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COST-EFFECTIVENESS REVIEW OF RAILROAD ELECTRIFICATION

Pan-Technology Consulting Corporation, Inc.
1747 Pennsylvania Ave., N.W.
Washington, D.C. 20036

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16. Abstract

A comparison was made between the costs of electric and diesel-electric motive power to haul traffic projected for the 1975-2005 time period over a hypothetical network of high density mainline routes carrying about 50 percent of the 1975 traffic. The routes were selected from the Federal Railroad Administration Base Rail Network. Input data on prices, operating conditions, and route profiles represented averages for four regions of the United States rather than the specific conditions of actual routes. The cost estimates focused primarily on social resource costs from the perspective of national economic efficiency. Sensitivity tests were performed to determine the impact of a variety of assumptions and data values on the comparative costs of the two systems.

It was concluded that electrification offers 9 percent savings in discounted costs for about 30 percent of the routes examined covering about 43 percent of the route miles in the hypothetical network.

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EXECUTIVE SUMMARY

In June 1971 the Office of High Speed Ground Transportation (now the Office of Research, Development and Demonstration) contracted with Pan-Technology Consulting Corp., Inc. to work with the DOT Rail Electrification Task Force in conducting a review of available data on the cost effectiveness of railroad electrification on a national scale in the United States.

The purpose of the study was to incorporate diverse reports, studies and sets of data into a standard cost-effectiveness format. The analysis assessed the comparative economics of diesel-electric and electric systems over the 1975-2005 period.

The assessment was made primarily from the viewpoint of national public policy, but the private sector point of view was also addressed. Electrification was evaluated from the public sector perspective by comparing costs in terms of total national resources. The evaluation from the private sector viewpoint was based on costs as they would be incurred by the railroad industry.

Cost comparisons were made between diesel-electric and electric systems hauling projected traffic for the 1975-2005 time period over a skeleton network comprising hypothetical routes carrying the highest density traffic in the U.S. Regional averages were used to specify profiles and other conditions. All significant costs that would differentiate between the two systems were considered.

It was found that electrification would result in cost savings from both the public and industry perspectives. Of the 14,290 miles of high density routes in the hypothetical skeleton network, 6,171 miles were found to be economical to electrify. The resulting cost savings was estimated to be about $360 million in total costs discounted to present value.

Sensitivity tests were performed to determine the impact of various assumptions and conditions on the comparative costs of electric and diesel-electric operation. The results of these tests indicate that individual routes may differ substantially from the conclusions drawn using averages for large regions. In particular, electrification is made more economical by use of slug locomotive units in drag service, by the presence of steep grades, by the availability of inexpensive catenary structures, by relatively inexpensive electric power, and by decreases in the utilization of locomotive time and power.

The network referred to herein as the "FRA Base Rail Network" is composed of 135,000 of the existing 207,000 rail route-miles, including 78,500 of the 81,900 signalled route-miles. This network was defined to contain no more lines than are necessary to permit a reasonably accurate description of the important rail arterials. Thus, if three actual rail lines serve points A and B, the network contains only one hypothetical line. The network analytically represents a unified national rail system, rather than the actual competing and parallel lines. The primary function of the network is to permit the study of major freight traffic flows over important mainline links in the national rail system.

1. BACKGROUND

The Department of Transportation (DOT) and, more specifically, the Office of High Speed Ground Transportation (OHSGT)* in the Federal Railroad Administration (FRA) have become increasingly concerned about the status of railroads in the United States. One aspect of the on-going discussions has been the question of electrification of U. S. railroads.

Railroad electrification has been considered by the federal government, by railroad companies and their suppliers periodically for many years. Many studies have been produced considering various aspects of electric motive power and using various assumptions about the technological performance, costs, and investment criteria. None was comprehensive or conclusive.

The passage of time has brought about several changes which bring decision-makers once again to the consideration of railroad electrification. The technology of electric motive power has continued to improve as a result of general technological advance and of specific efforts in other countries with electrified railroads. In addition, the trends in competing modes of transportation show continued problems of congestion. New knowledge and sensitivity to the depletion of natural and environmental resources, particularly fuels and air quality, also motivate a further evaluation of electric motive power as an alternative to diesel-electric. These developments heightened the need to review the assumptions, data, and results of past studies and to evaluate the current possibilities in a comprehensive and systematic fashion.

In order to explore this subject more fully and with knowledgeable individuals of the nation's railroads and associated industries, an Electrification Conference was called for April 20, 1971. At this meeting various issues pertaining to the public and private aspects of rail electrification were discussed. Following that conference, a one-page in-house status report was prepared by OHSGT for the Office of the Secretary recommending the establishment of a more formal task force with a supporting, independent consulting team. The Task Force on Railroad Electrification was subsequently formed and first met on September 14, 1971, under the chairmanship of William E. Loftus, Chief of the Policy Development Division of the Federal Railroad Administration (FRA). Members of the Task Force represented the Department of Transportation, the Association of American Railroads, individual railroad companies, manufacturers of railroad equipment and electric power companies.

* Now the Office of Research, Development and Demonstration

Two subcommittees were formed: the Subcommittee on Issues, chaired by Dr. W. J. Harris of the Association of American Railroads, and the Subcommittee on Standards, chaired by Mr. B. A. Ross of the American Electric Power Service Corporation.

Pan-Technology Consulting Corporation (Pan-Tek), an independent consulting company, was contracted by OHSGT to support the Task Force and to review the cost effectiveness of rail electrification. The Task Force was instrumental in reviewing the study team's approach, methodology and input data. Individual members supplied cost figures and technical parameters in addition to those available from the general literature. The Task Force subcommittees reviewed all technical parameters and cost data and recommended specific values after appropriate discussion.

In addition, Ad Hoc Committee on Railroad Electrification was formed by the Association of American Railroads with Dr. W. J. Harris as Chairman. This committee also contributed valuable assistance to the evaluation. It reviewed the study approach and data inputs and was able to collect information usually considered proprietary by individual railroads, making it available in a summary form for use in the evaluation.

2. STUDY OBJECTIVES

The primary objective of the study was to provide information which would enable national policy makers in the Department of Transportation to more thoroughly evaluate the cost-effectiveness of electric motive power for railroad operation in the coming decades. The study sought to up-date and integrate the existing, but highly varied and disparate, information on electric motive power, comparing the investment in electrification with continued use of diesel-electric motive power. The intent was to conduct a comprehensive, cost-effectiveness comparison of the two systems in which the many factors considered separately by past studies could be incorporated into a single analysis.

In its orientation toward public policy, the study sought to determine the economic value of rail electrification in terms of the national resources that might be saved. In comparing electric and diesel-electric systems, the following questions were to be addressed:

a. Is electrification in the period 1975-2005 attractive from a national cost point of view?

b. Where and under what conditions is electrification appropriate?

c. How much electrification is practical?

d. What is the effect of traffic growth over the period studied?

A secondary objective of the study was to provide information on the economic attractiveness of electrification from the perspective of the railroad industry. Private firms face a different set of costs from that of the nation as a whole. Their decisions are based on consideration of money flows resulting from interest charges, taxes and inflation in addition to the real costs of resources used. The study sought to evaluate the electric and diesel-electric systems from the railroad industry perspective to highlight possible problems in implementing electrification.

3. STUDY LIMITS

The study incorporates a review of existing publicly-available data. Because of the limitations of these data, it was not possible to analyze in this study the important deviations from national or regional averages that characterize the equipment, road, operations, management and financial situation on individual railroad lines. It will be apparent, particularly in the costing section, that in many instances, judgment had to be substituted for hard data at this time. For this reason, the calculations were programmed for the computer so that as better data are developed, they can be readily integrated into the analysis. Sensitivity tests have been made to show the potential effects of changing the costs of catenary, maintenance and other major items.

The study is significantly limited on the policy side in another direction. Even if electrification appears attractive as a cost saving investment, there are other major questions that must be asked: Do the railroads have even better alternatives for their investment funds? Does the nation have better alternatives for investing public moneys? Both questions should be answered before an investment decision is finally taken, but were not addressed by this study.

In order to obtain appropriate data for this analysis, it was necessary to have access to proprietary data from individual railroads, equipment manufacturers and electric utilities.

In particular, the study rests in considerable part on traffic projections by the Federal Railroad Administration (215)*. In order to develop these projections, proprietary data were obtained by the Federal Railroad Administration from individual railroads. While a maximum effort has been made to present all of the data sources and techniques of analysis used in the study, the report is limited by the need to preserve the proprietary nature of this and other data. Traffic projections and price data connected with specific routes and firms are not included in this presentation.

*Citations are noted by numbers in parentheses which refer directly to the corresponding numbered entry in the Bibliography.

4. APPROACH

This section describes the general approach taken in conducting the study. First the methodological framework for the system comparison is presented. Next, the concepts for the electric and diesel-electric rail systems are described. This is followed by discussion of the operating scenario, the sequence of events in operating the two systems used for analysis. The specific computational techniques and input data are discussed in subsequent sections.

4.1 SYSTEM COMPARISON

4.1.1 Standard Cost-Effectiveness Format. The literature on railway electrification is extensive. Over two hundred citations are to be found in the Bibliography attached to this report alone. However, the various authors have often addressed quite different aspects of the electrification problem. Factual support of the studies is uneven. Frequently, authors will deal with two or just a few variables and then draw conclusions relative to the advantages of an electric or a diesel-electric system, as the case may be. Sometimes the systems are compared but inputs are not put on a comparable basis. The problem of horsepower ratings for diesel-electric and pure electric locomotives is a case in point. No consistent evaluation technique has been employed by the various analysts which makes direct comparisons or integration of their work difficult.

