000034
00137   17*          I=NSUB(IS)                                                          000042
```

```
00140          SIIV90=SIIV90+TSITE9(I)     + ELECH9(I)                 000044
00141      350 CONTINUE                                                000051
00141     C * * SACC90=SUM OF ALL ANNUAL COST AND CREDITS 1990 DOLLARS. 000051
00143          SACC90=0                                                000051
00144          DO 352 I=1,20                                           000055
00147      352 SACPS9(I)=0                                             000055
00151          SACPS9(1)=TSAVL9                                        000056
00152          SACC90=SACC90+TSAVL9                                    000060
00153          SACC90=SACC90+TCILM9                                    000062
00154          SACPS9(2)=TCILM9                                        000064
00155          SACPS9(3)=TEMTP9                                        000066
00156          SACC90=SACC90+TEMTP9                                    000070
00157          SACPS9(4)=ELEEN9                                        000072
00160          SACC90=SACC90+ELEEN9                                    000074
00161          SACPS9(5)=TDFSM9                                        000076
00162          SACC90=SACC90+TDFSM9                                    000100
00163          SACPS9(6)=TDFSI9                                        000102
00164          SACC90=SACC90+TDFSI9                                    000104
00165          SACPS9(7)=ADDLA9                                        000106
00166          SACC90=SACC90+ADDLA9                                    000110
00167          DO 360 IS=1,NOSUSE                                      000115
00172          I=NSUB(IS)                                              000115
00173          SACC90=SACC90+EHELP9(I)                                 000116
00174          SACPS9(8)=SACPS9(8)+ EHELP9(I)                          000122
00175          IF(LSCEN2)SACC90=SACC90+ADLAB9(I)                       000126
00177          IF(LSCEN2)                                              000134
00177         1SACPS9(9)=SACPS9(9)  +ADLAB9(I)                         000134
00201          SACC90=SACC90+ESRRM9(I)                                 000142
00202          SACPS9(10)=SACPS9(10)  + ESRRM9(I)                      000146
00203          IF((LSCEN3).OR.(LSCEN4))SACC90=SACC90+RPEAK9(I)         000151
00205          IF((LSCEN3).OR.(LSCEN4))SACPS9(11)=SACPS9(11)+RPEAK9(I) 000157
00207          SACPS9(12)=SACPS9(12)  + EMAIN9(I)                      000166
00210          SACC90=SACC90+EMAIN9(I)                                 000172
00211      360 CONTINUE                                                000177
00213          IF(IPR.GT.2)WRITE(6,SUM90D)                             000177
00217          RETURN                                                  000207
00220          E N D                                                   000230
```

END OF COMPILATION: NO DIAGNOSTICS.

```
@FOR,S   NPVNAS
FOR 003E-05/15/78-13:23:04 (0,)

   SUBROUTINE NPVNAS     ENTRY POINT 000312

   STORAGE USED: CODE(1) 000327; DATA(0) 000101; BLANK COMMON(2) 003321

    COMMON BLOCKS:

    0003   AAAAAA 001230
    0004   BBBBBB 000070
    0005   EEEEEE 000135

   EXTERNAL REFERENCES (BLOCK, NAME)

    0006   RONINV
    0007   XPRR
    0010   XPRI
    0011   NWNL$
    0012   NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000013 125G      0001    000042 136G      0001    000056 145G      0001    000124 161G      0001    000155 164G
    0001    000171 173G      0002    002727 ADDLAB    0002    003320 ADDLA9    0002    002117 ADLABR    0002    003161 ADLAB9
    0002    002273 BENFCR    0005    000071 BEN2      0002    001505 CILMCS    0004    000067 CONST     0002    001347 COSEND
    0002 R  002777 COSEN9    0002    001323 COSMOD    0002    001313 COSNEW    0002    001333 COSTRA    0002    001535 DFSIPG
    0002    001525 DFSMPG    0003 R  000703 DISCON    0002 I  002473 EHCREW    0002    001545 EHELPM    0002    003137 EHELP9
    0002    002603 ELECHI    0002    003111 ELECH9    0002    002723 ELEENE    0002    003317 ELEEN9    0002 I  002363 ELEHEL
    0002    001655 EMAINT    0002    003203 EMAIN9    0002    001515 EMATPM    0002    000710 ESAVMP    0002    001765 ESRRMP
    0002    003225 ESRRM9    0005 I  000001 FIX       0002    002361 FLYCOS    0002    001130 FLYSC     0002    000204 FLYWCV
    0002    000162 FLYWMA    0002    000140 FLYWS     0003 R  001206 FNPV      0002 I  000050 GTTONS    0000 I  000004 I
    0002    001274 IANANO    0002    002737 IFLAG     0004 I  000044 IIIIII    0002    001276 ILUSE     0000    000051 INJP$
    0003 I  001205 IPR       0002    002337 IRANK     0004    000022 IRANKK    0002    000000 IRNAME    0002    001275 IROUTE
    0002    000020 IRROAD    0002    002750 ISEN      0002    000360 ISITES    0004    000045 ISUB      0000 I  000010 J
    0000 I  000011 JJ        0000 I  000007 K         0003    001204 KSTART    0002 R  000120 LOCFMI    0002    001307 LOCTRA
    0002    000060 LOCTYP    0002 R  000100 LOCUSE    0002 L  002742 LSCEN1    0002 L  002743 LSCEN2    0002 L  002744 LSCEN3
    0002 L  002745 LSCEN4    0004    000000 MDUMY     0002    000470 MILEPF    0002    000600 MILEPT    0002    001303 MODLOC
    0005    000045 MSUB      0003 R  000062 NAS       0000    000014 NETPV     0002    001277 NEWLOC    0002    002747 NH
    0002    002746 NL        0005    000000 NOFIX     0002    000054 NOLOC     0002    002736 NOSITE    0002    000034 NOSITT
    0002    002362 NOSUSE    0003 R  000000 NPV       0002    002751 NSUB      0005    000023 NSUB3     0003 I  000702 NYRCON
    0002    002315 RBEN      0005    000113 RBEN2     0002    001020 REGPL     0000 R  000000 RETINV    0002 I  000030 RMILES
    0003 R  001074 ROI       0003 R  000764 ROIPER    0002    001343 ROUTEE    0002    002776 ROUTE9    0002    002007 RPEAKD
    0002    003247 RPEAK9    0002    002733 R13A6     0002    002734 R13A7     0002    002735 R13A8     0002    002740 R135A7
    0002    002741 R135A8    0002 R  003271 SACC90    0002 R  003272 SACPS9    0002    002713 SAVLRP    0002 I  001240 SCENIO
    0002    002251 SDCOSI    0002    002227 SDSAVA    0002 R  003066 SIIV90    0002    001353 SITELE    0002    003022 SITEL9
    0002    000226 STABLD    0002 R  003067 SUMIV9    0002    001511 TCILMC    0002    003133 TCILM9    0002    000336 TCOSFS
    0002    003000 TCOSF9    0002    000040 TDENEB    0002    000044 TDENWB    0002    003136 TDFSI9    0002    003135 TDFSM9
    0002    001541 TDFSTI    0002    001531 TDFSTM    0002    001521 TEMTPM    0002    003134 TEMTP9    0002    001327 TOTMOD
    0002    002774 TOTMO9    0002    001317 TOTNEW    0002    002773 TOTNE9    0002    001337 TOTTRA    0002    002775 TOTTR9
    0002    002717 TSAVLR    0002    003316 TSAVL9    0002    001463 TSITEC    0002    003044 TSITE9    0000 R  000005 XI
    0000 R  000006 XII       0003 R  000704 XIR       0005    000070 ZUMACC    0005    000067 ZUMINV
```

```
00101    1*         SUBROUTINE NPVNAS                                                       000000
00101    2*   C * * THIS SUBR CALCULATES NET PRESENT VALUE AND NET ANNUAL SAVINGS.          000000
00101    3*   C * * NPV(I)=NET PRESENT VALUE                                                000000
00101    4*   C * * NAS(I,J)=NET ANNUAL SAVINGS        I=YR, J= ANALYSIS MODE               000000
00101    5*   C * * NYRCON = NO. OF YRS CONSIDERED AFTER 1990                               000000
00101    6*   C * * DISCON = DISCOUNT RATE OF 10 PERCENT                                    000000
00101    7*   C * * XIR(I,J) = OVER INFLATIONARY RATE FOR ELEMENT 'I' ; 'J' POINTS          000000
00101    8*   C * *               TO TYPE OF STUDY ( TO BE EXPLAINED).                      000000
00101    9*   C * * GET NET PRESENT VALUE FOR 1990                                          000000
00103   10*         INCLUDE COM1,LIST                                                       000000
00103   10*   COM1    PROC                                                                  000000
00104   10*         PARAMETER NP1=4,NP2=16,NP3=18,NP4=1,NP5=50                              000000
00105   10*         LOGICAL LSCEN1,LSCEN2,LSCEN3,LSCEN4                                     000000
00106   10*         REAL LOCUSE,LOCFMI                                                      000000
00107   10*         REAL NPV,NAS                                                            000000
00110   10*         INTEGER SCENIO,RMILES,GTTONS,ELEHEL,EHCREW,FIX                          000000
00110   10*   C * * BLANK COMMON                                                            000000
00111   10*         COMMON                                                                  000000
00111   10*        1 IRNAME(4,NP1),IRROAD(2,NP1),RMILES(NP1),NOSITT(NP1)  ,                 000000
00111   10*        2 TDENEB(NP1),TDENWB(NP1), GTTONS(NP1), NOLOC(NP1),                      000000
00111   10*        3 LOCTYP(4,NP1), LOCUSE(NP2),LOCFMI(NP2), FLYWS(NP3),                    000000
00111   10*        4 FLYWMA(NP3),     FLYWCV(NP3),     STABLD(NP3,NP1),TCOSFS(NP3)   ,      000000
00111   10*        5 ISITES(NP3,NP1),MILEPF(NP3,NP1),MILEPT(NP3,NP1),ESAVMP(NP3,NP1),       000000
00111   10*        6 REGPL(NP3,NP1),FLYSC(NP3,NP1),SCENIO(7,NP1), IANANO , IROUTE,          000000
00111   10*        7 ILUSE,NEWLOC(NP1),MODLOC(NP1),LOCTRA(NP1),COSNEW(NP1),                 000000
00111   10*        8 TOTNEW(NP1), COSMOD(NP1),TOTMOD(NP1), COSTRA(NP1),TOTTRA(NP1),         000000
00111   10*        9 ROUTEE(NP1),COSEND(NP1), SITELE(NP3,NP1),TSITEC(NP3),                  000000
00111   10*        A CILMCS(NP1),TCILMC(NP1),                            EMATPM(NP1),       000000
00111   10*        B TEMTPM(NP1), DFSMPG(NP1),TDFSTM(NP1), DFSIPG(NP1),TDFSTI(NP1),         000000
00111   10*   C * * SITE DEPENDENT ($)                                                      000000
00111   10*        D EHELPM(NP3,NP1), EMAINT(NP3,NP1), ESRRMP(NP3),                         000000
00111   10*        E RPEAKD(NP3,NP1), ADLABR(NP3,NP1),                                      000000
00111   10*        F SDSAVA(NP3),SDCOSI(NP3),BENFCR(NP3),RBEN(NP3),IRANK(NP3)               000000
00111   10*   C * * FLYWHEEL COST                                                           000000
00112   10*         COMMON FLYCOS                                                           000000
00113   10*         COMMON                                                                  000000
00113   10*        G NOSUSE,ELEHEL(NP1,NP3),EHCREW(NP1,NP3),ELECHI(NP1,NP3),                000000
00113   10*        H SAVLRP(NP1),TSAVLR(NP1),ELEENE(NP1),ADDLAB(NP1)                        000000
00113   10*   C                                                                             000000
00114   10*         COMMON R13A6,R13A7,R13A8,NOSITE,IFLAG,R135A7,R135A8                     000000
00114   10*        1,LSCEN1,LSCEN2,LSCEN3,LSCEN4,NL,NH,ISEN,NSUB(NP3)                       000000
00114   10*   C * * COMMON      INITIAL INVESTMENTS 1990 DOLLARS                            000000
00115   10*         COMMON                                                                  000000
00115   10*        1 TOTNE9    ,  TOTMO9    ,  TOTTR9   ,    ROUTE9   ,    COSEN9    ,      000000
00115   10*        2 TCOSF9(NP3)     ,SITEL9(NP3)     , TSITE9(NP3)     ,SIIV90             000000
00115   10*        3,SUMIV9(NP3)    ,ELECH9(NP3)                                            000000
00116   10*         COMMON          *  ANNUAL COST AND CREDITS 1990 DOLLARS.                000000
00116   10*        1 TCILM9,TEMTP9,TDFSM9,TDFSI9                                            000000
00116   10*        2              ,EHELP9(NP3)     ,ADLAB9(NP3)     ,EMAIN9(NP3),           000000
00116   10*        3 ESRRM9(NP3)      ,RPEAK9(NP3)      ,SACC90,SACPS9(20)                  000000
00116   10*        4, TSAVL9,ELEEN9,ADDLA9                                                  000000
00117   10*         COMMON/AAAAAA/NPV(NP5),     NAS(100,NP1),NYRCON,DISCON,XIR(12,4),       000000
00117   10*        1 ROIPER(4,NP3),ROI(4,NP3),KSTART,IPR,FNPV(NP3)                          000000
00120   10*         COMMON/BBBBBB/MDUMY(NP3),IRANKK(NP3),IIIIII ,ISUB(NP3),CONST            000000
00121   10*         COMMON/EEEEEE/NOFIX,FIX(NP3),NSUB3(NP3),MSUB(NP3),ZUMINV,ZUMACC         000000
00121   10*        1,BEN2(NP3),RBEN2(NP3)                                                   000000
00121   10*    END                                                                          000000
00122   11*         DIMENSION RETINV(4)                                                     000000
00123   12*         NAMELIST/NETPV/IIIIII,SACC90,SIIV90,FNPV,NAS,RETINV,NPV                 000000
00124   13*         DO 30 I=1,4                                                             000000
```

```
00124   C * * CHECK FOLLOWING STATEMENT OUT * * $&?????                000000
00127         NAS(1,I)=SACC90                                          000013
00130         IF(I.NE.1)NAS(1,I)=NAS(1,I)-SIIV90                       000015
00132      30 CONTINUE                                                 000026
00134         NPV(1)  =SACC90 /(1.0+DISCON)**0.5-SIIV90                000026
00135         DO 50 I=2,NYRCON                                         000042
00140         XI=I                                                     000042
00141         XI=XI-0.5                                                000045
00142         XII=XI-0.5                                               000050
00142   C * * GET NET ANNUAL SAVINGS                                   000050
00143         NAS(I,1)=0                                               000052
00144           DO 48 K=1,12                                           000056
00147           NAS(I,1)=NAS(I,1)   + SACPS9(K)*(1.+XIR(K,1))**XII     000056
00150      48   CONTINUE                                               000070
00150   C * * CALC NET PRESENT VALUE                                   000070
00152         NPV(I ) =NPV(I-1)    + NAS(I,1)/(1.+DISCON)**XI          000070
00153      50 CONTINUE                                                 000103
00155         NPV(NYRCON ) =NPV(NYRCON )  - COSEN9        /(1.+DISCON)**NYRCON   000103
00156         NPV(NYRCON ) =NPV(NYRCON )  + SUMIV9(IIIIII)             000116
00157         FNPV(IIIIII)=NPV(NYRCON)                                 000120
00160         DO 100 J=2,4                                             000124
00163         DO 75 I=2,NYRCON                                         000155
00166         NAS(I,J)=0                                               000155
00167         XI=I                                                     000156
00170         XI=XI-.5                                                 000161
00171         XII=XI-.5                                                000164
00172         DO 70 K=1,12                                             000171
00175           NAS(I,J)=NAS(I,J)   + SACPS9(K)*(1.+XIR(K,J))**XII     000171
00176      70 CONTINUE                                                 000203
00200         IF(I.EQ.NYRCON)NAS(I,J)=NAS(I,J)-COSEN9/(1.+DISCON)**NYRCON   000203
00202      75 CONTINUE                                                 000225
00204         JJ=1                                                     000225
00205         CALL RONINV(NAS(JJ,J),NYRCON,ROI(J,IIIIII),SIIV90,IPR)   000227
00206         ROIPER(J,IIIIII)=ROI(J,IIIIII)*100.                      000251
00207         RETINV(J)=ROI(J,IIIIII)                                  000254
00210     100 CONTINUE                                                 000260
00212         IF(IPR.GT.0)WRITE(6,NETPV)                               000260
00216         RETURN                                                   000267
00217         END                                                      000326

        END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@AFOR,S   RONINV
ATHENA EXTENDED FORTRAN 24I-05 (14 APR 77)
COMPILATION DONE ON 15 MAY 78 AT 13:43:18

     @SUBROUTINE  RONINV      ENTRY POINT 00522   SEQ 000102

   STORAGE USED (BLOCK, NAME, LENGTH)

          0001   @CODE          000567
          0000   @CONST+TEMP    000236
          0002   @SIMPLE VAR    000022
          0004   @ARRAYS        000100
          0005   N$BLNK  000000

  EXTERNAL REFERENCES

          0006   ITRAT
          0007   NWDU$
          0010   NI01$
          0011   NI02$
          0012   NEXP6$
          0013   NSTOP$
          0014   NER10$

 STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0002 R 000013 CONVG      0002 R 000010 CONVGI     0004 R 000000 DCF        0002 R 000015 DCFACT     0002 R 000001 DCFDES
    0002 R 000005 DUMSUM     0002 R 000016 DYDX       0002 R 000011 FMAX       0002 I 000003 I          0004 I 000062 IT
    0002 I 000000 ITLIM      0002 I 000012 J          0002 I 000002 KOUNT      0002 R 000020 PROI       0002 R 000006 ROIGSS
    0002 R 000007 ROIPGS     0002 R 000017 ROISAV     0002 R 000021 ROITEM     0002 R 000004 STAND      0002 R 000014 XP
    0004 R 000074 XX         0004 R 000076 YY         0000   000000 1F         0001   000161 10L        0001   000022 116G
    0001   000026 117I       0000   000035 12F        0001   000141 13L        0001   000041 130G       0001   000112 150I
    0001   000122 160G       0001   000131 163I       0001   000153 173I       0001   000063 175L       0001   000065 180L
    0000   000105 19F        0000   000003 2F         0001   000170 204G       0001   000213 214G       0001   000224 221I
    0001   000263 237I       0001   000315 25L        0001   000313 250I       0001   000323 255I       0001   000330 257I
    0001   000343 265I       0001   000360 267I       0001   000137 27L        0001   000370 271I       0001   000416 276I
    0000   000026 3F         0001   000427 304I       0001   000433 307I       0001   000455 320I       0001   000474 336G
    0000   000005 4F         0001   000155 47L        0001   000331 50L        0000   000057 51F        0000   000044 6F
    0001   000243 7L         0001   000333 8L         0000   000074 9F         0000   000120 9997F      0000   000134 9998F
    0001   000456 9999L

 00100     1*     C * * CASHFLOW ANALYSIS * * ROI PROGRAM * * CARL HEINZ * * GARRETT CORP.              1 00004
 00101     2*           SUBROUTINE RONINV(CASFLO,NYR, ROI,SIIV90,IPR)                                    2
 00101     3*     C * * MID YEAR DISCOUNTING                                                               3
 00101     4*     C * *                                                                                    4
 00101     5*     C * * CASFLO(I)=CASHFLOW FOT THE I'TH YEAR.                                              5
 00101     6*     C * * NYR= TOTAL NO. OF YEARS CONSIDERED.                                                6
 00101     7*     C * * CONVG = CONVERGENCE TOLERANCE USED IN ITERATION LOOP.                              7
 00101     8*     C * * ROI = RETURN ON INVESTMENT.                                                        8
 00101     9*     C * * ROIGSS = GUESS FOR ANSWER FRACTION FORM(NOT PERCENTAGE)                            9
 00101    10*     C * * DCF(I) = DISCOUNTED CASHFLOW FOR I'TH YEAR.                                       10
 00101    11*     C * * DCFDES =0.0 = ZERO DISCOUNTED CASH FLOW AT END OF NYR YEARS.                      11
 00101    12*     C * * ITLIM = MAXIMUN NUMBER OF ITERATIONS ALLOWED FOR CONVERGENCE.                     12
 00103    13*           DIMENSION CASFLO(50) ,DCF(50) ,IT(10),XX(2),YY(2)                                 13
 00103    14*     C * * READ IN DATA! 1ST CARD CONTAINS (1) NYR, (2) C15GSS,                              14
 00103    15*     C * * AND (3) CONVGI.                                                                   15
 00103    16*     C * * CONVGI=INPUT CONVERGENCE TOLERANCE. IF NOT INPUT THIS TOLERANCE                   16
 00103    17*     C * * IS AUTOMATICALLY DETERMINED.                                                      17
 00103    18*     C * * WHEN GUESSING ROIGSS IT IS BETTER TO GUESS LOW (IF POSSIBLE).                     18
```

```
00104                ITLIM=27
00104          C**   DCFDES=0.0     DCFDES SET BY SUBR ARGUMENT
00105                DCFDES=SIIV90                                       00006
00105          C * * CONTROL CARD FORMAT * *
00106              1 FORMAT(I5,5X,2F10.0)                                00010
00106          C * * READ CONTROL CARD.
00106          C** 5 READ(5,1,END=9999)NYR,ROIGSS,CONVGI
00107                KOUNT=0
00107          C * * READ IN CASHFLO FOR EACH YEAR (8F10.0) FORMAT
00107          C * * DATA CARD(S) FORMAT. * *
00110              2 FORMAT(8F10.0)                                      00011
00110          C * * READ DATA.
00110          C**   READ(5,2)(CASFLO(I),I=1,NYR     )
00110          C * *
00111                IF(IPR.NE.0)
00111               *WRITE(6,4)NYR,(CASFLO(I),I=1,NYR)
00122              4 FORMAT(1H1//20X,'ROI CASHFLOW ANALYSIS'//5X,'NUMBER OF YEARS=',I10   00027
00122               1//5X,'NET CASH FLOW PER YEAR='/(10F12.2))
00122          C * * SPECIAL EXPERIMENTAL GUESS ROUTINE FOR ROI FOR WESS PROGRAM.
00123                IF(ABS(SIIV90).LT.0.001) GO TO 175
00125                STAND= 100./SIIV90                                  00033
00126                DUMSUM=0                                            00036
00127                DO 170 I=1,NYR                                      00042
00132            170 DUMSUM=DUMSUM+STAND*CASFLO(I)
00134                IF((DUMSUM-100.).LT.0.0)GO TO 175                   00047
00136                ROIGSS=DUMSUM/(NYR)                                 00054
00137                ROIGSS=ROIGSS*0.001                                 00061
00140                GO TO 180                                           00063
00141            175 CONTINUE                                            00064
00142                ROIGSS=-.01
00143            180 CONTINUE                                            00066
00144                ROIPGS=100.*ROIGSS
00145                IF((ABS(ROIGSS).GT.1.E-12).AND.(IPR.GT.0))WRITE(6,3)ROIPGS   00071
00152              3 FORMAT(/5X,'GUESS FOR ROI=',F15.3,' PERCENT'///)    00113
00153                CONVGI=0.0
00154                IF( ABS(CONVGI).GT.1.E-10)GO TO 27                  00114
00156                FMAX=0.0                                            00120
00157                DO 11 J=1,NYR                                       00123
00162             11 IF( ABS(CASFLO(J)).GT.FMAX)FMAX= ABS(CASFLO(J))
00165                CONVG=0.000015*FMAX                                 00134
00166                GO TO 13                                            00137
00167             27 CONVG=CONVGI                                        00140
00170             13 IF(IPR.GT.0)WRITE(6,12)CONVG                        00142
00175             12 FORMAT('      CONVERGENCE TOLERANCE=',G17.6)        00154
00175          C
00175          C * *
00175          C
00176                ROI=ROIGSS
00177             47 CONTINUE                                            00156
00200                IT(1)=1
00201                XX(1)=ROI                                           00160
00202             10 CONTINUE                                            00162
00203                DO 20 I=1,NYR
00206                XP=I                                                00172
00207                XP=XP-0.5                                           00175
00207          C * * XP=XP-0.5      ! THIS ALLOW FOR MID YEAR DISCOUNTING.
00210             20 DCF(I)=CASFLO(I)/(1.0+ROI)**XP                      00200
00212                DCFACT=0                                            00211
00213                DO 21 I=1,NYR                                       00214
00216             21 DCFACT=DCFACT+DCF(I)
```

```
00220   79*          IF(IT(1) .EQ. 1)YY(1)=DCFACT                                              79 00220
00222   80*          IF(IT(1).NE.2)GO TO 7                                                     80 00225
00224   81*          XX(2)=ROI                                                                 81 00230
00225   82*          YY(2)=DCFACT                                                              82 00232
00226   83*          DYDX=(YY(2)-YY(1))/(XX(2)-XX(1))                                          83 00234
00227   84*          IF(DYDX.GE.0.0)GO TO 8                                                    84 00240
00231   85*        7 CONTINUE                                                                  85 00244
00232   86*          IF(IPR.GT.0)WRITE(6,6) DCFDES, DCFACT,ROI                                 86 00251
00241   87*        6 FORMAT('    DCF DESIRED=',G16.6,'    DCF ACTUAL=',G16.6,'  ROI=',        87 00264
00241   88*         1 G16.6)                                                                   88
00242   89*          ROISAV=ROI                                                                89
00243   90*          CALL ITRAT($25,$50,ROI,DCFACT,DCFDES,IT,1,CONVG,ITLIM)                    90 00266
00243   91*     C * * CONVERT FROM FRACTION TO PERCENT.                                        91
00244   92*          PROI=100.*ROI                                                             92 00301
00245   93*          IF(IPR.GT.0)WRITE(6,51)PROI                                               93 00304
00252   94*       51 FORMAT(//5X'   THE ROI FOR SEQUENCE OF NET CASH FLOWS IS:'               94 00314
00252   95*         1,2X,F10.3,' PERCENT')                                                     95
00253   96*          RETURN                                                                    96
00253   97*     C**   GO TO 5                                                                  97
00253   98*     C * * YOU CANNOT LOSE MORE THEN 100 %.                                         98
00254   99*       25 IF(ROI .LT. -.9999)ROI=-.9998                                             99 00316
00256  100*          IF(ROI .GT. 9.9999999) ROI=9.99998                                       100 00324
00256  101*     C * * IF(ROI .GT. 9.9999999) ROI=9.99998    # LIMITS PROFIT TO 1000%          101
00260  102*          GO TO 10                                                                 102 00331
00260  103*     C**50 GO TO 5                                                                 103
00261  104*       50 CONTINUE                                                                 104 00332
00262  105*          RETURN                                                                   105
00263  106*        8 ROITEM=99999.                                                            106 00334
00264  107*          IF(ROI .GT. 0.01)ROITEM=0.5*ROI                                          107 00336
00266  108*          IF(ROI .GT.0.0 .AND.ROI.LE.0.01)ROITEM=-.01-                             108 00344
00270  109*          IF(ROI .LE.0.0)ROITEM=.85*ROI -0.149997                                  109 00361
00272  110*          IF((KOUNT.GE.10).AND.(IPR.NE.0))WRITE(6,9)ROITEM,KOUNT                   110 00371
00300  111*          IF(ROITEM.EQ.99999.)WRITE(6,9) ROITEM,KOUNT                              111 00417
00306  112*          IF(ROITEM.EQ.99999.)STOP                                                 112 00430
00310  113*        9 FORMAT(//' * * * ROITEM=',G16.6,'    KOUNT=',I10,' * * *'//)             113 00434
00311  114*          KOUNT=KOUNT+1                                                            114
00312  115*          IF(KOUNT.GT.7 ) GO TO 9999                                               115 00437
00314  116*          ROI=ROITEM                                                               116 00442
00315  117*          IF(IPR.GT.0)WRITE(6,19)ROITEM                                            117 00444
00322  118*       19 FORMAT(' NEW GUESS FOR ROI=',G16.6,' PROVIDED AUTOMATIC BY PROGRA        118 00456
00322  119*         1M')                                                                     119
00323  120*          GO TO 47                                                                 120
00324  121*     9999 CONTINUE                                                                 121 00457
00325  122*          WRITE(6,9997)SIIV90                                                      122
00331  123*     9997 FORMAT('     SUM INITIAL INVESTMENTS 1990 $=',G16.6,' ** CHECK CAS        123 00465
00331  124*         1H FLOW ***')                                                            124
00332  125*          WRITE(6,4)NYR,(CASFLO(I),I=1,NYR)                                        125
00342  126*          WRITE(6,9998) KOUNT,ROI                                          -01        00501
00347  127*     9998 FORMAT('   *** CANNOT GET A GOOD GUESS FOR ROI   NEXT CASE PLEASE         128 00510
00347  128*         1 ***',/,'    KOUNT=',I10,'   BAD VALUE OF ROI=',G16.6,/                 129
00347  129*         2'     *** CHANGE ROI  TO  MINUS 99.99 PERCENT ***'//)                    130
00350  130*          ROI=-.9999                                                               131
00351  131*          RETURN                                                                   132 00512
00352  132*          E N D                                                                    133 00570
```

0 DIAGNOSTICS

CPU:9.586   CTP:.254   SUPS:23.400

```
@FOR,S   ITRAT
FOR 003E-05/15/78-13:23:18 (0,)

   SUBROUTINE ITRAT      ENTRY POINT 000121

   STORAGE USED: CODE(1) 000145; DATA(0) 000065; BLANK COMMON(2) 000000

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   NWDU$
    0004   NIO2$
    0005   NERR4$
    0006   NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000   000027 1F        0001   000037 10L      0001   000056 20L      0000 R 000024 DY       0000 R 000000 DYS
    0000   000050 INJP$     0000 I 000026 N        0000 R 000012 XS       0000 R 000025 XSS


 00101      1*          SUBROUTINE ITRAT($,$,X,Y,YD,IT,L,CONV,ITLIM)                                  000003
 00103      2*          DIMENSION IT(10),DYS(10),XS(10)                                              000003
 00104      3*          DY=Y-YD                                                                      000003
 00104      4*    C * * RETURN IF CONVERGENCE IS ACHIVED.                                            000003
 00105      5*          IF(ABS(DY).LE.CONV)RETURN                                                    000006
 00107      6*          IF(IT(L).LE.ITLIM)GO TO 10                                                   000015
 00111      7*          WRITE(6,1)L,X,Y,YD                                                           000021
 00117      8*        1 FORMAT(5X,'   ITRAT',2X,I2,2X,'FAILED',5X,'X=',E15.6,                        000032
 00117      9*         A 2X,'Y =',E15.6,2X,'YD =',E15.6)                                             000032
 00120     10*          RETURN 2                                                                     000032
 00121     11*       10 CONTINUE                                                                     000037
 00122     12*          IF(IT(L).NE.1)GO TO 20                                                       000037
 00124     13*          DYS(L)=DY                                                                    000041
 00125     14*          XS(L)=X                                                                      000043
 00126     15*          X=0.98*X                                                                     000045
 00127     16*          IT(L)=2                                                                      000047
 00130     17*          RETURN 1                                                                     000051
 00131     18*       20 CONTINUE                                                                     000056
 00132     19*          XSS=X                                                                        000056
 00133     20*          X=(DY*XS(L)-DYS(L)*X)/(DY-DYS(L))                                            000057
 00134     21*          XS(L)=XSS                                                                    000067
 00135     22*          DYS(L)=DY                                                                    000071
 00136     23*          IT(L)=IT(L)+1                                                                000073
 00137     24*          N=1                                                                          000076
 00140     25*          RETURN 1                                                                     000100
 00141     26*          END                                                                          000144