Within the last ten or fifteen years, cost-effectiveness techniques have been extensively used to analyze and compare public programs. These techniques encourage a consistent, and thus fair, costing and effectiveness analysis of alternatives. Cost-effectiveness analysis focuses on the costs of producing physical outputs without addressing the problem of assigning dollar values to the outputs. Effort is made to consider all the significant elements and relationships that arise in the production systems being analyzed. Diesel-electric and electric motive power are alternatives that can be readily compared in this way.

4.1.2 Fixed Effectiveness. In cost-effectiveness analysis, either costs are fixed and differences in the effectiveness of the alternatives are measured, or system effectiveness can be fixed and differences in the costs of competing systems are compared.

In the present study, it was convenient to fix effectiveness and allow costs to vary. This was done by establishing the annual tonnage of traffic that would be hauled and estimating the costs of electric and diesel-electric railroad systems required to move the traffic. Effectiveness in moving this traffic was also fixed by specifying the type of service provided (manifest or drag) and the distance and profile characteristics of the routes over which the traffic was to be hauled. Thus the fixed level of effectiveness, the transportation output, is closely related to the characteristics of the railroad network, which will be described as part of the overall rail transportation system in Section 4.2. It is convenient to make discussion of the source of traffic projections a part of that presentation. At this point, all that need be said is that traffic projections were used to fix the effectiveness required for each route in a national skeleton rail network and that costs were estimated for electric and diesel electric systems to achieve the required output for each route.

4.1.3 Significant Differentiating Costs. The cost comparison was made comprehensive by including costs for all significant cost elements in the two systems that would differentiate between them. Costs were not estimated for elements that were an insignificant part of the costs of the total system. Nor were costs estimated for elements in which there would be no difference between electric and diesel-electric systems.

In order to locate the costs to be considered in the analysis, each of the Interstate Commerce Commission's accounts was reviewed. As a rule, ICC cost accounts were excluded from consideration if they were less than one percent of a major category (i.e., Investment Costs, Maintenance of Roadway and Structures, Maintenance of Equipment, etc.). The Task Force subsequently recommended dropping some categories which were judged to be relatively insignificant and on which reliable data could not be obtained. In addition, each account was analyzed to determine if any difference would arise between the two systems and only those that would differentiate between the two were estimated.

4.1.4 Alternative Evaluation Measures. This study evaluates the comparative economics of the two systems in terms of two different but related measures in order to reflect the difference between public and private viewpoints. The measure customarily used in evaluating the costs of public programs is the social opportunity cost of the national resources used. The economy has a limited supply of labor, capital and natural resources. The cost of using these national resources is the value of the opportunities for other uses that are given up at the time the resources are committed to use. One program is superior to another if it achieves the same results using fewer or less valuable resources, that is, if it represents savings. Federal departments and agencies have used this measure in order to estimate the effects of their actions on the national economy as a whole.

On the other hand, in consideration of electrification by private industry, concern would focus on money costs or cash flow including the effects of tax payments, interest charges, and inflation costs. Individual companies are less concerned, for example, with the fact that resources must be marshalled "all at once" to put a new stock of electric locomotives on the tracks in 1975. Industry is concerned with the annualized monetary outlays they must make over the period of the loan used to finance this stock of locomotives. Industry is also concerned with the payment of taxes although most of these payments represent transfers rather than the use of resources.

The two measures used for evaluating the costs of electric and diesel-electric systems in this study are the Social Resource Costs and the Private Money Costs. The Social Resource Costs are the sum of the dollar values of national resources taken at the time at which they are removed from general availability for other uses and reserved for use in the alternatives to be evaluated. By Private Money Costs are meant the sum of the dollar values of payments made by railroad companies taken at the time at which payments are actually made.

The timing of resource use is often as important as the value and quantity used. For this reason, costs that are spread out over time are usually converted to "present value" by a discounting technique. Discounting accounts for the phenomena that a dollar (or the equivalent in resources) can be invested today at some rate of return. Thus a dollar cost (or resource requirement) not expended until next year is discounted to $.94 in present value terms because the resources could earn 6 percent in the intervening year. Similarly, a $1.00 benefit not realized until next year is discounted to $.94 today if the discount rate is 6 percent.

A discount rate of 10 percent is recommended for discounting federal programs. Thus the stream of costs arising from moving the projected freight volume over the study period was discounted to 1975 present value. The two discounted values can be compared to establish the economic advantage of the electric or diesel-electric system.

4.2 SYSTEM CONCEPT

In developing a cost-effectiveness comparison, it is useful to specify the characteristics of the physical system conceptualized for the analysis. The basic element of the system considered in this study was a skeleton rail network comprised of high density, mainline routes selected from the FRA Base Rail Network. This network was used because it was associated with a set of national traffic projections. The profile characteristics for these routes were specified using regional averages. For the capital equipment portions of the system, especially rolling stock, the specifications developed were point designs based on the judgment of suppliers and railroad industry representatives on the Task Force. These system elements are discussed in more detail below.

4.2.1 Mainline Routes. The network used to make the cost-effectiveness comparison, a hypothetical skeleton network based on the U. S. rail system, relates entirely to current mainline operations. It would be inappropriate to consider the electrification of switching yards and branch lines until the economic value of electrification on the mainlines has been determined. While it is true that the network employed herein is in fact hypothetical, it is nonetheless sufficient for an initial national evaluation of the economies of electrification under conditions typical of U. S. mainline railroad operations. The nationwide scale of the skeleton network facilitated analysis of the national value of electrification, a consideration not possible in case studies of individual routes.

4.2.2 Traffic Projections and the Selection of High Density Routes. The routes that comprise the skeleton network were selected from the FRA Base Rail Network using the associated traffic projections.

The Office of Systems Analysis and Information of the Office of the Secretary of Transportation has for the past few years been developing models for projecting transportation demand on the basis of economic growth and for simulating intercity freight movements. The FRA has actively participated in both these efforts which produced the FRA Base Rail Network and projections of rail traffic for 1980 utilized in this study (215).

The FRA traffic projections from 1965 to 1980 were based on projections of GNP, GNP breakdown by sector, and the Input-Output Table of Inter-industry coefficients. The results of these projections are published in Transportation Projections 1970 and 1980 (213). These traffic projections link freight shipments in the aggregate to economic output and growth. It remains to the network model to assign the aggregate freight shipments, first to interzonal shipments, and then to specific routes along a transportation network.

The DOT interzonal shipment model uses 506 zones comprised of SMSA's and counties. The FRA Base Rail Network includes 120,000 miles of mainline links. Interzonal shipments for 1965 were established using the 1 percent waybill sample and similar data for other modes. These interzonal shipments were assigned first to modes, and then to routes in the rail network by the minimum path method, taking into account distances, time (including mode congestion), and cost. The interzonal traffic projections were expanded from 1965 to 1980 using a growth factor procedure, the Fratar Model, (219) to expand relative interzonal flows in proportion to population growth and employment. Projected absolute interzonal shipments were made consistent with the aggregate traffic projections from the input-output model. The projected interzonal shipments were then assigned to the network to give traffic projections for each line for 1980.

Both of these techniques are in the development stage. Yet despite the tentative quality of the resulting projections, they are the best available systematic estimates of national freight shipments. They also have the advantage of being based on consideration of the way in which shippers choose between transportation modes. For these reasons they represent the best projections for use in a national policy-oriented review of electrification of the type undertaken in this study.