     END OF COMPILATION:        NO  DIAGNOSTICS.
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@AFOR,S   REPORT
ATHENA EXTENDED FORTRAN 24I-05 (14 APR 77)
COMPILATION DONE ON 15 MAY 78 AT 13:43:08

    *SUBROUTINE  REPORT      ENTRY POINT 01566   SEQ 000102

  STORAGE USED (BLOCK, NAME, LENGTH)

        0001   *CODE          001601
        0000   *CONST*TEMP    001172
        0002   *SIMPLE VAR    000012
        0004   *ARRAYS        000027
        0005   N$BLNK  003321
        0006   AAAAAA  001230
        0007   BBBBBB  000070
        0010   EEEEEE  000135

 EXTERNAL REFERENCES

        0011   DATE
        0012   TOD
        0013   NWDU$
        0014   NI03$
        0015   NI01$
        0016   NI02$
        0017   NER10$

STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

  0004 R 000005 ACOM     0005 R 002727 ADDLAB   0005   003320 ADDLA9   0005 R 002117 ADLABR   0005   003161 ADLAB9
  0005 R 002273 BENFCR   0010   000071 BEN2     0005 R 001505 CILMCS   0007   000067 CONST    0005 R 001347 COSEND
  0005   002777 COSEN9   0005 R 001323 COSMOD   0005 R 001313 COSNEW   0005 R 001333 COSTRA   0004 R 000000 DATIME
  0005 R 001535 DFSIPG   0005 R 001525 DFSMPG   0006   000703 DISCON   0005 I 002473 EHCREW   0005 R 001545 EHELPM
  0005   003137 EHELP9   0005 R 002603 ELECHI   0005   003111 ELECH9   0005 R 002723 ELEENE   0005   003317 ELEEN9
  0005 I 002363 ELEHEL   0005 R 001655 EMAINT   0005   003203 EMAIN9   0005 R 001515 EMATPM   0005 R 000710 ESAVMP
  0005 R 001765 ESRRMP   0005   003225 ESRRM9   0010 I 000001 FIX      0005 R 002361 FLYCOS   0005 R 001130 FLYSC
  0005 R 000204 FLYWCV   0005 R 000162 FLYWMA   0005 R 000140 FLYWS    0006 R 001206 FNPV     0005 I 000050 GTTONS
  0002 I 000003 I        0005 I 001274 IANAND   0002 I 000011 IDUM     0005 I 002737 IFLAG    0002 I 000005 II
  0007   000044 IIIIII   0005 I 001276 ILUSE    0002 I 000001 IPAGE    0006   001205 IPR      0005   002337 IRANK
  0007 I 000022 IRANKK   0005 I 000000 IRNAME   0005 I 001275 IROUTE   0005 I 000020 IRROAD   0002 I 000004 IS
  0005 I 002750 ISEN     0005 I 000360 ISITES   0007   000045 ISUB     0002 I 000000 I$       0002 I 000002 J
  0002 I 000010 JJ       0002 I 000006 KK       0002 I 000007 KKK      0006 I 001204 KSTART   0005 R 000120 LOCFMI
  0005 I 001307 LOCTRA   0005 I 000060 LOCTYP   0005 R 000100 LOCUSE   0005 L 002742 LSCEN1   0005 L 002743 LSCEN2
  0005 L 002744 LSCEN3   0005 L 002745 LSCEN4   0007   000000 MDUMY    0005 I 000470 MILEPF   0005 I 000600 MILEPT
  0005 I 001303 MODLOC   0010 I 000045 MSUB     0006 R 000062 NAS      0005 I 001277 NEWLOC   0005 I 002747 NH
  0005 I 002746 NL       0010 I 000000 NOFIX    0005 I 000054 NOLOC    0005 I 002736 NOSITE   0005 I 000034 NOSITT
  0005   002362 NOSUSE   0006 R 000000 NPV      0005 I 002751 NSUB     0010   000023 NSUB3    0006   000702 NYRCON
  0005   002315 RBEN     0010   000113 RBEN2    0005 R 001020 REGPL    0005 I 000030 RMILES   0006   001074 ROI
  0006 R 000764 ROIPER   0005 R 001343 ROUTFE   0005   002776 ROUTE9   0005 R 002007 RPEAKD   0005   003247 RPEAK9
  0005   002733 R13A6    0005   002734 R13A7    0005   002735 R13A8    0005   002740 R135A7   0005   002741 R135A8
  0005   003271 SACC90   0005   003272 SACPS9   0005 R 002713 SAVLRP   0005 I 001240 SCENIO   0005 R 002251 SDCOSI
  0005 R 002227 SDSAVA   0005   003066 SITV90   0005 R 001353 SITELE   0005   003022 SITEL9   0005 R 000226 STABLD
  0005 R 003067 SUMIV9   0005 R 001511 TCILMC   0005   003133 TCILM9   0005 R 000336 TCOSFS   0005   003000 TCOSF9
  0005 R 000040 TDENEB   0005 R 000044 TDENWB   0005   003136 TDFSI9   0005   003135 TDFSM9   0005 R 001541 TDFSTI
  0005 R 001531 TDFSTM   0005 R 001521 TEMTPM   0005   003134 TEMTP9   0005 R 001327 TOTMOD   0005   002774 TOTMO9
  0005 R 001317 TOTNEW   0005   002773 TOTNE9   0005 R 001337 TOTTRA   0005   002775 TOTTR9   0005 R 002717 TSAVLR
  0005   003316 TSAVL9   0005 R 001463 TSITEC   0005   003044 TSITE9   0006   000704 XIR      0010   000070 ZUMACC
  0010   000067 ZUMINV   0000   000000 1F       0000   000302 101F     0001   001234 1011G    0000   000312 102F
  0000   000321 104F     0001   001322 1055G    0000   000325 106F     0000   000337 108F     0000   000350 110F
  0001   001417 1117G    0000   000362 112F     0001   001430 1123G    0000   000370 114F     0001   001456 1144G
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0000   000400 115F     0001   001501 1153G    0001   001520 1164G    0000   000004 15F      0001   000120 177G
0000   000001 2F       0000   000404 202F     0001   000131 203G     0000   000413 204F     0000   000420 206F
0000   000436 208F     0000   000454 210F     0000   000471 212F     0000   000501 214F     0001   000154 216G
0000   000511 220F     0000   000516 222F     0000   000544 230F     0000   000554 250F     0001   000222 250G
0001   000226 251I     0000   000633 255F     0000   000563 256F     0000   000600 260F     0000   000616 264F
0000   000642 266F     0000   000660 268F     0000   000675 269F     0000   000704 274F     0000   000754 278F
0000   000002 3F       0000   000011 30F      0001   000274 301G     0000   000017 32F      0000   000023 34F
0000   000765 340F     0000   000773 344F     0000   001027 350F     0001   000405 357I     0001   000414 364I
0001   000417 370G     0001   001340 370L     0000   001037 372F     0000   001045 373F     0000   001050 374F
0000   001124 376F     0000   001126 377F     0000   001131 378F     0000   000003 4F       0000   000026 40F
0001   001544 410L     0000   000040 42F      0001   000506 435G     0000   000051 44F      0000   000057 45F
0001   000531 451G     0000   000065 46F      0001   000552 464G     0001   000573 477G     0000   000073 48F
0001   001551 510L     0001   000614 512G     0000   000116 52F      0001   000636 525G     0000   000146 54F
0000   000161 56F      0000   000175 60F      0000   000202 62F      0000   000260 63F      0001   001000 635G
0000   000263 64F      0000   000266 66F

00101    1*          SUBROUTINE REPORT                                                      1 00001
00103    2*          INCLUDE COM1,LIST                                                      2
00104    2*          PARAMETER NP1=4,NP2=16,NP3=18,NP4=1,NP5=50
00105    2*          LOGICAL LSCEN1,LSCEN2,LSCEN3,LSCEN4
00106    2*          REAL LOCUSE,LOCFMI
00107    2*          REAL NPV,NAS
00110    2*          INTEGER SCENIO,RMILES,GTTONS,ELEHEL,EHCREW,FIX
00110    2*    C * * BLANK COMMON
00111    2*          COMMON
00111    2*         1 IRNAME(4,NP1),IRROAD(2,NP1),RMILES(NP1),NOSITT(NP1) ,
00111    2*         2 TDENEB(NP1),TDENWB(NP1), GTTONS(NP1), NOLOC(NP1),
00111    2*         3 LOCTYP(4,NP1), LOCUSE(NP2),LOCFMI(NP2), FLYWS(NP3),
00111    2*         4 FLYWMA(NP3),     FLYWCV(NP3),     STABLD(NP3,NP1),TCOSFS(NP3)   ,
00111    2*         5 ISITES(NP3,NP1),MILEPF(NP3,NP1),MILEPT(NP3,NP1),ESAVMP(NP3,NP1),
00111    2*         6 REGPL(NP3,NP1),FLYSC(NP3,NP1),SCENIO(7,NP1), IANANO , IROUTE,
00111    2*         7 ILUSE,NEWLOC(NP1),MODLOC(NP1),LOCTRA(NP1),COSNEW(NP1),
00111    2*         8 TOTNEW(NP1), COSMOD(NP1),TOTMOD(NP1), COSTRA(NP1),TOTTRA(NP1),
00111    2*         9 ROUTEE(NP1),COSEND(NP1), SITELE(NP3,NP1),TSITEC(NP3),
00111    2*         A CILMCS(NP1),TCILMC(NP1),                              EMATPM(NP1),
00111    2*         B TEMTPM(NP1), DFSMPG(NP1),TDFSTM(NP1), OFSIPG(NP1),TDFSTI(NP1),
00111    2*    C * * SITE DEPENDENT ($)
00111    2*         D EHELPM(NP3,NP1), EMAINT(NP3,NP1), ESRHMP(NP3),
00111    2*         E RPEAKD(NP3,NP1), ADLABR(NP3,NP1),
00111    2*         F SDSAVA(NP3),SDCOSI(NP3),BENFCR(NP3),RBEN(NP3),IRANK(NP3)
00111    2*    C * * FLYWHEEL COST
00112    2*          COMMON FLYCOS
00113    2*          COMMON
00113    2*         G NOSUSE,ELEHEL(NP1,NP3),EHCREW(NP1,NP3),ELECHI(NP1,NP3),
00113    2*         H SAVLRP(NP1),TSAVLR(NP1),ELEENE(NP1),ADDLAB(NP1)
00113    2*    C
00114    2*          COMMON R13A6,R13A7,R13A8,NOSITE,IFLAG,R135A7,R135A8
00114    2*         1,LSCEN1,LSCEN2,LSCEN3,LSCEN4,NL,NH,ISEN,NSUB(NP3)
00114    2*    C * * COMMON      INITIAL INVESTMENTS 1990 DOLLARS
00115    2*          COMMON
00115    2*         1 TOTNE9    ,  TOTMO9    ,  TOTTR9   ,   ROUTE9   ,   COSEN9     ,
00115    2*         2 TCOSF9(NP3)     ,SITEL9(NP3)     , TSITE9(NP3)     ,SIIV90
00115    2*         3,SUMIV9(NP3)    ,ELECH9(NP3)
00116    2*          COMMON        *  ANNUAL COST AND CREDITS 1990 DOLLARS.
00116    2*         1 TCILM9,TEMTP9,TDFSM9,TDFSI9
00116    2*         2            ,EHELP9(NP3)     ,ADLAB9(NP3)     ,EMAIN9(NP3),
00116    2*         3 ESRRM9(NP3)      ,RPEAK9(NP3)      ,SACC90,SACPS9(20)
00116    2*         4, TSAVL9,ELEEN9,ADDLA9
00117    2*          COMMON/AAAAAA/NPV(NP5),     NAS(100,NP1),NYRCON,DISCON,XIR(12,4),
```

```
00117    2*       1 ROIPER(4,NP3),ROI(4,NP3),KSTART,IPR,FNPV(NP3)
00120    2*         COMMON/BBBBBB/MDUMY(NP3),IRANKK(NP3),IIIIII ,ISUB(NP3),CONST
00121    2*         COMMON/EEEEEE/NOFIX,FIX(NP3),NSUB3(NP3),MSUB(NP3),ZUMINV,ZUMACC
00121    2*       1,BEN2(NP3),RBEN2(NP3)
00122    2*         END
00123    3*         DIMENSION DATIME(5),ACOM(18)                                    3
00124    4*         DATA DATIME/6HRUN ON,6H       ,6H      A,6HT      ,6H      /    4
00126    5*         DATA ACOM/18*'  ,'/                                             5
00130    6*         CALL DATE(16,DATIME)                                            6
00131    7*         CALL TOD (28,DATIME)                                            7 00005
00132    8*       1 FORMAT(/)                                                       8 00023
00133    9*       2 FORMAT(//)                                                      9
00134   10*       3 FORMAT(///)                                                    10
00135   11*       4 FORMAT(////)                                                   11
00136   12*         IF(IFLAG.NE.1)GO TO 370                                        12
00136   13*   C * * 1ST  PAGE                                                      13
00140   14*         IPAGE=1                                                        14 00032
00141   15*         WRITE(6,15)DATIME,IPAGE                                        15 00034
00146   16*      15 FORMAT(1H1  T85,5A6,9X,'PAGE',I3 /)                            16 00046
00147   17*         WRITE(6,30)                                                    17
00152   18*      30 FORMAT( T28,'WAYSIDE ENERGY STORAGE STUDY'  )                  18 00053
00153   19*         WRITE(6,2)                                                     19
00156   20*         WRITE(6,32)                                                    20 00060
00161   21*      32 FORMAT( T33,'LIFE CYCLE COST' )                                21 00065
00162   22*         WRITE(6,1)                                                     22
00165   23*         WRITE(6,34)                                                    23 00072
00170   24*      34 FORMAT(T8 ,'ROUTE DATA')                                       24 00077
00171   25*         WRITE(6,1)                                                     25
00174   26*         WRITE(6,40)  (IRNAME(J,IROUTE),J=1,4),(SCENIO(J,ISEN),J=1,7)   26 00104
00207   27*      40 FORMAT(T10,'ROUTE NAME',T30,': ',3A6,A2,T59,'SCENARIO     : ',6A6,A4)   27 00136
00210   28*         WRITE(6,1)                                                     28
00213   29*         WRITE(6,42)  (IRROAD(J,IROUTE),J=1,2),    IANANO               29 00143
00223   30*      42 FORMAT(T10,'RAILROAD',T30,': ',A6,A4,T59,'ANALYSIS NO.: ',A4)  30 00163
00224   31*         WRITE(6,1)                                                     31
00227   32*         WRITE(6,44)  RMILES(IROUTE)                                    32 00170
00233   33*      44 FORMAT(T10,'ROUTE MILES',T30,': ' ,I4 )                        33 00176
00234   34*         WRITE(6,1)                                                     34
00237   35*         WRITE(6,45)NOSITT(IROUTE)                                      35 00203
00243   36*      45 FORMAT(T10,'NUMBER OF WESS SITES: ',I4)                        36 00211
00244   37*         IF(NOFIX.GT.0)WRITE(6,46)(FIX(I),I=1,NOFIX  )                  37
00254   38*      46 FORMAT(1H+,T50,'RULING GRADES: ',10(I5))                       38 00231
00255   39*         WRITE(6,1)                                                     39
00260   40*         WRITE(6,1)                                                     40 00236
00263   41*         WRITE(6,48)  TDENEB(IROUTE), TDENWB(IROUTE)                    41 00243
00270   42*      48 FORMAT(T10,'TRAFFIC DENSITY'   ,T30,': ',F6.1,' MILLION GTT/YEAR E   42 00254
00270   43*        1AST BOUND' /                                                   43
00270   44*        2T30,'  ',F6.1,' MILLION GTT/YEAR WEST BOUND')                  44
00271   45*         WRITE(6,1)                                                     45
00274   46*         WRITE(6,52)  GTTONS(IROUTE),NOLOC(IROUTE),(LOCTYP(J,IROUTE),J=1,4)   46 00261
00305   47*      52 FORMAT(///T20,'AVERAGE CONSIST'//                              47 00301
00305   48*        1T27,'GROSS TRAILING TONS', T48,': ', I5,    //                 48
00305   49*        2T27,'NO. OF LOCOMOTIVES ', T48,': ', I5,    //                 49
00305   50*        3T27,'LOCOMOTIVE TYPE'     , T48,': ', 4A6    /)                50
00306   51*         WRITE(6,3)                                                     51
00311   52*         WRITE(6,54)     LOCUSE(ILUSE)                                  52 00306
00315   53*      54 FORMAT(T20,'LOCOMOTIVE USAGE : ',F5.1,' LOCOMOTIVES/BILLION GTIM/Y   53 00316
00315   54*        1EAR')                                                          54
00316   55*         WRITE(6,1)                                                     55
00321   56*         WRITE(6,56) LOCFMI(ILUSE)                                      56 00323
00325   57*      56 FORMAT(T20,'LOCOMOTIVE FLEET MILEAGE: ',F6.2,' X ONE MILLION MILES   57 00331
```

```
00325          1/YEAR ')
00325     C * * 2ND PAGE        BLOCK OR INPUT DATA
00326          IPAGE=IPAGE+1
00327          WRITE(6,15)DATIME,IPAGE                                            00334
00334          WRITE(6,1)                                                         00346
00337          WRITE(6,60)                                                        00353
00342       60 FORMAT(T20,'WESS LOCATION DATA')                                   00360
00343          WRITE(6,3)
00346          WRITE(6,2)                                                         00365
00351          WRITE(6,62)                                                        00372
00354       62 FORMAT(T10,'SITE',T20,'FROM',T30,'TO',T40,'ENERGY SAVED*',T60,     00377
00354         1'REGENERATION',T80,'FLYWHEEL',T98,'ELECTRIC',T116,'ELECTRIC'/
00354         2 T20,'MILEPOST' ,T30,'MILEPOST',T40  ,'AT RAILROAD',T60,'POWER LEV
00354         3EL',   T80,'STORAGE' ,T98,'HELPERS',T116,'HELPER'
00354         A                     /T40,'METERING POINT',  T80,'CAPACITY' ,
00354         B ,T116,'CREWS')
00355          IF(LSCEN3)WRITE(6,63)
00361       63 FORMAT( T44,'(KWH)'/)                                              00406
00362          IF(.NOT.LSCEN3)WRITE(6,64)
00366       64 FORMAT( T44,'(GAL)'/)                                              00420
00367          DO 100 I=NL,NH
00372          IS=NSUB(I)
00372     C    IS=I
00373          WRITE(6,66)  ISITES(IS,IROUTE),MILEPF(IS,IROUTE),MILEPT(IS,IROUTE) 00426
00373         1,ESAVMP(IS,IROUTE),REGPL(IS,IROUTE),FLYSC(IS,IROUTE)
00373         2,ELEHEL(IS,IROUTE),EHCREW(IS,IROUTE)
00406       66 FORMAT(T10,I3,  T20,I5, T30,I5, T38,F10.1 , T59,F10.2,T78,F10.3    00444
00406         1,T98,I6,T116,I6)
00407      100 CONTINUE
00407     C * * 3RD PAGE   FLYWHEEL STATION COST($MILLION)  =CALCULATED
00411          WRITE(6,101)
00414      101 FORMAT(/9X,'* FOR TWO TRAINS(ONE IN EACH DIRECTION)')              00451
00415          IPAGE=IPAGE+1
00416          WRITE(6,15)DATIME,IPAGE                                            00454
00423          WRITE(6,102)                                                       00466
00426      102 FORMAT( T20,'FLYWHEEL STATION COSTS ($MILLIONS)'   )               00473
00427          WRITE(6,3)
00432          WRITE(6,104)(ISITES(NSUB(I),IROUTE),I=NL,NH)                       00500
00441      104 FORMAT(T20,'SITE:',T32,18I5)                                       00515
00442          WRITE(6,2)
00445          WRITE(6,106)FLYCOS,(FLYWS(NSUB(I) )     ,I=NL,NH)                  00522
00455      106 FORMAT(T10,'FLYWHEEL ® '/T10,'$',F5.3,'M/STORED MWH',T32,18F5.2/)  00537
00456          WRITE(6,2)
00461          WRITE(6,108)(FLYWMA(NSUB(I)),I=NL,NH)                              00544
00470      108 FORMAT(T10,'FLYWHEEL MACHINE'/T10,'® $0.06M/MW', T32,18F5.2 /)     00560
00471          WRITE(6,2)
00474          WRITE(6,110)(FLYWCV(NSUB(I)),I=NL,NH)                              00565
00503      110 FORMAT(T10,'FLYWHEEL CONVERTER'/T10,'® $0.03M/MW',T32,18F5.2 /)    00601
00504          WRITE(6,2)
00507          WRITE(6,112)(STABLD(NSUB(I),IROUTE),I=NL,NH)                       00606
00516      112 FORMAT(T10,'STATION BUILDING', T32,18F5.2)                         00623
00517          WRITE(6,2)
00522          WRITE(6,114)(TĈOSFS(NSUB(I) ),I=NL,NH)                             00630
00531      114 FORMAT(T10,'TOTAL COST'/T10,'FOR EACH',T32,18F5.2)                 00644
00532          WRITE(6,115)
00535      115 FORMAT(T10,'FLYWHEEL STATION')                                     00651
00535     C * * INITIAL  INVESTMENT ( 1977 $M)
00535     C * * ROUTE DEPENDENT
00535     C * * 4TH PAGE
00536          IPAGE=IPAGE+1
```