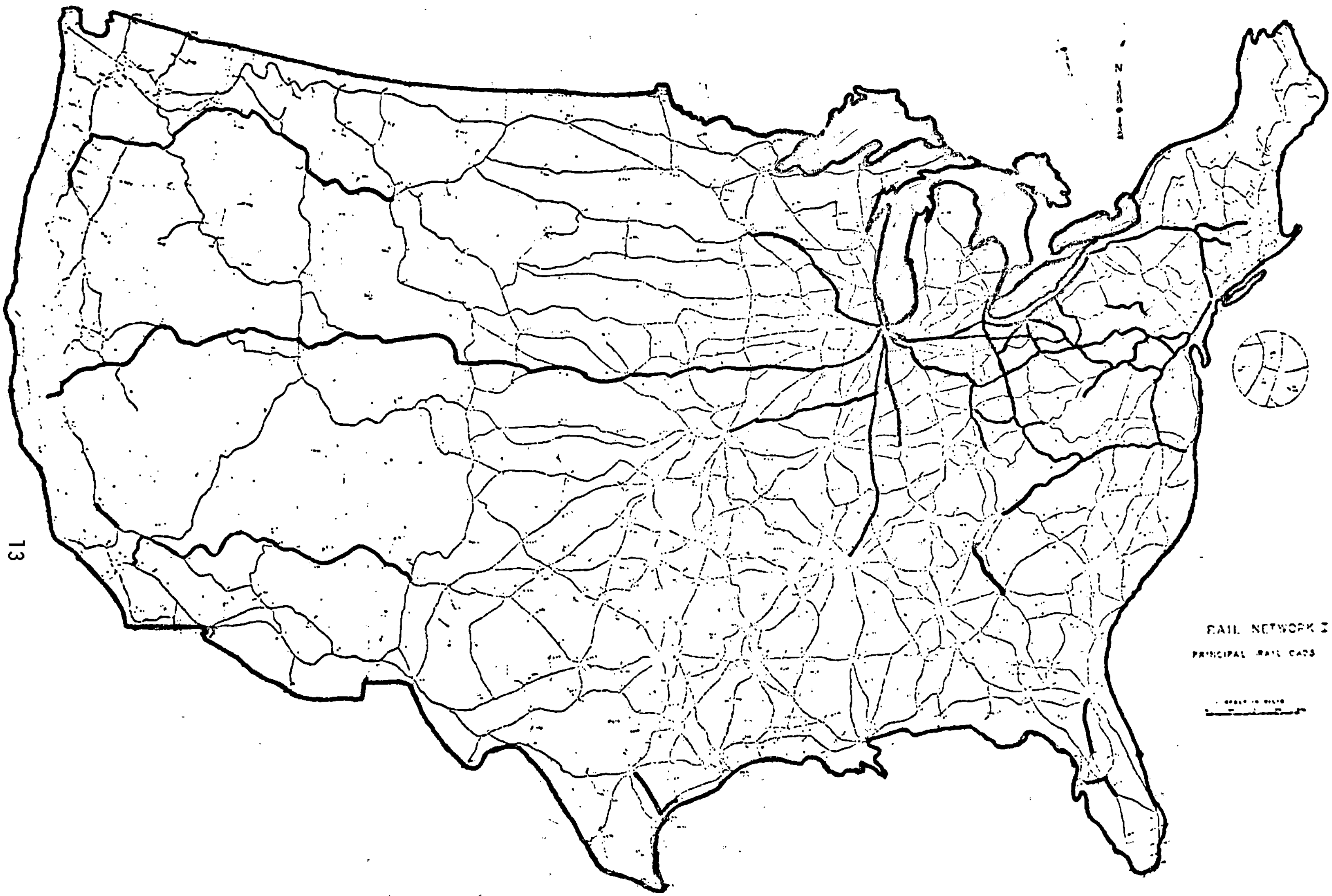
The skeleton network developed for this study from the FRA Base Rail Network was intended to represent those parts of the U. S. rail system on which electrification would be most likely to be feasible. This was done to determine the potential extent of electrification in the U. S. To develop the skeleton network, links were taken from the FRA Base Rail Network that were highest in traffic density and could be connected into routes of approximately 100 miles length or more between major cities or rail centers. The links included in these routes collectively carry about 50 percent of the national freight traffic projected for 1980. Tonnages for passenger service based on Amtrak projections were added subsequently but were not substantial enough to warrant changes in the skeleton network.

The routes of the skeleton network are shown in bold lines in Exhibit 4-1. Tonnages used for each route were the averages of link tonnages weighted by link lengths for 1965 and 1980. The routes thus produce the same total ton-miles of traffic as the sum of the links of which they are composed. The routes, their lengths, and tonnages are shown in Exhibit 4-2.

4.2.3 Regional Average Profiles. As noted above, the orientation of the study is towards providing initial and basic information suitable for developing a national policy toward rail electrification. There are, however, significant regional operating differences within the country, which even an analysis at the national level must take into consideration. Although aggregated regional data on railroad profiles is not readily available, it was possible to obtain the important coefficients needed to represent the significant regional differences among the East Coast, South, Mid West and Far West (Exhibit 4-3). In particular, differences in regional average curvatures and grades as well as the principal differences in operating limitations were included in the analysis. Data on ruling grades were also adapted to the regional data because of the importance of ruling grades in operations.

The coefficients expressing the train resistance due to grade and curvature were constructed for the four study regions by using data developed by Stanford Research Institute (199) for eight regions. Ruling grade data were derived from profiles from individual railroads presented before the Interstate Commerce Commission (135). These data pertained to the late 1920's and judgment was used to up-grade this information for modest reductions in grades obtained since that time. A summary of these coefficients is shown in Exhibit 4-4. Each of the routes in the skeleton network was assigned and average resistance due to grade and curvature according to the region it passed through and ruling grade according to the type of terrain it covered.

No other characteristics of routes are considered. The number and ownership of actual lines, their condition, maintenance programs, etc., are not included in this analysis. However, in planning any demonstration project, or any partial or total implementation of the electric system, these and other operating considerations must be addressed.



HYPOTHETICAL SKELETON NETWORK
HIGH DENSITY ROUTES
(ACCOUNTING FOR 50 PERCENT OF 1975 TRAFFIC)

Exhibit 4 1

Exhibit 4-2

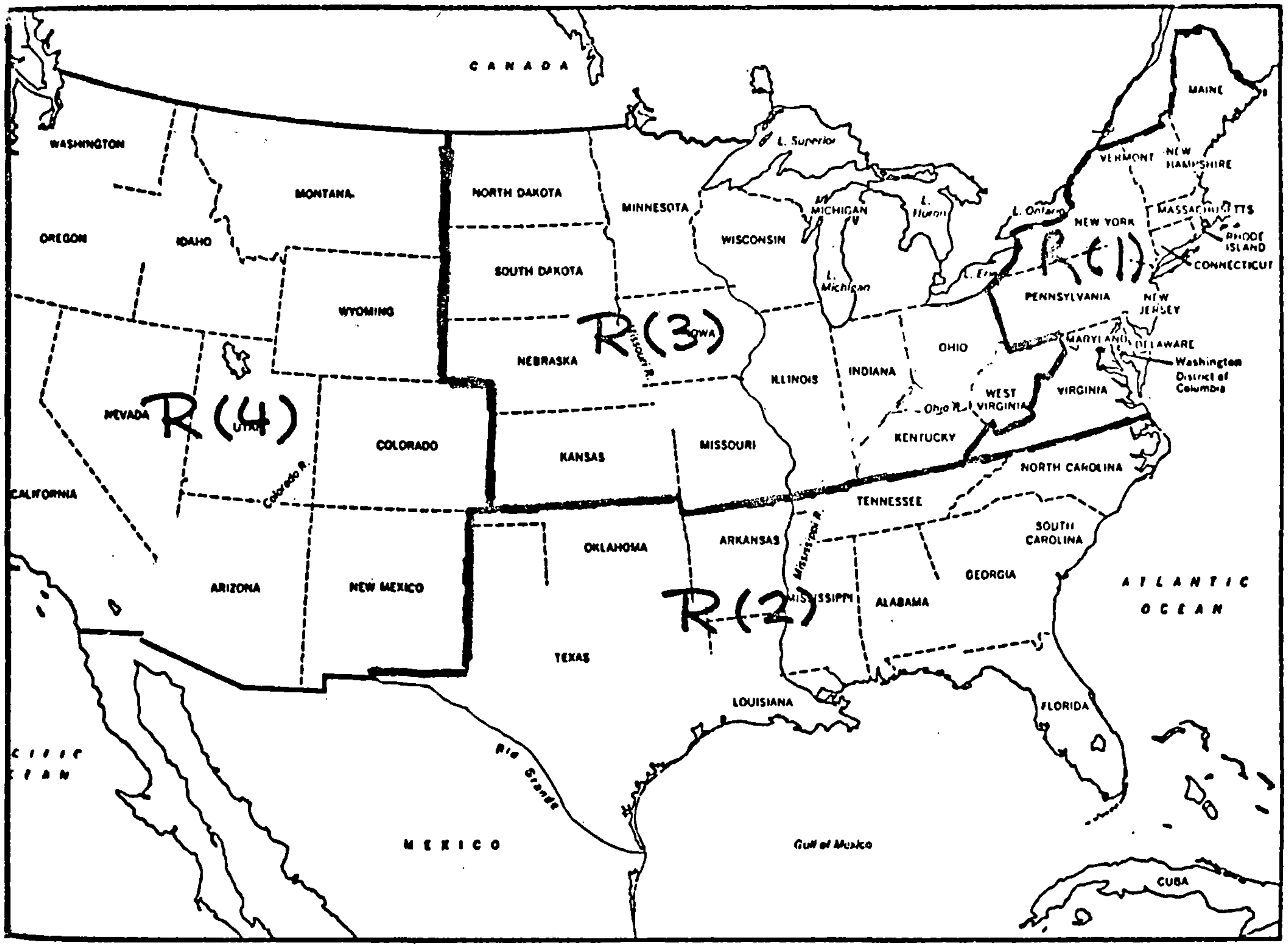
PROJECTED TRAFFIC VOLUMES
1975-2005

Region and Route [1]	Annual Gross Tons (in millions)		Annual Growth
East (1)	1975	2005	
1	131.8	265.6	2.25%
2	129.8	227.0	1.88
6	79.8	158.8	2.32
8	77.3	146.6	2.15
9	76.8	125.8	1.66
12	68.0	103.8	1.42
18	62.6	157.2	3.12
19	62.4	80.6	.86
25	54.5	114.4	2.50
35	48.0	57.7	.61
39	46.3	94.5	2.41
43	43.8	81.8	2.10
45	43.3	97.3	2.74
48	42.5	106.7	3.11
51	41.9	73.6	1.89
55	40.2	72.3	1.98
56	38.7	78.6	2.41
South (2)			
3	107.2	228.1	2.55
10	73.5	268.0	4.41
24	54.7	103.1	2.13
30	51.6	126.9	3.05
47	42.6	116.9	3.43
52	41.5	96.8	2.87
53	41.4	149.8	4.38
57	38.6	78.7	2.41
59	37.7	125.8	4.10

[1] Route designated by national rank order in traffic for 1975

Exhibit 4-2 (Cont.)

Region and Route	Annual Gross Tons (In millions)		Annual Growth
Mid-West (3)	1975	2005	
4	101.2	205.1	2.38%
5	82.0	184.4	2.74
11	70.1	134.5	2.19
13	67.7	140.8	2.47
14	65.0	139.6	2.58
15	65.0	139.6	2.58
16	64.5	135.3	2.50
17	62.7	134.5	2.58
20	62.3	111.6	1.97
21	61.6	147.4	2.95
22	55.8	111.1	2.33
23	55.2	107.1	2.23
27	54.0	92.4	1.81
29	52.2	109.3	2.49
31	51.2	83.9	1.66
34	48.6	81.8	1.75
36	48.0	126.8	3.29
38	47.7	99.1	2.47
40	45.9	98.3	2.57
41	45.4	94.0	2.46
44	43.4	106.6	3.04
46	42.7	92.8	2.62
49	42.4	97.1	2.80
50	41.9	92.5	2.68
54	40.2	72.3	1.98
58	38.6	78.7	2.41
West (4)			
7	78.8	179.0	2.77
26	54.4	136.9	3.13
28	52.6	136.9	3.24
32	49.4	132.0	3.33
33	48.7	107.9	2.69
37	48.0	95.4	2.31
42	43.9	111.6	3.16



United States of America

Exhibit 4-3 Regional Subdivisions

EXHIBIT 4-4

SUMMARY OF REGIONAL PROFILE COEFFICIENTS

Region	Average Resistance Due to Grades and Curves (pounds per ton)
East (1)	3.64
South (2)	3.81
Mid West (3)	4.29
West (4)	4.29

Type of Terrain	Typical Ruling Grade (percent)
Eastern Mountain	1.60
Midwestern & Flat	1.00
Western Mountain	1.75

4.2.4 Point Design. Because the orientation of this study is basically economics, only a modest amount of engineering analysis was undertaken. The study defined each of the major technical components of the two systems, such as locomotives and catenaries using a single set of specifications. For example, only one type of locomotive was employed (except for sensitivity tests) in the analysis of each motive power system. Each locomotive model was chosen as the best available in 1975, the first operational year of the 1975-2005 study period. These locomotives can be considered "nearly optimal" although no optimizing analysis was undertaken in the present study. While it is realized that in actual railroad operations, locomotives of various horsepower are used, under the limitations of this study the use of a single, nearly optimal point design constitutes a reasonable initial base from which to compare systems.

It should be noted here that the Task Force and, in particular, the Subcommittee on Standards, were instrumental in developing equipment specifications. Thus the specifications represent the composite judgment of their membership from the railroad industry, locomotive and signal equipment manufacturers, utility companies and the Department of Transportation.

4.2.5 Rolling Stock

4.2.5.1 Locomotives. The characteristics of the diesel-electric and electric locomotives used in the analysis are given in Exhibit 4-5. They were of substantially the same weight and have the same number of axles. The electric is almost twice as powerful in terms of rail horsepower. A comparison of diesel-electric and of electric locomotives solely on a horsepower basis is misleading, however. Other parameters, such as adhesion and overload capacity, must be included in the analysis. The purpose of the cost-effectiveness analysis is to avoid over-simplistic comparisons and to evaluate a total system in which all of the significant locomotive characteristics are realistically analyzed. The locomotive specifications selected represent a consensus of the Task Force as to the locomotive design available from U. S. locomotive manufacturers in 1975.

The new locomotives are essentially state-of-the art engines as of 1975. There is one exception to this statement in that certain European locomotive designs might be incorporated to yield higher adhesion ratios than present prototypes

Exhibit 4-5

Locomotive Characteristics

	Electric	Diesel-Electric
Weight	180 tons	180 tons
Number of Axles	6	6
Rail Horsepower	5300	2800
Diesel Output Horsepower	6000 equivalent	3300
Adhesion Factor	.25	.18
Overload Capacity (one hour rating)	10%	--

of these locomotives would appear to deliver. This study assumes high adhesion ratios, thus indicating an acceptance of some European technology by U. S. manufacturers. The adhesion coefficients specified for electric and diesel-electric do not represent absolute values characteristic of the two classes. They represent the consensus of the Task Force that there would most likely be an advantage favoring the electric locomotive. The same may be said for overload capacity. The adhesion ratio, like many other variables, is incorporated into a sensitivity analysis to test its importance in the final results of the study.

4.2.5.2 Freight Cars. The freight cars used in both systems were of current designs, lifetime and costs. The weight of freight cars is important in calculating locomotive requirements and fuel costs in particular. A weighted average value was calculated from data obtained from ICC's Transport Statistics (130,131).

4.2.6 Fixed Assets. In addition to rolling stock, the following principal fixed assets are included in the systems for comparison:

Electric	Diesel-Electric
Catenary	Not applicable
Substations	" "
Electric Distribution Lines	" "
Signals	" "
Communications	" "
Tunnel & Subway Clearance	" "
Bridge, Trestle, Culvert Clearance	" "
Shops and Engine Houses	Shops and Engine Houses
Shop Equipment	Shop Equipment

These items represent the fixed capital of the systems considered. It was found after considering railroad system components that all other items not included, either (1) do not differ significantly as between the two systems, or (2) are not of sufficient size to warrant inclusion in the current comparison study.

4.2.6.1 Catenary. Catenaries are the major fixed component of the electrical system. There are numerous designs in use - single or double track cantilevered supports, portal structures, steel, concrete or wood supports - depending on terrains, number of tracks, service and speeds. Because this study was not an engineering project, technical specifications were not developed for each individual route. Instead, a single design for a 50 KV catenary was assumed for all routes. However, it must be recognized that it may not be possible to universally adopt a 50 KV system. Furthermore, it might be more economical to operate certain regions or areas on 25 KV and even less, as for instance, in heavily urbanized areas. Lower voltages may be required in tunnels or underpasses, depending on particular circumstances. As a consequence a larger number of substations would be required.

For the implementation of any project, this question requires detailed engineering and economic study. For the objectives of this study, an average design and cost based on a 50 KV system was adopted. The specifications adopted by the Task Force for this study are representative of very simple and austere catenary suspensions and single wood or concrete support poles.

4.2.6.2 Substations. Electric substations and switching stations for distributing and controlling the power to the catenaries were also specified on the basis of a 50 KV system.

4.2.6.3 Electrical Distribution Lines. Electrical distribution lines are feeder lines to the substations from high tension overland transmission lines. Lacking sufficient precedent, it is not clear whether supply lines should be thought of as part of the railroad system or the utility system. For present purposes they constitute an incremental cost that is costed as part of the electric system.

4.2.6.4 Signals. The literature on electrification frequently associates electric operations with technically advanced signalling systems, such as microwave systems, The present system does not envision ultra-high speeds for freight traffic and a review of existing installations showed that no entirely new signalling systems will be required. Most high density lines already are equipped with a CTC system capable of handling current and projected traffic volumes.

Most existing signal systems are incompatible with the use of high voltage AC electric power. For this reason, modifications of various kinds are required to make the signal system compatible with electrified operation (195). For this study no specific designs were specified. The assumed requirement was the achievement of compatibility without upgrading the signal system to handle additional traffic.

4.2.6.5 Communications. The energized catenary and the passing pantograph and electric locomotive interfere inductively with adjacent railroad and other communication lines. This necessitates an effective shielding of the communication lines, such as sheathing and grounding. Alternatively, different communication systems may be considered. But here, as in the case of signals, it was not necessary to consider the implementation of an entirely new system. Only those modifications necessary to reduce interference from electrified operations were required of the system.

4.2.6.6 Tunnels and Subways. Tunnel clearances ranging from a maximum of 25 inches to a minimum of 16 inches between loading guage and tunnel roof are now being employed in European 25 KV operations (55). For 50 KV systems, the required clearances are larger. Since most tunnels have been constructed to accommodate steam or diesel-electric operations, existing clearances are too small in many places to accommodate high tension catenary wire. As a result, tunnel alterations and/or catenary system modifications must be considered.

There are several ways by which this problem can be solved. Two suggested structural solutions are lowering the track bed or raising the tunnel roof. Non-structural solutions include techniques of lowering the catenary voltage in the tunnel, thereby requiring an additional substation and two switching stations.

Apart from difficulties in accurately costing these changes, it was not possible within the limits of this study to obtain adequate information on the frequency, location and clearances of tunnels and subways. For this reason, rather than specifying the most economical solutions for each route, it was necessary to assume an average distribution of tunnels over the network and, as will be detailed in Section 5.3.4, to charge the electric system with an average cost for average expected alterations.

4.2.6.7 Bridges, Trestles and Culverts. These structures present the same design and analysis problems as tunnels and subways. The specification for the study system was similarly an average frequency of occurrence and an average cost of modifications.

4.2.6.8 Shops and Engine Houses. Maintenance requirements for electric locomotives are different from those of diesel-electrics because the electric locomotive has no mechanical prime mover to maintain. Based on European statistics, it is estimated that the Maintenance requirement for electric locomotives, in terms of dollars, is about one-third to one-half that of the diesel-electric. The maintenance facilities required are smaller because of the absence of the complex moving parts of the diesel engine. Therefore, fewer shops and engine houses are required for the electric system than for the diesel system.

4.2.6.9 Excluded Assets. Although there are considerably more investment items in railroad systems as included in the ICC accounts, it was found that, under the criteria of the study, the items discussed above represent the significant differentiating system components. In a more extended effort it would be possible to include more items, but the increment of information gained would not greatly alter the results obtained. Given the accuracy of cost data available, and upon recommendation of the Task Force, it was decided not to burden the analysis with items of relatively little cost impact.

4.3 OPERATING SCENARIO

The purpose of the operating scenario is to describe the general conditions and the sequence of events under which the two locomotive systems are assumed to operate for analysis of costs. The operating scenario must of necessity be a compromise between simplifying abstractions and detailed realism. Neither extreme is desirable. The principal factor in shaping a compromise position is to develop a scenario that incorporates as realistically as possible the major characteristics of the two systems.