```
      WRITE(6,15)DATIME,IPAGE
      WRITE(6,3)
      WRITE(6,202)
  202 FORMAT(T30,'INITIAL INVESTMENT (1977 $M)'/)
      WRITE(6,204)
  204 FORMAT(T10 ,'ROUTE DEPENDENT      ')
C     IF((LSCEN2).OR.(LSCEN4))
      WRITE(6,206) NEWLOC(IROUTE), COSNEW(IROUTE), TOTNEW(IROUTE)
  206 FORMAT(/T10,I5,' NEW ELECTRIC LOCOMOTIVES REQUIRED  @  ',T55,F11.3
     1,' EACH  :    ',F8.3 )
C     IF((LSCEN1).OR.(LSCEN3))
      WRITE(6,208) MODLOC(IROUTE), COSMOD(IROUTE), TOTMOD(IROUTE)
  208 FORMAT(/T10,I5,' MODIFIED LOCOMOTIVES REQUIRED',T51,'@    ',F11.3,
     1,' EACH  :    ',F8.3 )
C     IF((LSCEN1).OR.(LSCEN2).OR.(LSCEN4))
      WRITE(6,210) LOCTRA(IROUTE),COSTRA(IROUTE),TOTTRA(IROUTE)
  210 FORMAT(/T10,I5,' LOCOMOTIVES TRANSFERRED', T51,'@    ', F11.3,
     1,' EACH  :    ',F8.3 )
      WRITE(6,1)
C     IF(LSCEN4)
      WRITE(6,212) ROUTEE(IROUTE)
  212 FORMAT(T15,' ROUTE ELECTRIFICATION',T73,':    ',F8.3)
      WRITE(6,1)
      WRITE(6,214)COSEND(IROUTE)
  214 FORMAT(T15,' END OF PROGRAM COST ',T73,':    ',F8.3 )
C * * SITE DEPENDENT
      WRITE(6,220)
  220 FORMAT( // T10,'SITE DEPENDENT  '    )
      WRITE(6,222)
  222 FORMAT(/ T15,'SITE', T25,'FLYWHEEL', T42,'SITE',  T58,'ELECTRIC'
     1, T80,'TOTAL'/
     1 T25,'STATION',T38, 'ELECTRIFICATION' ,  T58,'HELPERS',T78,
     2'SITE COST')
      DO 240 II=1,NOSITE
      I=NSUB(II)
      WRITE(6,230)ISITES(I,IROUTE),TCOSFS(I )     ,SITELE(I,IROUTE),
     1 ELECHI(I,IROUTE),TSITEC(I)
  240 CONTINUE
  230 FORMAT( T14, I4, T23,F8.3, T40,F8.3, T56,F8.3 ,T76,F8.3)
      IPAGE=IPAGE+1
      WRITE(6,15)DATIME,IPAGE
      WRITE(6,1)
      WRITE(6, 250)
  250 FORMAT(T30,'ANNUAL COSTS AND CREDITS (1977$M)'    )
      WRITE(6,2)
      WRITE(6,204)
      WRITE(6,2)
      WRITE(6,256)SAVLRP(IROUTE),TSAVLR(IROUTE)
  256 FORMAT(T10,'SAVING IN LOCOMOTIVE REPLACEMENT',T46,'@$',F8.0,
     1 ' EA',T63,':',T65,F10.3)
      WRITE(6,1)
      WRITE(6,260) CILMCS(IROUTE), TCILMC(IROUTE)
      WRITE(6,1)
      WRITE(6,264) EMATPM(IROUTE), TEMTPM(IROUTE)
      WRITE(6,1)
      WRITE(6,255)ELEENE(IROUTE)
  255 FORMAT(T10,'ELECTRICAL ENERGY',T63,':',T67,F8.3)
      WRITE(6,1)
      WRITE(6,266) DFSMPG(IROUTE), TDFSTM(IROUTE)
      WRITE(6,1)
```

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00752          WRITE(6,268) DFSIPG(IROUTE), TDFSTI(IROUTE)              01165
00757          WRITE(6,1)                                               01174
00762          WRITE(6,269)ADDLAB(IROUTE)                               01201
00766      269 FORMAT(T10,'ADDITIONAL LABOR',T63,':',T67,F8.3)          01207
00767          WRITE(6,1)
00767    C     WRITE(6,270) EESVPK(IROUTE), TEESAV(IROUTE)
00772      260 FORMAT(T10,'CHANGE IN LOCOMOTIVE MAINT. COSTS',T46,'$$ ',F7.3,   01214
00772         1'/MILE   :     ',F8.3 ,' '  )
00773      264 FORMAT(T10,'ELECTRIFICATION MAINTENANCE     ',  T46,'$$ ',F7.3 ,
00773         1'/MILE   :     ',F8.3 ,' '  )
00774      266 FORMAT(T10,'DIESEL FUEL SAVING(TRAIN MOVEMENT)',T46,'$$ ',F7.3,
00774         1'/GAL    :     ',F8.3 ,' '  )
00775      268 FORMAT(T10,'DIESEL FUEL SAVING(IDLING)      ',  T46,'$$ ',F7.3 ,
00775         1'/GAL    :     ',F8.3 ,' '  )
00776          WRITE(6,220)
01001          WRITE(6,2)                                               01221
01004          WRITE(6,274)                                             01226
01007      274 FORMAT( T15 ,'SITE',T25,'ELECTRIC', T40,'ADDITIONAL      ', T60,   01235
01007         1 'ENERGY SAVING', T80,'REDUCTION IN', T100,'ELECTRIFICATION'/
01007         2  T25,'HELPER' ,T40,'LABOR        ',T60,'AT RAILROAD',  T80,
01007         3  'PEAK DEMAND', T100,'MAINTENANCE' /  T25,'MAINTENANCE',T60,
01007         4  'METERING POINT')
01010          DO 280 II=1,NOSITE
01013          I=NSUB(II)
01014          WRITE(6,278)ISITES(I,IROUTE),EHELPM(I,IROUTE),ADLAHR(I,IROUTE),   01241
01014         1 ESRRMP(I )       ,     RPEAKD(I,IROUTE), EMAINT(I,IROUTE)
01025      278 FORMAT(T14,I4,T27, F8.3,  T43, F8.3 ,  T63, F8.3 , T83, F8.3,   01257
01025         1 T102,F8.3)
01026      280 CONTINUE
01030          IPAGE=IPAGE+1
01031          WRITE(6,15)DATIME,IPAGE                                  01262
01036          WRITE(6,3)                                               01274
01041          WRITE(6,340)                                             01301
01044      340 FORMAT(T20,'INDIVIDUAL SITE RANKING')                    01306
01045          WRITE(6,3)
01050          WRITE(6,344)                                             01313
01053      344 FORMAT(T15,'SITE',T28,'NET ANNUAL',T46,'INITIAL SITE',   01323
01053         1 T69,'BENEFIT/COST',T102,'RANKING'/
01053         2T28,'SITE DEPENDENT',T46,'DEPENDENT',T72,'RATIO'/
01053         3 T28,'SAVINGS  $M',T48,'COST  $M'  //)
01054          DO 354 I=NL,NH
01057          WRITE(6,350)ISITES(MSUB(I),IROUTE),SDSAVA(MSUB(I)),SDCOSI(MSUB(I))   01326
01057         1, BENFCR( MSUB(I)),IRANKK(I)
01067      350 FORMAT(T14,I3,T28,F8.3,   T46,F8.3, T69,F8.3,T103,I4)    01341
01070      354 CONTINUE
01072      370 IF(IFLAG.NE.2)GO TO 410
01072    C * * SUMMARY OF LIFE CYCLE COST(1990$)
01072    C * * 7TH PAGE
01074          IPAGE=IPAGE+1                                            01344
01075          WRITE(6,15)DATIME,IPAGE                                  01347
01102          WRITE(6,3)                                               01361
01105          WRITE(6,372)                                             01366
01110      372 FORMAT(/T20'SUMMARY OF LIFE CYCLE COSTS'/)               01373
01111          WRITE(6,3)
01114          WRITE(6,40)  (IRNAME£J,IROUTE),J=1,4),(SCENIO(J,ISEN),J=1,7)   01400
01127          WRITE(6,373)IANANO                                       01435
01133      373 FORMAT(    1H+,T115,A4)                                  01443
01134          WRITE(6,3)
01137          WRITE(6,374)                                             01450
01142      374 FORMAT(T64,'OMB=A94',T84,'4R METHOD',T99,'SENSITIVTY 1',T118,   01460
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01142  238*        1'SENSITIVITY 2'/  T15,'WESS SITES',T66,'($MILLIONS)'/                  238
01142  239*        2 T64,'NPV',T70,'INIT. COST',T84,'INTERNAL RATE', T99,                 239
01142  240*        3 'INTERNAL RATE',T118,'INTERNAL RATE'/T70,'(1990$)',T84,'OF RETURN    240
01142  241*        5 %',T99,'OF RETURN %',T118 ,'OF RETURN %'/)                           241
01143  242*          DO 399 I=KSTART,NOSITE                                               242
01146  243*          KK=NOSITE+KSTART-I                                                   243
01147  244*          II=I+1-KSTART                                                        244 01463
01150  245*          WRITE(6,376)( NSUB(J ),J=1,KK )                                      245 01471
01157  246*      376 FORMAT( 3X,18I3)                                                     246 01506
01160  247*          KKK=KK-1                                                             247
01161  248*          WRITE(6,377)(ACOM(JJ),JJ=1,KKK)                                      248 01511
01170  249*      377 FORMAT(1H+,3X,18A3)                                                  249 01525
01171  250*          WRITE(6,378) FNPV(II)       ,SUMIV9(II),ROIPER(2,II),ROIPER(3,II),   250
01171  251*         1 ROIPER(4,II)                                                        251
01201  252*      378 FORMAT(1H+,T59,F8.2,T69,F8.2,T84,F10.2, T99,F10.2,T118,F10.2)         252 01543
01202  253*      399 CONTINUE                                                             253
01204  254*          IDUM=1                                                               254
01205  255*      410 IF(IFLAG.NE.3)GO TO 510                                              255 01545
01207  256*          IDUM=1                                                               256 01550
01210  257*      510 CONTINUE                                                             257 01552
01211  258*          RETURN                                                               258
01212  259*          E N D                                                                259 01602

    0 DIAGNOSTICS

CPU:7.778   CTP:.196   SUPS:18.778
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APPENDIX F

TRAIN PERFORMANCE CALCULATOR

INTRODUCTION AND SUMMARY

This appendix summarizes features of the AiResearch train performance calculator (TPC) program. A detailed definition of route data and schedule data requirements is included, together with a program listing and program nomenclature. This program was developed to support train performance calculations (TPC's) required by the WESS study performed for FRA. A summary of program features is shown in Table F-1.

TABLE F-1

TPC FEATURES

Program Feature	Description
Principal emphasis	Power demand and energy required from the wayside for multitrain operation of long-haul freight trains
Remote run on line	No
Batch run	Yes
Input media	Disc file or cards
Output medium	Line printer
Computer size required	Medium
Computer now in disc	Univac 1100
Language	ANSI Fortran
Modifications required for interchange	None
Data	
Access mode	Sequential
Form	Point
Organized	Separate route of schedule data
Ease of use	Good
Economy	Good
User's manual	None available

TPC General Description

The TPC developed by AiResearch for the analysis of WESS is a computer program that simulates the operation of many trains over a railroad route. The TPC contains characteristics of the locomotives and rolling stock as internal program parameters; route and schedule data are input to the program. The program computes speed, time, distance, acceleration, locomotive input power, efficiency, power factor, apparent power, and energy input from the pantograph. It also computes tractive effort during motoring and braking from both the propulsion system and the friction braking system. To define substation power versus time and energy requirements, it analyzes specific energy consumption in watt-hours per ton-mile for each train and accumulates the power and energy requirements for all trains operating over specific sections of the route. Simulation of up to 100 trains over a 24-hr period of operation can be performed. Outputs include the time history of a selected train over the route and a listing of 5-min power demands for each subdivision of the route (up to 10 subdivisions). It also outputs the total route 5-min power demand for an entire 24-hr period. Total energy requirements for each division and the total route also are output for the 24-hr period.

The basic route data inputs required in a route file for each route are listed below. Detailed information on route data requirements and input format is provided later in this appendix under the paragraph, "Track Data Requirements".

- Curvature, deg
- Grade, percent
- Civil speed limit, mph
- Elevation, ft

The basic schedule information required in a schedule file for each train is listed below. Detailed information on schedule data requirements and input format is provided later under "Train Schedule Requirements".

- Train identification
- Direction of travel
- Trailing tons
- Start time
- Location of intermediate stop
- Intermediate stop dwell
- Start location
- Number of locomotives (minimum)

Complete listings of the program and program nomenclature are presented at the end of this appendix.

The program is based on the calculation of train resistance from the modified Davis formulas and the use of representative propulsion system efficiency and power factor characteristics based on E60C locomotive data, as shown in the algorithms of Figures F-1 and F-2, respectively. In these algorithms, efficiency and power factors are assumed to be a function of speed only. Speed is defined as V, efficiency as ETA, and power factor as PF.

The tractive effort and propulsion power calculation logic for blended friction and regenerative braking, coast, or motoring is shown in Figure F-3.

The program simulates operation of the train in accordance with speed limits by means of an algorithm that represents a dead-band type of speed control with rate of change of acceleration or deceleration and anticipation of stopping distances. This logic is shown in Figure F-4.

TPC USES

The TPC is useful in performing any of the following tasks:

(a) Determining the power and energy demand that results from operation of multiple trains over a route in accordance with a definite schedule and trailing ton distribution between trains.

(b) Determining the effect of motive power on the performance of a train over a route.

(c) Evaluating the effect of track relocation, grade changes, curve changes, speed restrictions, and other route changes on performance, schedule, motive power requirements, and energy consumption.

(d) Evaluating the effect of schedule changes, train size, and motive power assignment on power demand and energy requirements.

The TPC provides a valuable, simple, and time-saving method for simulating train performance as well as changes in route characteristics or schedule factors.

TPC AVAILABILITY

The AiResearch TPC is available immediately. It includes a complete program listing, program nomenclature, track data requirements, and schedule data requirements; these are enclosed at the end of this appendix. This program contains no proprietary information. It is available to any interested user.

GENERAL-PURPOSE TPC

The AiResearch TPC is designed primarily as a tool for analyzing of long-haul freight service, with emphasis on energy and power demand requirements of multitrain operations. It also can be employed for intercity rail passenger service.

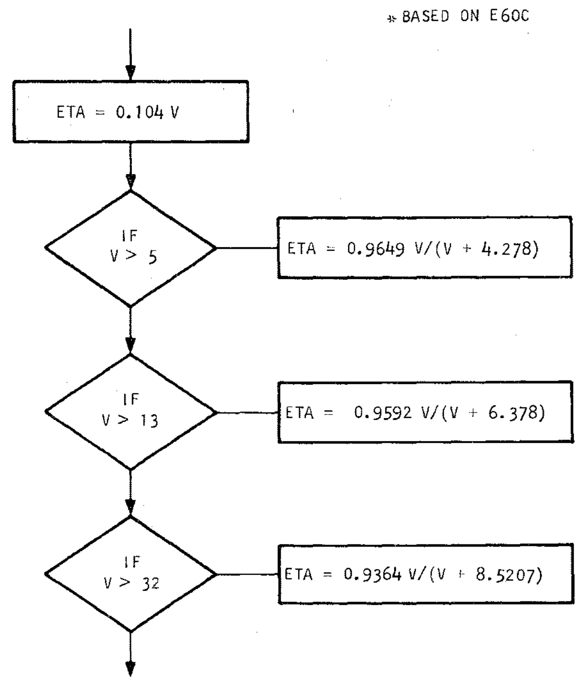

Figure F-1. TPC, Propulsion System Efficiency Algorithm*

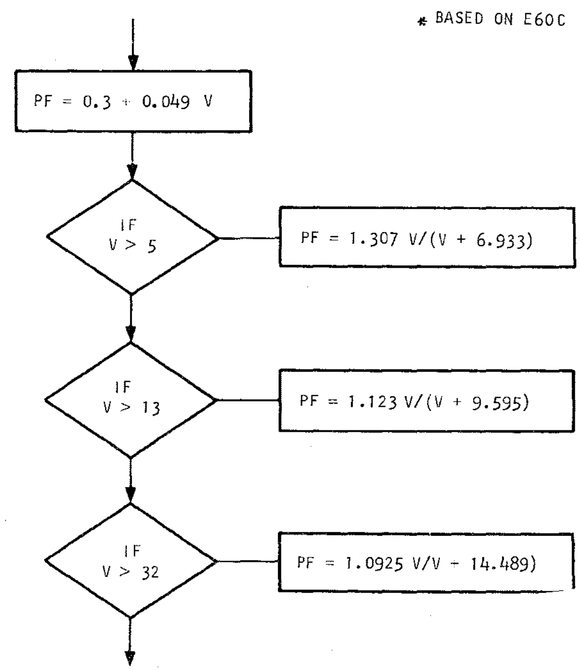

Figure F-2. TPC, Propulsion System Power Factor Algorithm*

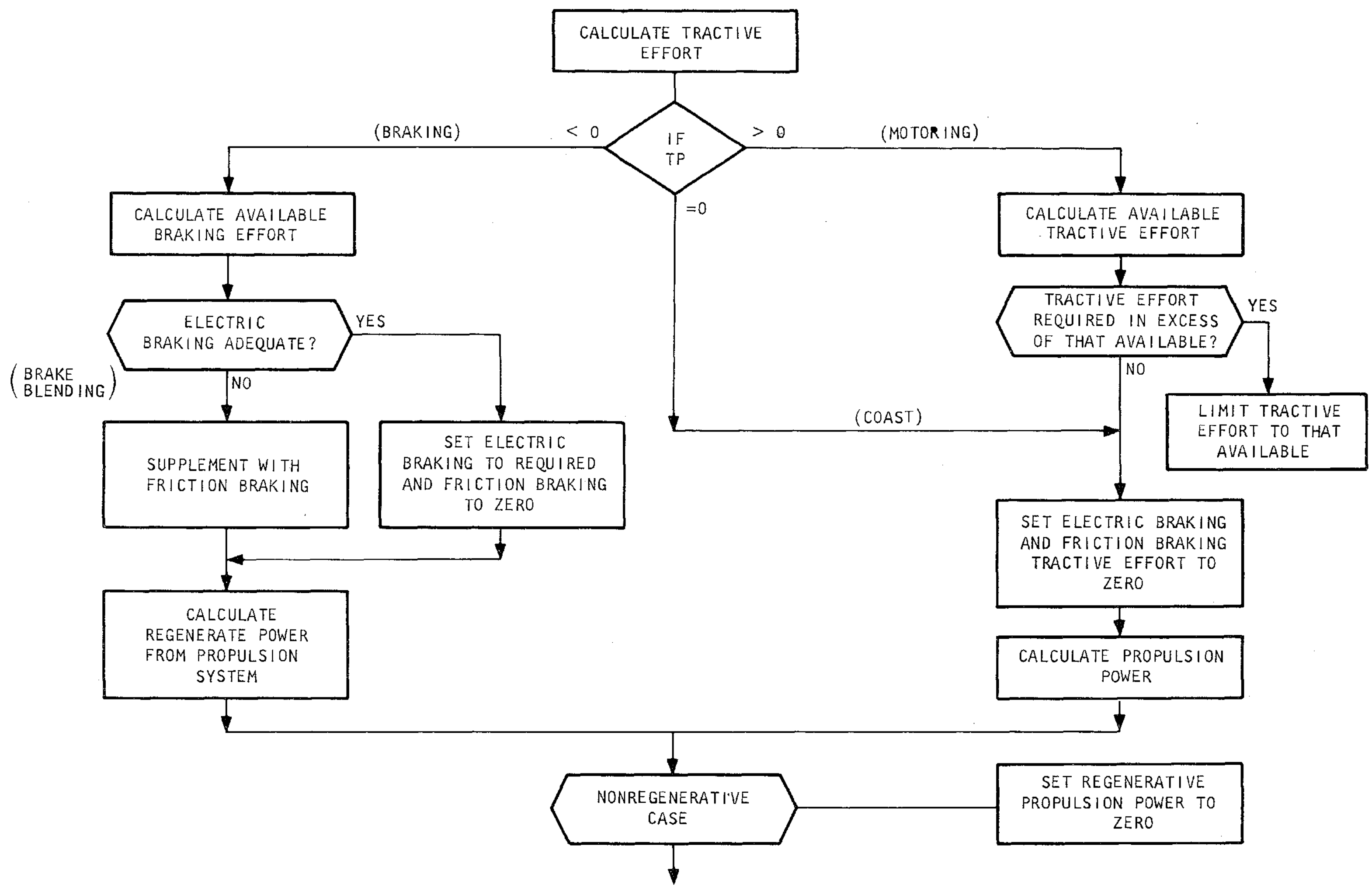

Figure F-3. TPC, Tractive Effort and Propulsion Power

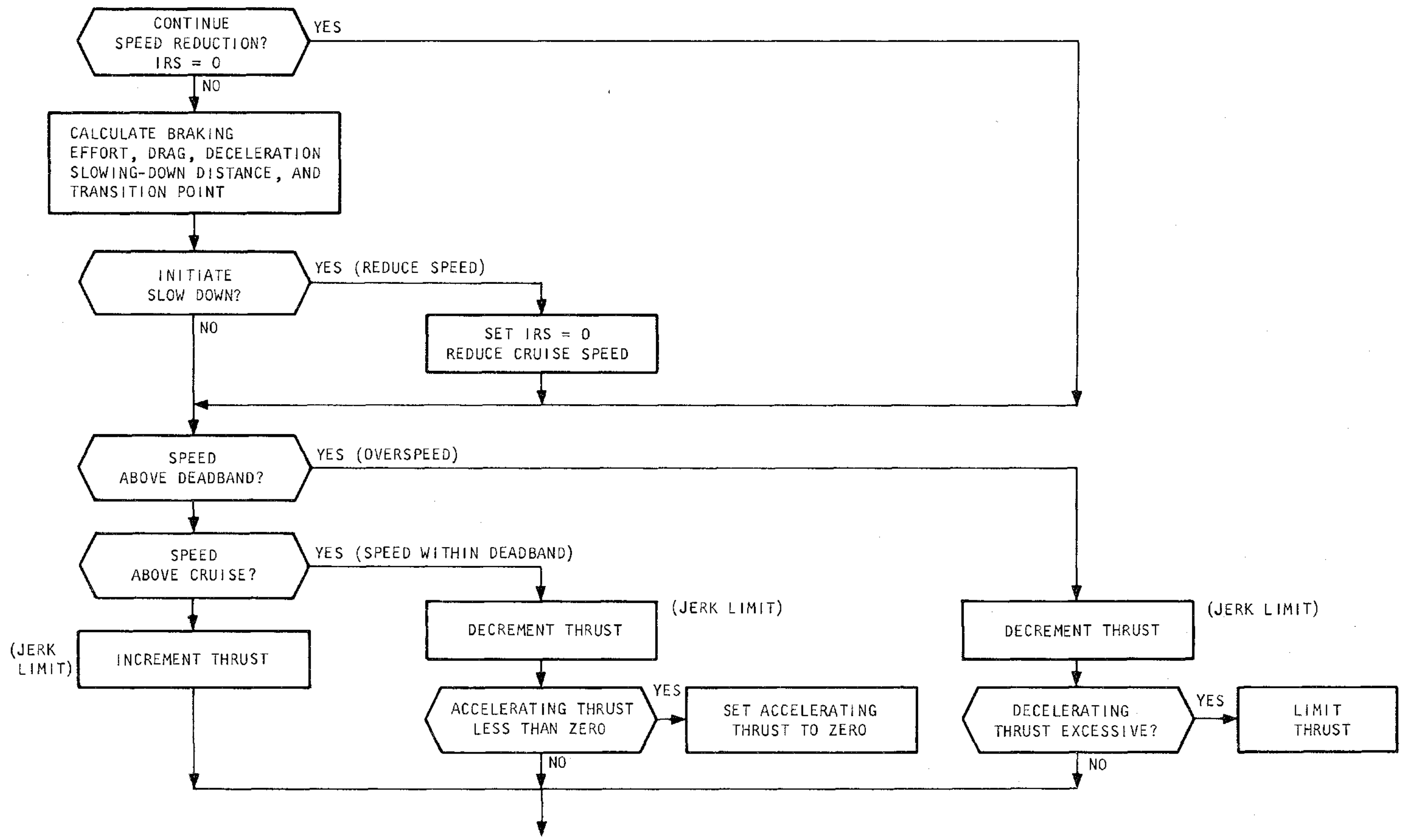

Figure F-4. TPC, Speed Control Logic

The TPC is not suited to the analysis of multistop rail rapid transit operations. Although it includes only electric locomotive motive power, it could be modified for other propulsion types.

MACHINE CONSIDERATIONS

Batch-Processing and Time-Sharing

The AiResearch TPC is well-suited to running under batch control because no user interaction is required during program execution. Basic locomotive and trailing car characteristics are included in the program. Route and schedule data inputs are developed prior to the run.

Input/Output

The program is designed as a self-contained main program that receives input from the route and schedule files. These files may be input from a card reader or tape files. It is designed to output data on a line printer.

Machine Size

The TPC is used on a medium-size engineering computer, a Univac 1100, in a time-sharing mode with other batch jobs. It requires no excessive storage or time to calculate typical runs.

Cost of Use

The TPC is a simple program that analyzes complete routes such as Harrisburg to Pittsburgh or Los Angeles to Salt Lake City at moderate costs per run.

Programming Language

The TPC is written in ANSI Fortran and should therefore be compatible with most computer installations.

Interchangeability

Selection of ANSI FORTRAN ensures that the program is almost completely interchangeable with any computer system without any major problem.

User Considerations

The TPC is easy to use on any computer installation. It requires only simple program changes to accommodate changes in motive power and the development of route and schedule data. Track data and schedule data requirements are defined in the ensuing paragraphs of this appendix. Track data are read in a sequential mode as present in the route data file. The entire route data file is read at one time and is processed prior to execution of a run. Schedule data are processed in a similar manner. Route data are entered in point form, e.g., by milepost location. Curvature, speed limit, and grade data are entered at the point to define the characteristics over the interval to the next point of change. Grade data may be alternately entered as elevation data in point form.

All route data are combined on one record in a common file. Schedule data are maintained in a separate file. No problem has been experienced in the use of this approach.

TRACK DATA REQUIREMENTS

Figure F-5 shows the format of a route data input card. The route data card contains the milepost location, degree of curvature, grade, civil speed, and elevation data that define the route profile. Location inputs may be increasing, decreasing, or mixed. Whenever a change occurs in the milepost reference, the equivalent location in terms of the new reference must be specified on the route data input card that identifies the location of the change in milepost reference. The equivalent location is specified in field 7 of the route card. The following card may then utilize the new reference for milepost locations. Up to 1000 route data input cards may be included in the route data file. A route data input card is required only for each location where changes in route data occur.

Grade data may be input directly as the grade to the next grade change location where the grade is expressed as a percent of grade. An alternate method of inputting grade data is to input elevation data at each grade change location with the elevation data expressed in feet. In the absence of elevation input data, the program defaults to the input grade data. If elevation data and grade data are both omitted, the program defaults to zero grade.

The route data are input to the program and are stored in a route matrix RT(1000,9). The relationship between the route matrix elements RT(I,J) and the route data input cards is as follows:

Milepost Location--the milepost location in card field 1, card columns (cc) 1-10, is the identification of the location for a change in any one or more input route parameters. It is expressed in miles with an F10.3 format. It may start at any number within this format and be monotone, increasing or decreasing in the "forward" direction of travel. The reference milestone may change. Whenever the reference milestone changes, the equivalent milestone based on the new reference must be defined in field (7) at the last data point by using the old reference. For the next data point, mileposts based on the new reference should be used. The milepost location is stored in RT(I, 1)

Curvature--The curvature of a section that starts at the milepost defined by field (1) is shown in field (2), cc 11-20, in degrees deflection per 100 feet of chord (the customary railroad engineering unit) using an F10.3 format. The curvature is stored in RT (I, 2).

Grade--The grade for a section of the route that starts at the milepost defined by field (1) is shown in field (3), cc 21-30, with the grade expressed in percent using an F10.3 format. The grade is stored in RT (I, 3).

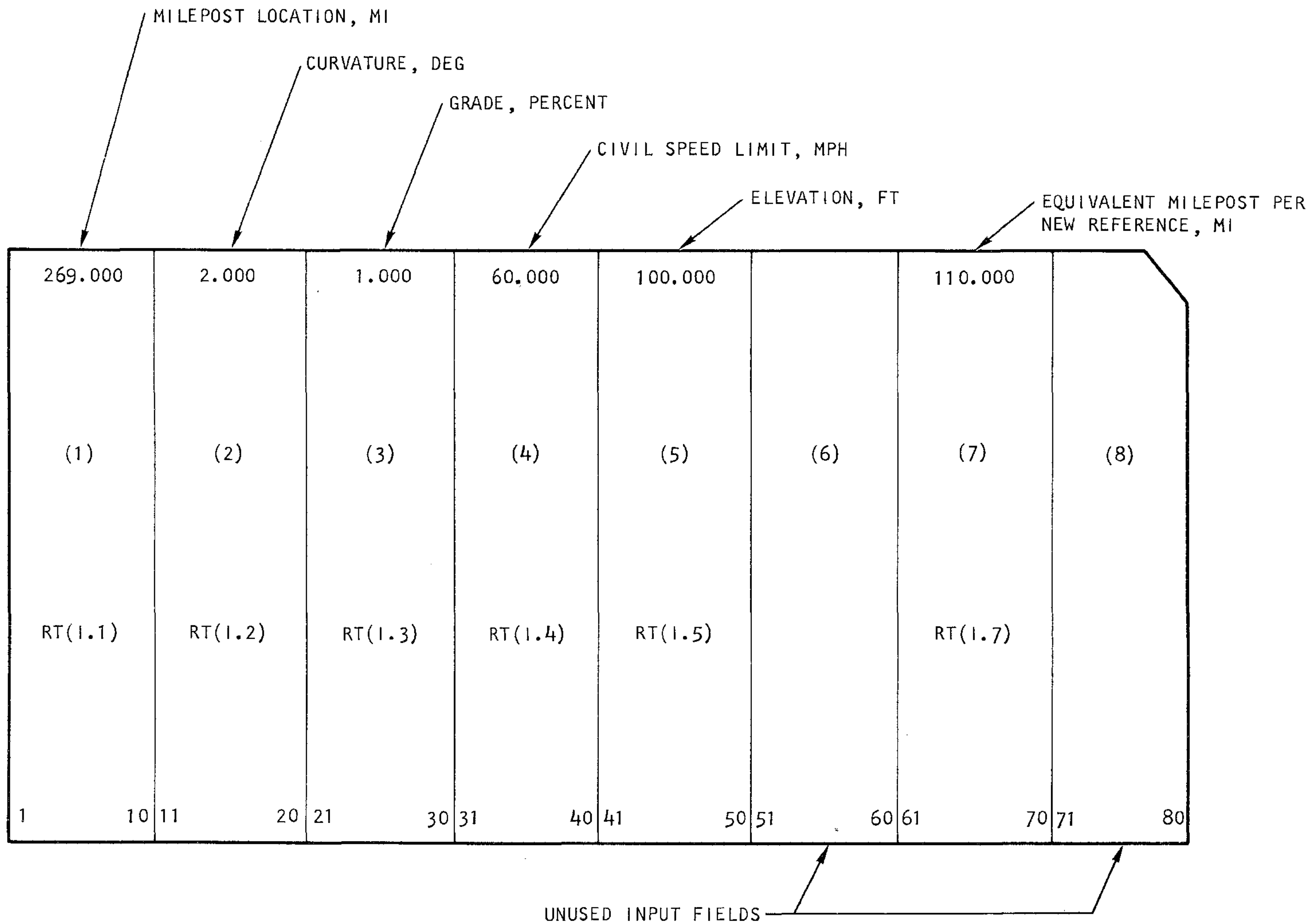

Figure F-5. Route Data Input Card Format

Civil Speed Limit--The civil speed limit for a section that starts at the milepost defined by field (1) is shown in field (4), cc 31-40; the speed limit is expressed in miles per hour using an F10.3 format. The civil speed is stored in RT (I, 4).

Elevation--The elevation at the location milepost defined by field (1) is shown in field (5), cc 41-50. Elevation is expressed in feet above a reference elevation by using F10.3 format. The elevation data are stored in RT (I, 5). The same common reference elevation must be used for all inputs. Elevation data may be positive or negative.

Unused Field--Field (6) is not used for input. This field (cc 51-60) should remain blank.

Milepost Reference Change--If the milestone reference is to change, the milepost location defined in field (1) must be expressed as an equivalent milepost, based on the new reference in field (7). The milepost locations are expressed in miles using an F10.3 format. The new equivalent milepost location is stored in the route matrix as RT (I, 7).

Unused Field--Field (8) is not used for input. This field (cc 71-70) should remain blank.

Stored Route Data

Stored route data must be contained in a deck or file with the individual milepost cards in the "Forward" route direction sequence. A negative number (-.001) is required in card columns 31-40, field (4), of the last milepost-card to stop the train at the end of the route.

The end of the file is identified by a card immediately following the last milepost card. This end of file card must contain 9999. in card columns 1-10, field (1), of the route deck.

1. Reverse Direction

Route data are required only for the forward direction of a route. Train operation may be simulated for forward or reverse route directions by input of the appropriate code in the train schedule data. The program automatically computes the proper reverse route matrix from the forward route input data.

2. Data Entry

The route data must be entered only when a change occurs in any one or more parameters. If no change is required in a given parameter, the field must be left blank or the parameter may be repeated. To distinguish a zero parameter as a new or different value, a zero must be entered as .001. If a true zero is entered, the program will assume no change from the previous value of the parameter at the last milepost data card having a non-zero value.

Train Schedule Requirements

Figure F-6 shows the format of a train schedule data input card. One card is required for each train. A train may travel between two points with one intermediate stop. It may start at any time during the day and may start at any location. Any dwell up to 24 hr may be specified for the intermediate stop. If a train is required to stop at more than one intermediate point along the route, a separate schedule card is required to start the train at the first intermediate stop at a specified time, continue to the second intermediate stop, dwell, and then proceed to the end of the route. The second section of the route requires reidentification of the train. The dwell at the first intermediate stop must be greater than 24 hr to prevent continuation of that train.

The schedule data input card contains the train identification, direction of travel code, trailing tons, start time, intermediate stop location, and number of locomotives. In the absence of any start location input, the train will start at the appropriate terminal, as determined by the input direction of travel code. The program is capable of reading 100 schedule cards. The last schedule card must be followed by a card having a negative one in card columns 9-10 to indicate the end of the schedule deck.

The train identification (up to eight alphanumeric digits) is stored as a train identification vector ID (I). The remaining schedule input data are stored as a schedule matrix SCH (I, J). The same train index (I) is common to both elements to identify the train schedule parameters for a given train.

The schedule input card is divided into 15 fields, as shown in Figure F-6. Each field is as defined below:

> Train Identification--Any alphanumeric identification containing up to 8 characters may be used for train identification. The train identification is contained in field (1), cc 1-8 of the schedule card in A8 format. The program stores train identification data as ID (N).
>
> Direction of Travel Code--The direction of travel is selected by a code. If the direction of travel is in the "forward" direction of the route (direction of the route deck sequence) the code is "0". If a "reverse" direction is desired, the direction code "1" is entered in field (2), cc 9-11 of the schedule card in F3.0 format. The program defaults to the "forward" direction if no entry is made in field (2). The program stores direction of travel in the first column of the schedule matrix SCH (I,1).
>
> Trailing Tons--The number of trailing tons is entered in field 3, cc 12-30, in F19.6 format. The program defaults to the number of locomotives only when this field is blank. The program stores the trailing tons in the second column of the schedule matrix.
>
> Start Time--The schedule departure time for the train is entered in fields (4), cc 31-32, and (6) cc 34-35. Field (4) contains the hours and field (6) contains the minutes. Field (5), cc 33, provides

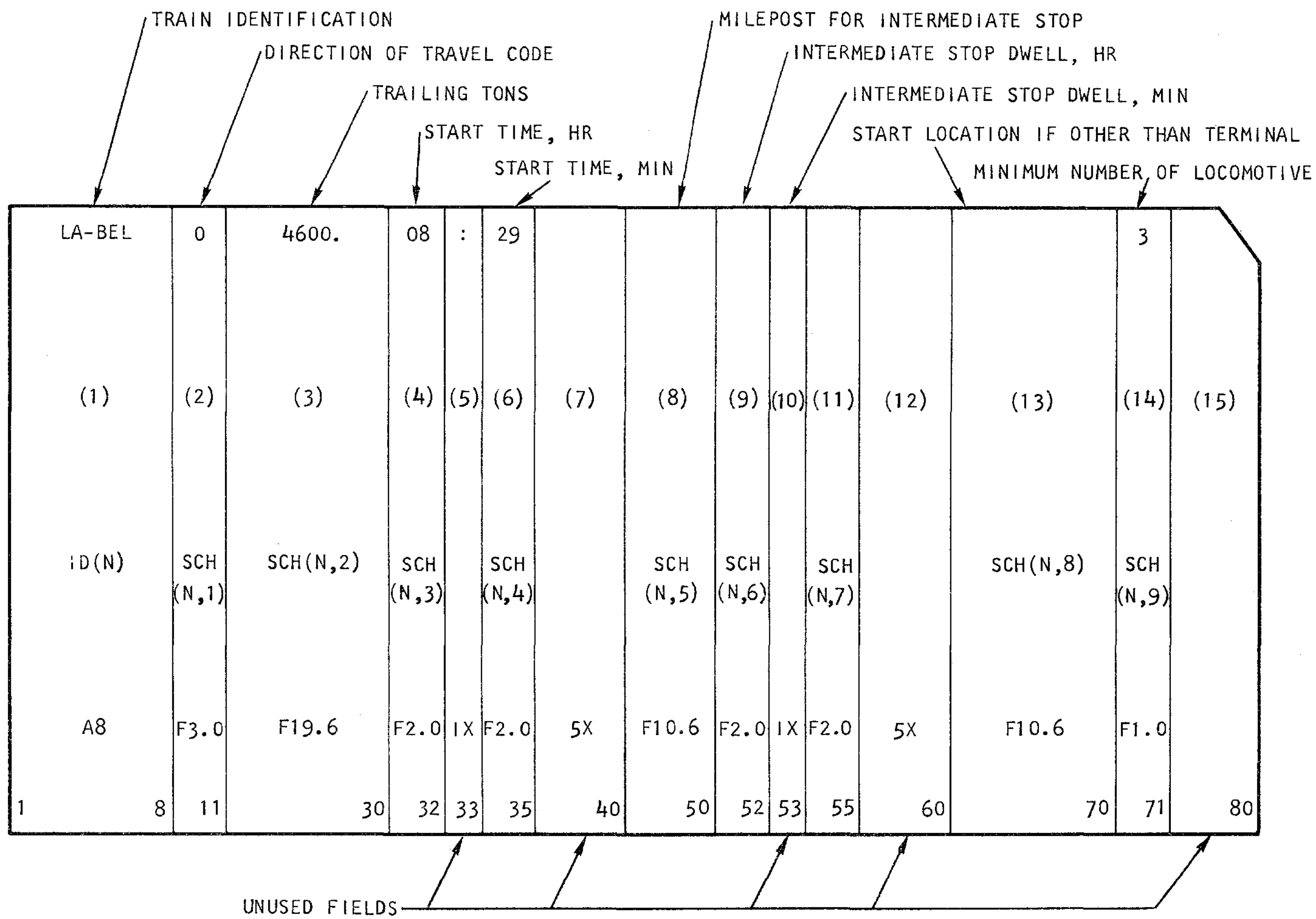

Figure F-6. Schedule Data Card

space for a colon to facilitate card reading, and is ignored by the program. The program stores the start time hours in the third column of the Schedule Matrix SCH (N, 3) and the minutes in the fourth column SCH (N, 4). The format of the data is F2.0. In the absence of start time input the program defaults to departure at 0000 hours.

Unused Field--Field (7) is unused.

Intermediate Stop Milepost--Field 8, cc 41-50, defines the location of the intermediate stop, if any. This location must be expressed in terms of the common reference milepost location, as shown in column 8 of the route matrix listing. If this field is not punched, no intermediate stop is made. The format of this field is F10.6. The location is stored in column five of the schedule matrix SCH (N,5).

Intermediate Stop Dwell--The dwell for an intermediate stop is entered in field (9), cc 51-52, and field (11), cc 54-55. Field (9) contains the dwell hours and field (11) contains the dwell minutes. Field (1), cc 53, provides space for a colon to facilitate card reading, and is ignored by the program. The program stores the dwell time hours in the sixth column of the schedule matrix (SCH (N,6); minutes are stored in the seventh column SCH (N,7). The format of the data is F2.0. In the absence of dwell time data input the program defaults to zero dwell. Dwell is ignored if the intermediate stop data is zero.

Unused Field--Field (12) is unused.

Start Location--Start locations, other than those at the terminals, must be specified by entry of the start location milepost. This is done by using a common reference milepost, as shown in column 8 of the route matrix output listing. The milepost location is entered into field (13), cc 61-70, in F10.6 format. The program stores the start location in column 8 of the schedule matrix SCH (N,8). In the absence of input in field (13), the program starts at the terminals, as determined by the direction code input in field (2).

Minimum Number of Locomotives--The program selects the number of locomotives needed for operation over the maximum grades for the specified trailing tons and performance. If a number of locomotives are specified in field (14), cc 71, the number of locomotives will be no less than that specified in this field. The format of this field is F1.0. The program stores the minimum number of locomotives required in the ninth column of the schedule matrix.

Unused Field--Field (15) is unused.

Data Entry

Schedule data must be entered in start time sequence.

TRAIN PERFORMANCE COMPUTER TPC PROGRAM LISTING

The following printout defines the TPC program.

```
C      TPC
C      TRAIN PERFORMANCE SIMULATION
C NEGATIVE 1 IN CC10 INDICATED END OF SCH DECK
C      LAST CARD IN DATA DECK MUST CONTAIN 9999. IN CC 1-10
C      NEGATIVE SPEED LIMIT IN CC 40-50 INITIATES STOP AT LOC IN CC 1-10
       REAL KVA,NL,NC
       DOUBLE PRECISION ID
       DIMENSION SCH(100,9),ID(100)
       DIMENSION RT(1000,9),RT1(1000,9)
       DIMENSION RTF(1000,8),RTR(1000,8)
C      DIRECTION CODE 0= OUT 1= IN
C      CONSTANTS
       IREGN=1
       NSEL=1
       NS=10
       GEE=21.927
       TAU1=1.
       TIMX1=300.
       AJERKR=2.
C      TRAIN CHARACTERISTICS
C      LOCOMOTIVES
       PAUX=75.
       AFL=150.
       NAL=6
       TONL=275.
       WTL=2000.*TONL
       MF=1.08
       TEMAX=102000.
       BEMAX=81600.
       CONTINUE
       VXT=25.
       VXB=30.
       DECMAX=.5
C      TRAILING CARS
       AFC=98.
       NAC=4
       TONC=85.
       WTC=2000.*TONC
C        INPUT SCHEDULE DATA
       DO 5 I=1,100
```