This section will be concerned with the way in which the two systems might be expected to be set up and operated. The discussion will cover the time frame, initial and final conditions, types of freight and passenger service, track capacity and usage, scheduling, maintenance, and conversion to electrified operation.

4.3.1 Time Frame. A railroad system operates continuously. In studying the cost-effectiveness of two alternative systems, it must be decided what period the analysis should span. Obviously, the period considered should be of reasonable technological and economic predictability. For this reason, cost-effectiveness analysis usually covers life span of the principal system component under investigation. In this case, the determining component is the electric locomotive. Major technological advances and changes in engine design and construction could occur over the lifetime of the initially purchased locomotive engines, but it is not likely that these locomotives would be retired prematurely unless their replacement by other types of engines constituted a cost savings.

The "economic lifetime" of the electric engines that have been in use is approximately thirty years. Analyses of U. S. data, European and South African statistics indicate a sharp rise in maintenance costs at the end of a thirty-year service life, making replacement at that time likely. Of course, there are much older units in service, particularly in the United States. While this demonstrates a longer mechanical lifetime, it may also be attributed to economic factors associated with the specific railroad operations having older equipment. The thirty-year lifetime was used to set the time frame of 1975 to 2005 for the study.

4.3.2 Initial Conditions, 1975. The operating scenario of this study assumed that equipment existing in 1975 will continue to be utilized. In particular, the diesel-electric locomotive inventory on hand in 1975 was credited as an initial asset to both systems. Its age distribution and motive power characteristics were also taken into account. As units were retired during the study period, they were replaced by purchase of new diesel-electric locomotives.

Other assets existing in 1975 were also treated as initial assets for both systems. They included freight cars, tracks, and diesel-electric shops and shop equipment.

4.3.3 Final Conditions, 2005. Under most circumstances, the operation of capital equipment over a period of time does not leave the value of the capital at zero but at some residual value. It has been found in making cost-effectiveness comparison that some consideration must be given to the fact that different systems have a greater residual value at the end of the study period then others.

Both systems were assumed to purchase locomotives during the course of the study period that would not have lost their value by 2005. Residual values of assets attributed to the two systems are considered a credit and used to reduce 30 year system costs accordingly. In private money cost estimation, the residual value was adjusted for the amounts of loans outstanding on investments.

4.3.4 Freight and Passenger Service. The diesel-electric and electric locomotive have different operating characteristics and advantages. The objective in the present study was not to develop an optimal mix of diesel-electric and electric engines. Rather the question was to establish the general superiority of one type of locomotive over the other. The proposition can be phrased crudely as a "go/no-go" decision with respect to prospective electrification.

Diesel-electric locomotives are usually conceded to have an advantage in the lower speed regimes. Electric locomotives are said to excel at higher speeds, at rapid acceleration and situations where overload capabilities can be used.

The railroads operate many types of trains. The decision to distinguish between types of service allows comparison of diesel-electric and electric in operations that highlight their differing characteristics.

Freight operations were divided into two classes, lower speed drag service and higher speed manifest service. The information on the division of freight operations between drag and manifest is not very precise. It appears that, on a national basis, manifest represents approximately 35 percent of the gross ton miles hauled and drag the remaining 65 percent. Ratios for individual railroad operations vary widely. Furthermore, in actual practice, the division between drag and manifest is relatively fluid depending on commodities hauled and scheduling. For this study the general definition for drag service was that service in which the tractive effort of the locomotive consist is just great enough to haul the train over the ruling grade. Drag service is thus tractive effort oriented in determining locomotive tonnage ratings. Trains in drag service achieve average speeds as permitted by the horsepower of the locomotive consist and the profile of the route. Manifest service was defined as that in which the locomotive consist is determined by a need to meet established run times less than those of drag trains. It is representative of "horsepower" oriented operations.

In order to compare the costs of drag operations, train size was fixed, and the number of electric or diesel-electric locomotives required to move the traffic was then calculated. (The actual calculations will be described in detail in Section 5.2.1 below.) This was done so that any advantages from the additional power in the electric system could be used to increase speeds and thus, lower run times and reduce total inventories of rolling stock.

Thus, under drag operation the difference between the electric and the diesel-electric systems was costed both in terms of fewer trains and hence fewer locomotives required, and in terms of a reduced freight car inventory.

For manifest service maximum operating speeds were fixed at 80 mph maximum with average speeds of 40 mph. To incorporate known operational constraints which force trains to operate below maximum cruise speeds, various load factor values were introduced in calculating the inventory of required locomotives. The advantages of electric locomotives arose through differences in numbers of locomotives purchased. The precise nature of these calculations are discussed under Section 5.2.1.

Traffic densities for passenger service on routes with Amtrak service were converted to tonnages and added to the manifest service to provided on those routes.

4.3.5 Track Capacity and Usage. Average 24-hour track capacities with CTC signalling were obtained for main lines. These values were used to calculate the trackage needed to carry projected traffic. Because peaking and scheduling problems do not permit full utilization of such track capacities, the effective capacity was assumed to be three-fourths of the 24 hour value. (see section 5.2.4.)

4.3.6. Scheduling. Problems related to the direction of traffic, peak loading, dispatch practices and other conditions leading to uneven scheduling of trains were not addressed in this study. Basically, it was assumed that the system approximates a "steady state" operation of locomotives and cars. It was anticipated that any unevenness in operations will impact the diesel-electric and electric systems in essentially similar manner. Thus, while total hardware inventories might well be increased if such scheduling problems were addressed, the relative performance of the two systems should not be greatly affected.

4.3.7 Maintenance. Maintenance requirements were set for the components of the two systems. Important differences exist between the two systems with respect to locomotive maintenance. Lower maintenance requirements for electric engines result in greater locomotive availability, reducing locomotive inventory requirements. This was taken into account in determining locomotive inventories.

Freight car maintenance was not considered in the analysis as the differential between the two systems was estimated to be small.

Maintenance to the catenary and sub-stations in the electric system is a significant cost factor and was included in the analysis. Maintenance requirements for electrical distribution lines were found by the Task Force to be negligible, as were the differential maintenance costs for the signalling and communication systems and were dropped from the analysis.

4.3.8 Conversion from Diesel-Electric to Electric

Past studies have indicated that electrification tends to be most economical on routes of high traffic density. For this reason, it was expected that there would be a cross-over point in traffic density. At traffic densities above the cross-over point, electrified operation would be more efficient; below that point, diesel-electric would be more economical. In other words, there would be a level of utilization below which the high level of capital investment in electrification would not pay.

Because the traffic projections used accounted for growth over the 30 year period, it was expected that some routes would pass through the cross-over point during the study period. Others would warrant electrification in 1975 and some would not reach the cross-over point during the study period.

The scenario developed for analysis provided for a sequence of investments that reflected these possibilities. When a route reached the cross-over point in traffic density, conversion from diesel-electric to electric motive power was made by purchasing the capital equipment needed for electric and selling the equipment no longer needed for diesel-electric. Regardless of whether the route was being operated by diesel-electric or electric, investments were made every 5 years to replace worn-out equipment. Economic lifetimes were established for capital equipment to determine the replacement rates.

An additional complication was added to this conversion scenario. The routes and traffic projections for the skeleton network reflected all traffic moving between major traffic centers without distinguishing between railroad companies serving the same routes. This made it necessary to consider the possibility that there would be a mixture of diesel-electric and electric service along a single route, but on different tracks. This situation could arise when the traffic density was high enough to warrant electrification of a single track and in addition, the operation of a second single track, not necessarily on the same right-of-way, under diesel-electric service. As traffic growth occurred over the 30-year period, mixed service would be economical when traffic was above the cross-over point for a single track, but not above the cross-over point for a second. The operating scenario was constructed to allow this type of investment pattern.

5. COMPUTATIONAL TECHNIQUES

This section describes the equations, data, and computer program used to compute the costs for the two systems using the operating scenario as described above.

The major calculations involved in the cost comparison program were done by computer. Essentially, there are four parts to the program used. They are graphically displayed in Exhibit 5-1.

The Traffic Extrapolation subprogram computed the traffic density for each route from the data for 1965 and 1980 drawn from the FRA Base Rail Network. Next, the Basic Transportation Inputs were computed using the traffic extrapolations and physical parameters such as the equipment characteristics for the two systems and the regional average profiles. The next subprogram computes the Investment and Operating Costs by using price and cost factors to assign value to the required transportation inputs. The final sub-program, EVAMEA (Evaluation of Mutually Exclusive Alternatives) computed present values and ranked the two systems by minimum total cost. The equations and data used in these subprograms are discussed in the following sections.

5.1 TRAFFIC EXTRAPOLATIONS

As indicated in earlier sections, the FRA furnished data on the traffic densities on the links in the Base Rail Network for 1965 and 1980. Selected high-density links were combined into the routes of the skeleton network and traffic levels developed for each route for 1965 and 1980. From these data, the Traffic Extrapolation subprogram computed an annual growth rate for each route. This growth rate was then used to compute average densities by routes for each five-year point between 1975-2005.

5.2 BASIC TRANSPORTATION INPUTS

This section gives a brief description of the assumptions and approach for computing the input resources needed for railroad operations at the levels required for given traffic densities. Four input resources were developed: the locomotive inventory, the fuel and energy consumed, the freight car inventory, and the miles of tracks and sidings. Although tracks themselves are not costed, they are the determinants for catenary, substation and related requirements. The quantity needed of each was dependent on traffic projections and a set of physical parameters and relationships.