```
      READ(5,501) ID(I),(SCH(I,J),J=1,9)
      IF(SCH(I,1).LT.0.) GO TO 6
    5 CONTINUE
      STOP
    6 WRITE(6,502)
      NID=I-1
      WRITE(6,503)(ID(I),(SCH(I,J),J=1,9),I=1,NID)
C     INPUT ROUTE DATA
      DO 10 I=1,1000
      READ(5,101)RT(I,1),RT(I,2),RT(I,3),RT(I,4),RT(I,5),RT(I,6),RT(I,7)
      IF(RT(I,1).GT.999.) GO TO 12
   10 CONTINUE
      STOP
   12 NR=I-1
      RT(1,8)=RT(1,1)
      DIF1=ABS(RT(2,1)-RT(1,1))
      DO 14 I=2,NR
      J=I+1
      K=I-1
      DIF=ABS(RT(J,1)-RT(I,1))
      IF(RT(I,7).NE.0.) DIF=ABS(RT(J,1)-RT(I,7))
      RT(I,8)=RT(K,8)+DIF1
      DIF1=DIF
      IF(RT(I-1,5).EQ.0.) GO TO 14
      IF(RT(I,5).EQ.0.) GO TO 14
      RT(I-1,3)=(RT(I,5)-RT(I-1,5))/(52.8*(RT(I,8)-RT(I-1,8)))
      IF(RT(I-1,3).EQ.0.) RT(I-1,3)=.001
   14 CONTINUE
      DO 20 I=2,NR
      IF(RT(I,2).NE.0) GO TO 16
      RT(I,2)=RT(I-1,2)
   16 IF(RT(I,3).NE.0) GO TO 18
      RT(I,3)=RT(I-1,3)
   18 IF(RT(I,4).NE.0) GO TO 20
      RT(I,4)=RT(I-1,4)
   20 CONTINUE
      DO 21 I=1,NR
      DO 21 J=1,8
      RTF(I,J)=RT(I,J)
   21 CONTINUE
```

```
      DO 22 I=1,NR
      RTF(I,7)=RTF(I,8)
   22 CONTINUE
      RT1(NR,1)=RT(1,1)
      RT1(NR,2)=0.
      RT1(NR,3)=0.
      RT1(NP,4)=-.001
      RT1(NR,5)=RT(1,5)
      RT1(NR,8)=RT(1,8)
      DO 23 I=2,NR
      K=NR+1-I
      RT1(K,1)=RT(I,1)
      RT1(K,2)=RT(I-1,2)
      RT1(K,3)=-RT(I-1,3)
      RT1(K,4)=RT(I-1,4)
      RT1(K,5)=RT(I,5)
      RT1(K,8)=RT(I,8)
   23 CONTINUE
      DO 24 I=1,NR
      DO 24 J=1,8
      RTR(I,J)=RT1(I,J)
   24 CONTINUE
      DO 25 I=1,NR
      RTR(I,7)=RTR(I,8)
   25 CONTINUE
      DO 254 N=1,NID
      IROUTE=INT(SCH(N,1))
      NL=SCH(N,9)
      TT=SCH(N,2)
      NC=TT/TONC
C     INITIALIZATION
      IFLAG=0
      VMW1=0.
      TIM=0.
      TXX=0.
      ACC=0.
      ACC1=0.
      V=0.
      V1=0.
```

```
      AJERK=AJERKR
      TN=0.
      VP1=0.
      EV=0.
      ER=0.
      ISR=1
      EV1=0.
      CLOCK=0.
      THETA=3600.*SCH(N,3)+60.*SCH(N,4)
      IF(IROUTE.EQ.1) GO TO 27
      DO 26 I=1,NR
      DO 26 J=1,8
      RT(I,J)=RTF(I,J)
   26 CONTINUE
      GO TO 29
   27 DO 28 I=1,NR
      DO 28 J=1,8
      RT(I,J)=RTR(I,J)
   28 CONTINUE
   29 IF(SCH(N,5).NE.0.) GO TO 30
      GO TO 335
   30 TEST=SCH(N,5)
      CONST=RT(1,8)
   31 DO 32 I=1,NR
      IF(RT(I,8).EQ.TEST) GO TO 33
   32 CONTINUE
      WRITE(6,515) ID(N)
      GO TO 254
   33 RT(I,4)=-.001
      IRET=I
  335 TAU=TAU1
      TIMX=TIMX1
      DO 39 I=1,NR
      NX=NL
   34 WT=NX*WTL+NC*WTC
      AMASS=(MF*NX*WTL+NC*WTC)/GEE
      TNI=AJERK*AMASS*TAU
      TG=WT*RT(I,3)/100.
   35 TRLX=NX*((1.3+.03*VXT)*TONL+29.*NAL+.0024*AFL*VXT**2)
      TRCX=NC*((1.3+.045*VXT)*TONC+29.*NAC+.0005*AFC*VXT**2)
      TCX=.8*RC*WT/2000.
```

```
      TOX=TRLX+TRCX+TCX+TG
      TLX=NX*TEMAX
      IF(TLX.GT.TDX) GO TO 36
      NX=NX+1
      GO TO 34
   36 RT(I,9)=NX
      RT(I,6)=RT(I,4)
   37 TRL=NX*((1.3+.03*RT(I,6))*TONL+29.*NAL+.0024*AFL*RT(I,6)**2)
      TRC=NC*((1.3+.045*RT(I,6))*TONC+29.*NAC+.0005*AFC*RT(I,6)**2)
      TC=.8*RC*WT/2000.
      TD=TRL+TRC+TC+TG
      TDYN=BEMAX*NX
      IF(RT(I,6).GT.VXB) TDYN=NX*BEMAX*VXB/RT(I,6)
      IF(TD.LT.-TDYN) GO TO 38
      GO TO 39
   38 IF(RT(I,6).LT.VXB) GO TO 39
      RT(I,6)=RT(I,6)-5.
      GO TO 37
   39 CONTINUE
C      OUTPUT TRAIN ID
      IF(N.NE.NSEL) GO TO 40
      WRITE(6,507) ID(N)
C     OUTPUT ROUTE HEADER
      WRITE(6,201)
C     OUTPUT UNIT HEADER
      WRITE(6,202)
C     OUTPUT ROUTE DATA
      WRITE(6,203) ((RT(I,J),J=1,9),I=1,NR)
   40 IF(IROUTE.EQ.1) GO TO 42
      DO 41 I=1,NR
      RT(I,1)=RT(I,8)
   41 CONTINUE
      GO TO 44
   42 DO 43 I=1,NR
      RT(I,1)=CONST-RT(I,8)
   43 CONTINUE
C      OUTPUT TRAIN ID
C     OUTPUT TIME HISTORY HEADER &UNITS
   44 IF(N.NE.NSEL) GO TO 45
      IF(IREGN.EQ.0) WRITE(6,512) ID(N)
```

```
      IF(IREGN.EQ.1) WRITE(6,513) ID(N)
      WRITE(6,204)
      WRITE(6,205)
   45 I=1
      S=RT(I,1)
      IF(SCH(N,8).NE.0) S=SCH(N,8)
      IF(SCH(N,8).NE.0..AND.IROUTE.EQ.1) S=CONST-SCH(N,8)
      RC=RT(I,2)
      G=RT(I,3)
      VC=RT(I,6)
      NX=RT(I,9)
      SPACE=(ABS(RT(NR,1)-RT(1,1)))/NS
C     CONTINUE LINK
   46 J=I+1
      IF(S.GT.RT(J,1)) GO TO 50
      GO TO 90
   50 I=I+1
      NX=RT(I,9)
      ISR=1
      IF(RT(J,2).EQ.0.) GO TO 60
      RC=RT(J,2)
   60 IF(RT(J,3).EQ.0.) GO TO 70
      G=RT(J,3)
   70 IF(RT(J,6).EQ.0.) GO TO 80
      VC=RT(J,6)
   80 IF(S.GE.RT(J+1,1)) GO TO 46
   90 IN=I+1
      DO 110 II=IN,NR
      IF(RT(II,6).NE.0.) GO TO 100
      GO TO 110
  100 IF(RT(II,6).LT.VC) GO TO 120
  110 CONTINUE
  120 ST=RT(II,1)
      VCN=RT(II,6)
      IF(VCN.LT.0.) GO TO 130
      GO TO 140
  130 ISTOP=1
      VCN=0.
      STT=ST
```

```
C     DRAG CALCULATIONS. GRADE
  140 TG=WT*G/100.
C     LOCOMOTIVE DRAG
      TRL=NX*((1.3+.03*V)*TONL+29.*NAL+.0024*AFL*V*V)
C     CAR DRAG
      TRC=NC*((1.3+.045*V)*TONC+29.*NAC+.0005*AFC*V*V)
C     CURVE DRAG
      TC=.8*RC*WT/2000.
C     TOTAL TRAIN DRAG
      TD=TRL+TRC+TC+TG
C     PROPULSION EFFICIENCY
      ETA=.104*V
      IF(V.GT.5.) ETA=.9649*V/(V+4.276)
      IF(V.GT.13.) ETA=.9592*V/(V+6.378)
      IF(V.GT.32.) ETA=.9364*V/(V+8.5207)
C     POWER FACTOR
      PF=.3+.049*V
      IF(V.GT.5.) PF=1.307*V/(V+6.993)
      IF(V.GT.13.) PF=1.123*V/(V+9.595)
      IF(V.GT.32.)  PF=1.0925*V/(V+14.489)
C     ELECTRICAL BRAKING EFFORT AT PRESENT SPEED
      TDYN=BEMAX*NX
      IF(V.GT.VXB) TDYN=NX*BEMAX*VXB/V
      TB=TD+TDYN
C     SWITCH TO CONTINUE BRAKING IF ISR IS ZERO
      IF(ISR.EQ.0) GO TO 160
C     BRAKING EFFORT AT NEXT CIVIL SPEED
      TRLN=NX*((1.3+.03*VCN)*TONL+29.*NAL+.0024*AFL*VCN*VCN)
      TRCN=NC*((1.3+.045*VCN)*TONC+29.*NAC+.0005*AFC*VCN*VCN)
      TDN=TRLN+TRCN+TC+TG
      TDYNN=BEMAX*NX
      IF(VCN.GT.VXB) TDYNN=NX*BEMAX*VXB/VCN
      TBN=TDN+TDYNN
C     AVERAGE BRAKING EFFORT (APPROXIMATE) & DECL RATE
      TBBAR=(TB+TBN)/2.
      DECL=TBBAR/AMASS
C     SLOWING DOWN DISTANCE & TRANSITION POINT
      XT=((V+VCN)*(V-VCN)/DECL)/7200.
      STAT=ST-XT
      IF(S.GT.STAT) GO TO 150
```

```
      GO TO 160
  150 ISR=0
      VC=VCN
  160 IF(V.GT.1.05*VC) GO TO 180
      IF(V.GT.VC) GO TO 170
      TN=TN+TNI
      GO TO 190
C     SPEED IN DEADBAND
  170 TN=TN-TNI
      IF(TN.LT.0.) TN=0.
      GO TO 190
C     SPEED ABOVE DEADBAND
  180 TN=TN-TNI
C     TRACTIVE EFFORT AND PROPULSION LIMITING
  190 IF(TN.LT.-AMASS*DECMAX) TN=-AMASS*DECMAX
      TP=TN+TD
      IF(TP) 200,220,210
C     BRAKING
  200 TPT=NX*BEMAX
      IF(V.GT.VXB) TPT=NX*BEMAX*VXB/V
      IF(TP.LT.-TPT) GO TO 302
      EB=TP
      FB=0.
      GO TO 228
  302 EB=-TPT
      FB=TP-EB
      TP=EB+FB
  228 THP=EB*V/375
      PP=THP*ETA*.746
      GO TO 230
C     MOTORING
  210 TPT=NX*TEMAX
      IF(V.GT.VXT) TPT=NX*TEMAX*VXT/V
      IF(TP.GT.TPT) TP=TPT
C     COASTING
  220 EB=0.
      FB=0.
      PP=TP*V*.746/(375.*ETA)
  230 IF((IREGN.EQ.0).AND.(PP.LT.0)) PP=0.
      RF=SQRT(1.-PF*PF)
```

```
      PQ=PP*RF/PF
C     VEHICLE INPUT POWER
      VP=PP+PAUX*NX
C     VEHICLE INPUT KVA
      KVA=SQRT(VP*VP+PQ*PQ)
C     VEHICLE DYNAMICS
      TN=TP-TD
      ACC=TN/AMASS
      ABAR=(ACC+ACC1)/2.
      ACC1=ACC
      V=V+ABAR*TAU
      VBAR=(V+V1)/2.
      V1=V
      S=S+VBAR*TAU/3600.
C     VEHICLE ENERGY
      PBAR=(VP+VP1)/2.
       VP1=VP
      IF(PBAR.LT.0.) GO TO 931
      EV=PBAR*TAU/3600.+EV
      GO TO 932
  931 ER=ER+PBAR*TAU/3600.
      EV=(PBAR*TAU/3600.)*.96**4*.99+EV
  932 TONMI=WT*(S-RT(1,1))/2000.
      SP=1000.*EV/TONMI
      VMW=VP/1000.
      VMVA=KVA/1000.
      TPP=TP/1000.
      FBB=FB/1000.
C     UPDATE TIME
      THETA=THETA+TAU
      IF(VMW.LT.0) GO TO 234
      IF(IFLAG.EQ.1) GO TO 232
      GO TO 238
  232 REMP=ER*.96*.96*.99/.96
      VMW1=0.
      IXX=1
      IFLAG=0
      GO TO 238
  234 IF(IFLAG.EQ.1) GO TO 236
      ER=0.
```

```
      IFLAG=1
      IXX=1
      TXX=0.
  236 RMAX=AMAX1(-VMW,VMW1)
      VMW1=RMAX
  238 TXX=TXX+TAU
      IF(TXX.GE.60.) IXX=1
      IF(TXX.GE.60.) TXX=0.
      IF(N.NE.NSEL) IXX=0
      IF(IXX.EQ.1) WRITE(6,206)THETA,ACC,V,STA,VMW,ETA,PF,VMVA,EV,TPP
     1,FBB,SP,RC,G,VC,RMAX,REMP
      IF(IXX.EQ.1) IXX=0
      TIM=TIM+TAU
      IF(TIM.GE.TIMX) IWC=1
      IF(TIM.GE.TIMX) TIM=0.
      IF(IROUTE.EQ.0) STA=S
      IF(IROUTE.EQ.1) STA=CONST-S
      IF(ISTOP.EQ.1) GO TO 240
      IF(V.LT.0.) V=0.
      GO TO 46
  240 IF(S.GE.STT) GO TO 250
      IF(V.LT.0.) GO TO 250
      GO TO 46
  250 S=STT
       V=0.
      DWELL=3600.*SCH(N,6)+60.*SCH(N,7)
      IF(SCH(N,5).EQ.0.) GO TO 254
      IF(DWELL.GT.86400.) GO TO 254
  702 IF(CLOCK.GE.DWELL) GO TO 252
      CLOCK=CLOCK+TAU
      GO TO 46
C     END OF DWELL
  252 CLOCK=0.
      I=IRET
      ISR=1
      SCH(N,6)=99.
      IF(N.EQ.NSEL) IXX=1
      VC=RTF(IRET,4)
      IF(IROUTE.EQ.1) VC=RTR(IRET,4)
      SCH(N,5)=0.
```

```
      ISTOP=0
      GO TO 46
  254 CONTINUE
  101 FORMAT(7F10.3)
  201 FORMAT(1H0,81HMILE POST CURVATURE   GRADE  CIVIL SPEED ELEVATION G
     1RADE SPEED LOCATION NUM LOCOS)
  202 FORMAT(1H0,71H  MILES    DEGREES       %          MPH        FEET
     1 MPH         MILES  )
  203 FORMAT(1H,9F10.3)
  204 FORMAT(1H0,106HTIME   ACC SPEED DIST     VEH  EFF  PF   MVA F-PANTO
     1    TE    FB SPECIFIC PWR CURVE GRADE SPEED LT FW RE-MP)
  205 FORMAT(1H0,106HSEC   M/H/S MPH   MI     MW    PU  PU   MVA  KWHR
     1   KLB    KLB  WHR/TON-MI   DEG    %   MPH      MW KWHR )
  206 FORMAT(F7.0,F5.2,F5.1,F6.1,F6.2,F5.3,F5.3,F6.2,F8.0,F7.0,F7.0,
     1F10.2,F6.2,F6.2,F6.0,F6.2,F6.0)
  501 FORMAT(A8,F3.0,F19.6,F2.0,1X,F2.0,5X,F10.6,F2.0,1X,F2.0,5X,F10.6
     1,F1.0)
  502 FORMAT(1H1,75HTRAIN  ID  ROUTE DIR  TRL TONS  START    STOP MP
     1DWELL START MP NO LOCOS)
  503 FORMAT(1H ,A8,F7.4,F10.0,F7.0,1H:,F3.0,F14.2,F4.0,1H:,F3.0,F10.2,F
     13.0)
  506 FORMAT(12F10.2)
  507 FORMAT(1H0,9H TRAIN ID,A8)
  508 FORMAT(1H ,10X,11F10.2)
  509 FORMAT(1H0,59X,41HSYSTEM ENERGY INCLUDING TRANSMISSION LOSS,1X,F1
     1.0)
  510 FORMAT(1H0,10X,10HAVE LOAD: ,F10.2,3X,11HDISCH CAP: ,F10.2,3X,12HC
     1HARGE CAP: ,F10.2)
  511 FORMAT(1H0,1X,4HTIME,44X,16HSUBSTATION POWER,44X,11HTOTAL POWER)
  512 FORMAT(1H0,39H NON REGENERATIVE PERFORMANCE TRAIN ID ,A8)
  513 FORMAT(1H0,39H     REGENERATIVE PERFORMANCE TRAIN ID ,A8)
  514 FORMAT(1H0,45X,17HSUBSTATION ENERGY)
  515 FORMAT(1H0,17H STOP FOR TRAIN: ,A8,10H NOT FOUND)
      STOP
      END
```

TRAIN PERFORMANCE COMPUTER PROGRAM NOMENCLATURE

The following printout defines the program nomenclature.

NOMENCLATURE

FORTRAN SYMBOL	DESCRIPTION	UNITS
ABAR	AVERAGE ACCELERATION	MPH/SEC
ACC	ACCELERATION	MPH/SEC
ACC1	OLD ACCELERATION	MPH/SEC
AFC	FRONTAL AREA OF CAR	SQ FT
AFL	FRONTAL AREA OF LOCOMOTIVE	SQ FT
AJERK	JERK RATE	MPH/S/S
AJERKR	RATED JERK RATE	MPH/S/S
AMASS	EFFECTIVE TRAIN MASS	G LBS
BEMAX	MAXIMUM BRAKING EFFORT PER LOCO	LBS
CLOCK	DWELL TIMER	SEC
CONST	LOCATION OF TRAIN AT START	MI
DECL	DECELERATION	MPH/SEC
DECMAX	MAXIMUM DECELERATION LIMIT	MPH/SEC
DIF	ABSOLUTE DISTANCE TO NEXT ROUTE MATRIX LOCATION	MI
DIF1	ABSOLUTE DISTANCE FROM LAST ROUTE MATRIX LOCATION	MI
DWELL	DWELL TIME AT INTERMEDIATE STOP (INPUT AS HR:MIN)	SEC
EB	ELECTRICAL BRAKING EFFORT	LBS
ER	REGENERATED ENERGY AT PANTOGRAPH	KWHR
ETA	PROPULSION SYSTEM EFFICIENCY	PU
EV	NET VEHICLE ENERGY CONSUMPTION	KWHRS
EV1	ENERGY INPUT TO VEHICLE-OLD	KWHR
FB	MECHANICAL (FRICTION) BRAKING EFFORT	LBS
FBB	MECHANICAL (FRICTION) BRAKING EFFORT	KILO-LBS
G	GRADE	%
GEE	ACCELERATION DUE TO GRAVITY (21.927)	MPH/SEC
I	INDEX	
ID	TRAIN INDEX	
IFLAG	CONTROL FOR COMPUTATION OF FLYWHEEL CAPACITY	
II	INDEX	
IN	NUMBER OF ROUTE DATA CARDS	
IREGN	REGENERATION CODE 1=REGN 0=NON-REGN	
IRET	INDEX FOR INTERMEDIATE STOP IN ROUTE MATRIX	
IROUTE	ROUTE CODE 0=WESTBOUND 1=EASTBOUND	
ISR	SPEED REDUCTION CODE	
ISTOP	STOPPING CODE	
IWC	WRITE COMAND	
IXX	TIME HISTORY OUTPUT CODE 1=OUTPUT 0=NON-OUTPUT	
J	INDEX	
K	INDEX	
KVA	VEHICLE INPUT APPARENT POWER	KVA
MF	LOCOMOTIVE MASS FACTOR	
N	TRAIN SCHEDULE INDEX	
NAC	NUMBER OF AXLES ON CARS	
NAL	NUMBER OF AXLES ON LOCOMOTIVES	
NC	NUMBER OF CARS IN TRAIN	
NID	NUMBER OF TRAINS IN SCHEDULE	
NL	NUMBER OF LOCOMOTIVES IN TRAIN	
NR	NUMBER OF CARDS IN ROUTE DATA	
NS	NUMBER OF FEED POINTS	
NSEL	TRAIN SELECTED FOR OUTPUT (ID NUMBER)	

PAUX	LOCOMOTIVE AUXILIARY POWER	KW
PBAR	AVERAGE POWER	KW
PF	PROPULSION SYSTEM POWER FACTOR	PU
PP	PROPULSION POWER	KW
PQ	PROPULSION REACTIVE POWER	KVAR
RC	RADIUS OF CURVATURE	DEGREES
REMP	REGENERATIVE ENERGY AT METERING POINT	KWHR
RF	REACTIVE FACTOR	PU
RMAX	MAXIMUM REGENERATED POWER	MW
RT	ROUTE MATRIX 1-LOCATION,2-CURVE,3-GRADE,4-SPEED,5-ELEVATION ,6-GRADE SPEED,7-LOCATION(NEW REFERENCE),8-LOCATION(START REFERENCE),9-MINIMUM NUMBER OF LOCOMOTIVES	
RTF	FORWARD ROUTE MATRIX	
RTR	REVERSE ROUTE MATRIX	
RTI	REVERSE ROUTE MATRIX(INTERMEDIATE)	
S	DISTANCE FROM START	MILES
SCM	SCHEDULE MATRIX	
SP	SPECIFIC ENERGY	KWH/TMI
SPACE	DISTANCE BETWEEN FEED POINTS	MI
ST	SPEED TRANSITION LOCATION	MILES
STA	TRAIN LOCATION	MILES
STAT	LOCATION AT START OF SPEED REDUCTION	MILES
STT	STOPPING LOCATION	MILES
TAU	COMPUTING INTERVAL	SEC
TAU1	NOMINAL COMPUTING INTERVAL	SEC
TB	BRAKING EFFORT	LBS
TBBAR	AVERAGE BRAKING EFFORT	LBS
TBN	BRAKING EFFORT AT NEXT LOWER SPEED LIMIT (TOTAL)	LBS
TC	CURVE RESISTANCE	LBS
TD	TRAIN DRAG	LBS
TDN	TRAIN DRAG AT NEXT LOWER SPEED LIMIT	LBS
TDYN	PROPULSION BRAKING EFFORT	LBS
TDYNN	PROPULSION BRAKING EFFORT AT NEXT LOWER SPEED	LBS
TEMAX	MAXIMUM TRACTIVE EFFORT	LBS
TEST	LOCATION OF INTERMEDIATE STOP (START BASE)	
TG	GRADE DRAG	LBS
THETA	TIME AFTER START	SEC
THP	TRACTION HORSEPOWER AT WHEELS	HP
TIM	OUTPUT CLOCK TIME	SEC
TIMX	INTEGRATION INTERVAL FOR WAYSIDE ENERGY	SEC
TIMX1	NORMAL OUTPUT INTERVAL	SEC
TN	NET ACCELERATING TRACTIVE EFFORT	LBS
TNI	JERK LIMITED TRACTIVE EFFORT INCREMENT	LBS
TONC	CAR WEIGHT	TONS
TONL	LOCOMOTIVE WEIGHT	TONS
TONMI	TON MILES (TOTAL LOCO+CARS)	TON-MI
TP	TRACTIVE EFFORT REQUIRED	LBS
TPP	TRACTIVE EFFORT	MIL-LBS
TPT	TRACTIVE EFFORT AVAILABLE	LBS
TRC	CAR-DRAG	LBS

TRCN	CAR DRAG AT NEXT LOWER SPEED LIMIT	LBS
TRL	LOCOMOTIVE DRAG	LBS
TRLN	LOCOMOTIVE DRAG AT NEXT LOWER SPEED LIMIT	LBS
TT	TRAILING TONS	TONS
TXX	OUTPUT INTERVAL	
V	TRAIN SPEED	MPH
VBAR	AVERAGE SPEED	MPH
VC	SPEED LIMIT	MPH
VCN	SPEED LIMIT - NEXT LOWER	MPH
VMVA	APPARENT POWER INPUT TO TRAIN	MVA
VMW	REAL POWER INPUT TO TRAIN	MW
VMW1	MAXIMUM REGENERATED POWER FROM VEHICLE DURING LAST REGENERATIVE PERIOD	
VP	VEHICLE REAL POWER INPUT	KW
VP1	OLD VEHICLE REAL POWER INPUT	KW
VXB	TRANSITION SPEED-BRAKING	MPH
VXT	TRANSITION SPEED-MOTORING	MPH
V1	OLD SPEED	MPH
WT	TRAIN WEIGHT	LBS
WTC	CAR WEIGHT	LBS
WTL	LOCOMOTIVE WEIGHT	LBS
XT	SPEED REDUCTION DISTANCE	MI

APPENDIX G

REPORT OF NEW TECHNOLOGY

No "subject inventions" resulted from the Wayside Energy Storage Study. However, an improvement over present equipment was developed in concept which could have a significant impact on U. S. railroad operations. This is the dual-mode locomotive which is described on pp 20-25 of Volume 1 and pp 2-39 through 2-53 of Volume 2 of this report. This locomotive is a modification of a standard diesel-electric locomotive to which a pantograph, transformer, converter, and smoothing inductor are added. The resulting dual-mode locomotive can then operate either as a conventional diesel-electric locomotive or as an electric locomotive powered from an overhead catenary. Such locomotives can then provide the benefits of both diesel-electric and electric locomotives without the drawbacks of either. For example, the dual-mode locomotive can operate on electrified lines with the energy efficiency, long life, and reduced maintenance of an electric locomotive but when required, can operate with full performance on non-electrified lines as a diesel-electric locomotive. The application of dual-mode locomotives to railroad routes with local electrification on ruling grades can result in annual returns on investment up to 27% based on reductions in required locomotive consist, energy savings, and reduced maintenance.

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