COMPUTER PROGRAM

OVERALL FLOW DIAGRAM

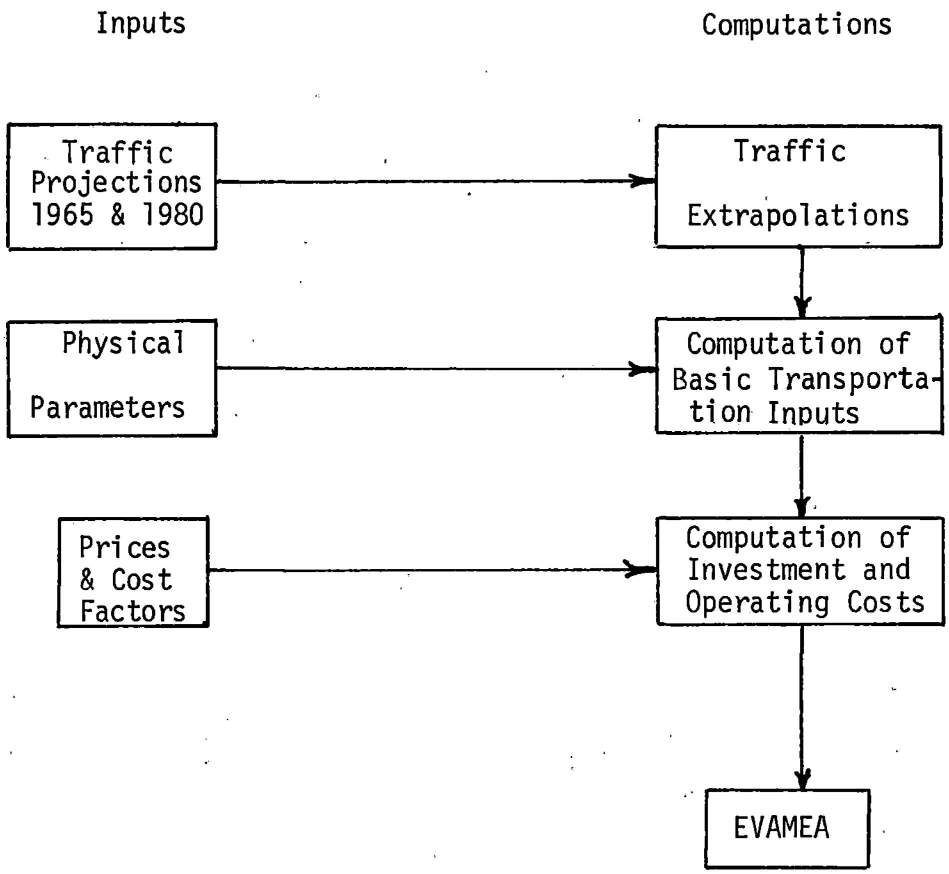


Exhibit 5-1

5.2.1 Locomotives. The locomotive inventory was calculated by dividing the total energy or tractive effort required to move the projected freight over the route during a given year by the energy delivered by one locomotive operating for a year. The technical basis for estimating the number of locomotives required is derived from the way in which tractive effort and horsepower are utilized in different speed regions. The number of locomotives for faster, manifest traffic tends to be a function of horsepower. The locomotives required for slower, drag service tends to be a function of adhesion and tractive effort.

At slow speeds (less than 15 mph) tractive effort is limited by adhesion between rail and wheel. Adhesion will usually permit tractive efforts of about 0.18 of the weight per axle although an improvement to 0.25 and higher can be achieved by electric locomotives. Since the maximum weight per axle is limited by the track structure to about 70,000 lbs. in the U. S., tractive effort per axle is generally about 12,600 lbs. maximum (for 60,000 lbs. per axle, it would be 10,800 lbs.). In addition, the tractive effort delivered at the draw bar is limited to 240,000 lbs. maximum to avoid breaking the draw bar or the coupling knuckle. Thus, at low speeds it is not useful to employ more than about 18 axles per train at 12,600 lbs. tractive effort per axle. Nor is it useful, at these speeds, to have horsepower in excess of that needed to produce 240,000 lbs. of tractive effort. At 15 mph, 240,000 lbs. of tractive effort require 9,600 rail horsepower. At this speed more than 9,600 rail horsepower cannot be utilized per train. These conditions hold for .18 adhesion and will be slightly different for .25 adhesion.

In addition to limiting the usable power at low speeds, the strength of couplings limits the trailing tonnage. If the full 240,000 lbs. capacity were applied, the tractive effort would be sufficient to haul about 5,300 trailing tons over a 2 percent grade or 9,600 trailing tons over a 1 percent grade. In practice, safety margins require operations somewhat below these limits.

At higher speeds, higher power is needed to maintain speed and to accelerate, especially when operating on up-grades. In these speed ranges, required tractive effort is generally far below the limits set by adhesion, weight on drivers, and knuckle strength. Instead, tractive effort and speed are usually limited by the horsepower output of the locomotive.

The technical conditions of operation in high and low speed regimes provide the means for estimating the number of locomotives needed for manifest, (or high speed) and drag (or low speed) freight services.

5.2.1.1 Manifest Service. Operating at higher speeds, manifest trains are limited in speed and tonnage by the horsepower of the locomotive consist. The number of locomotives needed to haul projected manifest traffic can be calculated by equating the total energy that can be delivered by an inventory of locomotives to the energy required to move the traffic at scheduled speeds. Differences in locomotive characteristics result in differences in the number of locomotives required.

The energy required is the product of the total train resistance and the distance hauled, or

$$E = G_m R D\ (5280),$$

where

E = energy required in the ft-lbs per year
G_m = manifest traffic in gross tons per year (including locomotive weight)
R = train resistance in lbs per gross ton
D = length of the link in miles.

The most complicated term in the equation for energy required is the resistance R. Train resistance is generally expressed as a function of velocity, grade, and curvature. Total train resistance is the sum of locomotive resistance and car resistance. This is given by

$$R = \frac{(G_m - T)R_L + TR_C}{G_m},$$

where
R = train resistance in lbs per ton
T = tons per year trailing
R_L = resistance of locomotives in lbs per ton
R_C = resistance of cars in lbs. per ton.

According to the Davis formulae, the locomotive and car rolling resistances are given by

$$R_L = 1.3 + \frac{29A_L}{W_L} + 0.03V + \frac{0.288V^2}{W_L}$$

and

$$R_C = 1.3 + \frac{29A_C}{W_C} + 0.045V + \frac{0.0435V^2}{W_C}$$

where

A_L = number of axles per locomotive
W_L = weight per locomotive in tons
A_C = number of axles per car
W_C = weight per car in tons
V = velocity in miles per hour.

To each of these expressions must be added the resistance caused by grades and curves. For purposes of computing horsepower and energy requirements, regional average resistance values for grade and curvature were used. Such regional averages have been developed by the Stanford Research Institute in a study for the Office of Civil and Defense Mobilization, "A System Analysis of the Effects of Nuclear Attack on Railroad Transportation in the Continental United States." (199).

Thus, the train resistance per gross ton is given by

$$R = \frac{(Gm-T)}{G_m}\left[\frac{29a_L}{W_L} + 0.03V_m + \frac{0.288V_m^2}{W_L}\right] +$$

$$\frac{T}{G_m}\left[\frac{29a_C}{W_C} + 0.045V_m + \frac{.0435V_m^2}{W_C}\right] +$$

$$1.3 + R_{gc} ,$$

where R_{gc} = average resistance due to grades and curves in lbs. per ton.

The energy that can be delivered by L_m locomotives depends on their horsepower rating, their availability and the load factor at which they can be operated over the route.

Availability is defined as the fraction of time the locomotive is running or ready to run as opposed to being tied up in servicing, inspection or maintenance. The load factor takes into account the periods during a run in which the locomotive is operated at less than full throttle because of speed limits, delays, or down-grades. Regional values for load factor were also developed by the SRI study. The energy delivered by L_m locomotives is

$$E = fH_pAL_m(1.74 \cdot 10^{10}),$$

where

H_p = rated rail horsepower of locomotive
E = energy in ft-lbs per year
f = locomotive load factor
A = locomotive availability factor
L_m = number of locomotives.

Using the equations for energy required and energy delivered, eliminating E, and solving for L_m we have

$$L_m = \frac{G_mRD(5280)}{fH_pA(1.74 \cdot 10^{10})} = 3.04 \cdot 10^{-7} \frac{G_mRD}{fH_pA}$$

The availability factor provides a means of evaluating the differences in locomotive fleets that arise from differences in the amount of time that locomotives must spend in activities other than hauling freight. Electric locomotives were assumed to spend only 5 percent of their lifetime in maintenance as compared with 11 percent of diesel-electrics. It was also assumed that they would lose no time in routine turnaround servicing (fueling, lubrication, watering, engine inspection) as compared with 5 percent for diesels. The electric availability under these assumptions would be 95 percent as compared with 84 percent for diesel-electric.

The load factor provides a way to evaluate the overload capacity of the electric as it applies to maifest service. The load factor was calculated by dividing the actual power generated during the run by the power that would be generated if the locomotive were operated at full horsepower during the entire run. Because the electric locomotive can operate at 10 percent over its rated horsepower for periods up to one hour, it can deliver 110 percent of its rated horsepower each time the operating conditions permit full throttle. The electric locomotive can thus deliver a higher proportion of its rated horsepower over the entire run.

To calculate load factors, we have used data which were provided by the Electro Motive Division of General Motors for a Battelle study of environmental impacts (29). These data show the percent of time each throttle position is used.

Throttle Position	Percent of Time
8	30
7	3
6	3
5	3
4	3
3	3
2	3
1	3
Brake	8
Idle	40

It was assumed that power varies linearly with throttle position and that full throttle time is typically broken into 10 portions, each 3 percent long on a typical 300-mile run. At 30 mph, the total trip time is 10 hours. Three percent of 10 hours is 0.3 hours, a period easily within the overload period of the electric locomotive. The electric motors could be used to full overload capacity if there were only 3 separate periods of full throttle, each 10 percent of trip time, so long as they were followed by lower throttle periods that would permit cooling. It was also assumed that that the 40% of locomotive time spent idling was mostly in yards and on sidings rather than during the run.

From the above data, the load factor for the diesel-electric, with no overloading capability is,

$$f_D = \frac{.3(8) + .03\ (1 + 2 + 3 + 4 + 5 + 6 + 7)}{.59(8)}$$

$f_D = .685.$

The load factor for the electric, assuming that 10% overload is used for each 0.3 hour period of full throttle is

$$f_E = \frac{.3(1.10)(8) + .03(1 + 2 + 3 + 4 + 5 + 6 + 7)}{.59(8)}$$

$f_E = .737.$

Thus, the 10 percent overload capability has improved the load factor by .052 or 7.6 percent.

5.2.1.2 Drag Service. The locomotive inventory required for drag service can be calculated by equating the locomotive hours available from the inventory to the locomotive hours required to produce the required tractive effort over the run. An inventory of L_d locomotives with availability factor A yields 8760 AL_d locomotive hours of running time per year. The required number of locomotive hours is the product of the number of locomotives needed to provide sufficient tractive effort to haul the tonnage over the ruling grade times the trip time, or

$$\frac{G_d(20g + R)}{TE} \left(\frac{D}{V_d} \right),$$

where

g = compensated ruling grade in percent
R = train rolling resistance in lbs/ton at velocity on the grade
TE = the tractive effort of one locomotive at velocity on the grade in lbs.
D = distance of the link in miles

V_d = average velocity over the link in miles per hour for drag service.

G_d = gross tons of drag traffic per year.

The locomotive tractive effort may be taken from its performance curve or calculated on the basis of weight on drivers times the adhesion factor.

Equating these two expressions and solving for L_d we have one equation for L_d in terms of

$$L_d = \frac{G_d(20g = R)}{8760A\ (TE)} \quad \left(\frac{D}{V_d}\right) .$$

The average velocity (and thus the run time) depends on the horsepower of the locomotive consists used. The horsepower of the locomotives required on the ruling grade will determine the speeds achievable on other portions of the run. For these higher speeds, velocity is related to horsepower as in manifest service. The energy required is

$$G_dRD(5280)$$

and the energy delivered by L_d locomotives

$$L_d fAH_p \quad (1.74) \cdot 10^{10}).$$

Equating energy required to energy delivered, we have

$$(5280\ G_dRD = L_d fAH_p(1.74 \cdot 10^{10})$$

or

$$L_d = \frac{G_dRD}{fAH_p} \qquad (3.04 \cdot 10^{-7})$$

where R is a function of V_d and V_d^2 This gives a second equation for L_d in terms of constants and V_d. These two simultaneous equations can be solved to give L_d and V_d.

5.2.2 Fuel and Energy. The fuel and electrical energy requirements were based on the calculations of energy required to move the tonnages over the profile under manifest and drag service with allowances made for the various types of losses that occur in each system. For the diesel-electric, the losses included spillage and evaporation of fuel, efficiency losses in the diesel engine and electrical transmission, auxiliary losses, and idling losses. For the electric, the losses included transmission line and catenary losses, losses in the electrical locomotive systems, auxiliary losses and idling losses.

The energy required for manifest service was given above as

$$E_m = G_m RD \ (5280).$$

The energy required for drag service can be calculated using the same equation with train resistance calculated at drag velocities. Total energy E thus

$$E = [G_m R_{V_m} + G_d R_{V_d}] \ (5280D),$$

where

E = energy in foot-lbs per year
G_m = manifest traffic in gross tons/year
G_d = drag traffic in gross tons/year
R_{V_m} = train resistance at manifest velocity in lbs/ton
R_{V_d} = train resistance at drag velocity in lbs/ton.

D = distance of link in miles

The energy in foot-pounds was converted into gallons of fuel oil using fuel consumption relationships developed by Ernest C. Poole (175). Repeated tests have shown that fuel consumption of diesel locomotives averages .0324 gallons per million foot-pounds. Shrinkage losses of 2 to 4 percent were also accounted for.

The energy in foot-pounds was converted into KWH of electric power by allowing for losses in transmission, conversion and auxiliaries. Using the conversion factor $3.76 \cdot 10^{-7}$ KWH/ft-lb. and assuming total losses of 16%, the purchased electrical power was computed as $4.77 \cdot 10^{-7}$ KHW for each foot-pound of energy required.

5.2.3 Freight Cars. The number of freight cars needed was computed on the basis of average car capacity, car utilization, and run times determined by the average speeds. Because the electric has higher horsepower and higher average speeds in drag service, the cars spent less time on the road. It was assumed that at a given point in time, the freight car inventory is composed of several subsets one of which is the cars actually in trains en route. The number of cars in other subsets is determined by the inefficiency or desirability of other activities of cars such as classification or short time storage of goods. Even though most of the cars in the total inventory are in these other subsets, reductions in the en route subset represent a potential for real savings. In fact, if the reduction is not realized, the surplus cars that are no longer en route may cause congestion in classification yards, branch lines, and sidings. To reflect this savings, the diesel-electric system was charged with the costs of the cars it would need over and above those needed by electric system.

In manifest service, the number of cars required rolling stock inventory will be the same for both diesel-electric and electric under the assumption that both achieve the same speeds and run times.

To the extent that differences in locomotive performance result in differences in drag service run times, some differences in car inventory will result. The en route portion of the car inventory will be reduced by the same percent as the reduction in run time.

The car inventory was computed from the velocity, distance, tonnage per car, car utilization, and gross tonnge, according to

$$C = \frac{G_d D}{8760 W_c V_d}$$

where

C = the number of cars per year
G_d = gross tons per year, drag service
W_c = gross tons per car.
V_d = average velocity, drag service.

- Car weight was assumed to be an average of 72 tons, gross. The SRI study, among others, has shown that the utilization factor of freight cars in the U. S. may be as low as 10 percent.

5.2.4 Tracks. The mileage and number of tracks and directly related equipment such as catenaries were calculated by assuming maximum capacities for tracks with CTC signal systems taken from W. W. Hay's Introduction to Transportation Engineering (111). The following capacities were used:

Tracks	Maximum Capacity (thousand gross tons per day)
1	225
2	800
3	1000

These values are the result of both theoretical and empirical study of CTC track capacities. 75 percent of the capacity was assumed to be available for daily use to allow for peaking problems. The annual practical single track capacity is thus

$$225{,}000 \times 365 \times 0.75 = 61.5 \text{ million gross tons per year.}$$

20 percent additional track miles were allowed for sidings.

Parameter Values. Exhibit 5-11 presents a summary of the physical parameter values used for the four regions.

5.3 COST COMPUTATIONS

This section discusses the assumptions, equations, and data used to compute the costs of using the required transportation inputs. The basic costs involved in the two systems were classified as Investment Costs, Annual Operating Costs and Research and Development Costs. Since no position on an R&D program has been defined, these costs were not included in the cost comparison, and a point design approach was followed. Problems of relative prices and environmental costs were also considered in computing system costs.

As described in Section 4.1.3, this study considered only differential costs between the two systems. Within the limits of this study, only significant costs were included. The price and cost factors used represent the best estimates available from analysis of the literature and discussion with the Task Force. The base values were supported by consensus of the Task Force. Other figures have been used in making sensitivity tests.

5.3.1 Pricing Assumptions. In the analysis of the economic use of resources there has been considerable discussion of the fact that prices of various resources do not fully reflect their cost to society. Much concern has been devoted to measuring external costs and to the fact that some resources found in our natural environment have never been priced at all. Nevertheless, a complete reassessment of the theory of the social use of resources must be more completely developed before it is available for practical policy making.

Thus, in this study, with notable exceptions remarked on below, the relative price structure has been accepted as indicating the limitations on resource use with respect to the railroad industry. Insofar as the use of inflators reflects not only dollar changes but relative shifts in resource scarcity, technology, and environmental protection costs, some considerable element of changing resource availabilities have been included in this analysis. Care has been taken to make price projections reflect the best knowledge on these variables.

5.3.2 Energy Prices. One set of prices indicating a need for specific attention in the present analysis pertain to electric energy and diesel fuel. The recently published Federal Power Commission 1970 National Power Survey (69,70) estimates a 19 percent increase in the real cost of electric power during the next two decades. This increase reflects the combined effect of environmental protection costs, technological change, and resource scarcities. This real measure of change does not include the effects of general inflation anticipated over the same period.

The situation with respect to diesel oil pricing is much more complicated. No Federal agency has as yet gone on record as to the anticipated real or inflated price changes to be anticipated in the near future. The complexities of estimating the resources available within the U. S. and overseas, of anticipating import restrictions and the regulatory behavior of foreign governments make long range price projections extremely difficult to make.

It is held in the literature that domestic oil reserves will be running short during the study period and that increasing reliance will have to be placed on foreign sources of oil, primarily the Middle East. As the U. S. bids for more and more oil on the world market, it will be competing not only with the growing demands of other industrialized nations, but also with rapidly growing demands from countries in the process of industrialization. This will undoubtedly raise the price of oil on the world market. Unfortunately, the complexities of economic and political relationships in the world oil market make estimation of the rate of price increase extremely difficult.

The extraction of crude oil from oil shales located in the U.S. is an alternative to continued increase of imported oil. Given the quality of the shales and the current state of extraction technology, shale oil is not an economically competitive supply. But as the price of oil increases, a point will be reached at which large scale extraction of oil from shale deposits will be profitable. As investments are made in the technology and capital structure needed for shale oil extraction, improvements in efficiency and productivity should result that would offset pressures of price increases, at least for a decade or so. Thus the point at which the price of imported and domestic crude oil equals the price of crude extracted from U.S shale deposits is a plateau in an otherwise increasing trend in the price of oil.

For this study, it is assumed that the depletion of domestic reserves would lead to increasing oil imports and increasing real costs at 3% per year of oil until the price of oil made the exploitation of oil shale economically competitive. At this point, about 1990, prices would level off for a decade due to technological improvements and increasingly efficient utilization of oil shale capital equipments. Following this plateau, it was assumed that real oil costs would increase at 19% per year. The values used are presented in Exhibits 5-4 and 5-6.

5.3.3 <u>Environmental Costs</u>. Environmental costs arise in two basic ways. In one case, external costs arise because of the damage done to the environment by an economic activity. In the second case, internal costs arise because of efforts to avoid causing environmental damages. The government actions associated with the environmental "crisis" of recent years have sought to prevent or control external environmental costs. In some cases, the government itself has absorbed the internal costs of environmental protection. In other cases, firms and individuals have been required to meet these costs. In either case, the costs are borne by the national economy.

Whether environmental costs are external or internal or are borne by the government or by individuals, they must be accounted for in an analysis of the social costs of an investment such as electrification. Unfortunately, the techniques for estimating external costs of specific actions are not available for ready use. For the purpose of this study, only costs that would be internal to the railroads under existing or proposed laws and regulations are included.

In general, there are environmental costs associated with all aspects of economic activity. Man extracts resources from his environment, transforms them in complex ways, and returns residuals to the environment. Actions in all three of these categories involve environmental costs. For the purposes of this study, it is assumed that the internal environmental costs associated with the inputs used by the railroads should be reflected in their prices. This leaves for analysis, the environmental costs of actions taken by the railroads themselves.

5.3.3.1 Air Pollution. Environmental costs relative to air pollution arise in the railroad industry in the form of diesel engine exhaust and the burning of old vehicular equipment. The latter will not vary between diesel and electric.

Discussions with the Environmental Protection Agency indicate that no accurate measurement of diesel locomotive emissions has been made although a contract calling for these data has recently been signed. Most measures of diesel emissions have been made on trucks. Based on such measures Battelle Columbus Laboratories (29) has compared emissions from diesel locomotives with the power plant emissions associated with electric locomotive operations. These estimates show that the emissions are of different kinds, the electric being a heavy emitter of particulates and sulfur oxide and the diesel of carbon monoxide and oxides of nitrogen. Part of the price increase in electric power will result from efforts to substantially reduce particulate and sulfur oxide emissions below these levels. Without data on diesel emissions, EPA is far from analyzing the resultant external costs and developing emission standards. State and local actions may come more quickly, but the timetable is hard to predict.

In addition to differing in the types of pollutants emitted, the two types of locomotives differ in the location and distribution of emissions. The diesel emissions are disbursed and mobile and on the site of railroad rights-of-way while the electric emissions are concentrated at fewer stationary sources not located on railroad property. From the national point of view there may be little difference in the damages and costs resulting. Yet from the viewpoint of neighbors of railroads or generating stations, it will make quite a difference. For the purposes of this study, it was assumed that such differences, to the extent they were important nationally, would be reflected through the price system.

5.3.3.2 Water Pollution. Water pollution appears primarily in the railroad industry in the form of oil spills. Again, EPA has developed no factual data related specifically to the railroad industry on this area of pollution.

5.3.3.3 Sanitary Wastes. The principal area under sanitary pollution problems now identified relates to the handling of sanitary waste on passenger trains. Since this problem would not vary between electric and diesel-electric operations, it has not been explored at this time.

It is possible that old vehicular equipment might be buried instead of burned, but again, no government agency has taken a position on this problem. Also, it is questionable that there would be significant variations as between diesel-electric and electric.

5.3.3.4 Noise. In a number of cities, switching yards are close to highly populated areas. In some instances, municipal ordinances have or are being developed to address the noise pollution problem. As yet, EPA has not identified this as a major national pollution problem and has developed no data or standards to this point. This study analyzed only mainline operations for electrification opportunities. It was left to a later time to consider the electrification of yard operations with the possibility of reducing urban noise.

5.3.3.5 Aesthetics. Although aesthetic judgments are difficult to render in economic terms, there have been suggestions that the catenary structure would have a damaging effect on the visual environment that ought to be reflected in electric vs. diesel-electric comparisons. To the extent that simple, light, inexpensive catenary structures are used, this problem would be reduced. In addition, most railroad right-of-way, especially in areas where most people see it, is already burdened by structures of low aesthetic value. It is doubtful that very serious objection will be raised to catenary installation along existing right-of-way. Given this judgment there is little aesthetic difference that need be costed into the diesel-electric vs. electric comparison.

5.3.4 Investment Prices. The investment costs for both diesel-electric and electric systems were based on a series of investment price inputs. These were used with the computed transportation inputs in cost-estimating relationships to compute investment costs. Exhibit 5-2 presents a list and discussion of investment prices. The cost-estimating relationships are discussed in Section 5.3.8.

In addition, the replacement investment costs and residual values were based on linear depreciation using a set of economic lifetimes. These are shown in Exhibit 5-3.

5.3.5 Operating Cost Factors. Railroad operating costs, according to the ICC Uniform System of Accounts for Railroad Companies (132) consist of: Maintenance of Roadway and Structures (Accounts 200 to 282), Maintenance of Equipment (Accounts 300 to 339), Traffic Expense Accounts (Accounts 350 to 360), Transportation Expense Accounts (Accounts 370 to 420), Miscellaneous Operating Expenses (Accounts 440 to 449) and General Operating Expenses (450 to 462). As discussed in Section 4.1.3 most of these accounts need not be considered in this study. For each operating cost item, cost factors were developed from the literature and Task Force discussion. Cost factors for the significant and differentiating costs which were included in the calculation of Annual Operating Costs are listed in Exhibit 5-4.

In addition to these operating costs, state and local taxes on property were included as a cost of business in calculating Private Money Costs. The tax rates were developed by analyzing Commerce Clearing House data (200).

The rates given reflect the combined effect of assessment and tax rates. The rates used are also given in Exhibit 5-5.

Exhibit 5-2

INVESTMENT PRICES

INVESTMENT ITEM	PRICE, REFERENCE AND COMMENTS
New Diesel-Electric Locomotive	$391,000/unit (93) Price used is that for a 3300 HP (2805 rail HP) diesel-electric locomotive, reflecting current and new future design trends.
Used Diesel-Electric Locomotive	$118,000/unit (131) This figure represents an average weighted value for diesel-electric locomotives in use at the inception of the study period in 1975. The price is calculated from ICC acquisition statistics covering the period of 1949-1969. Values were appropriately depreciated and finally projected to a 1975 value.
New Electric Locomotive	$575,000/unit (93) Price used is that of a 6000 HP (5300 rail HP) electric locomotive.
New Freight Cars	$19,000/unit (130) Average price per car based on 1969 ICC statistics and projected to 1975.
Used Freight Cars	$5,100/unit (131) Average weighted value for freight cars at the inception of the study period in 1975.

EXHIBIT 5-2 (cont.)

INVESTMENT PRICES

INVESTMENT ITEM	PRICE, REFERENCE AND COMMENTS
Catenary	East $60,000/track mile (56) South 50,000/track mile Midwest 50,000/track mile West 55,000/track mile Quotes on catenary costs vary widely depending on design and construction. The figures entered were suggested by the Standards Committee. They are representative of generally austere and simple catenary support designs.
Substations	$10,000/track mile (56) An average national value for a 50 KV system as adopted by the Standards Committee.
Electrical Distribution Lines	East $1,000/track mile (56) South 1,000/track mile Midwest 1,000/track mile West 2,000/track mile This cost covers the connection of the substations with high tension transmission lines, which may or may not be built or exist parallel to the railroad right of way. The Standards Committee agreed on the above cost figures, taking into account expected higher cost in the far western region.
Signaling	$11,500/track mile (195) Price refers to cost of adapting standard CTC system to electric operation.
Communications	$6,700/track mile (95) The value adopted covers the cost of required shielding of railroad communications lines to protect against inductive interference.

EXHIBIT 5-2 (cont.)

INVESTMENT PRICES

INVESTMENT ITEM	PRICE, REFERENCE AND COMMENTS
Tunnels & Subways	East $300/track mile (130) South 90/track mile Midwest 70/track mile West 250/track mile These figures were calculated to account for alterations required for accommodating catenary wire and preserving minimum loading gauge. Since actual locations of tunnels could not be obtained for this study, average figures are used. They are based on the average tunnel investment per track mile in each region and represent 10 percent of the original investment cost. The use of these average figures results in a general tunneling charge for electrification. With respect to any particular link, the charges may be too high or too low, depending on the presence and nature of tunnels.
Bridges, Trestles & Culverts	East $2000/track mile (130) South 700/track mile Midwest 700/track mile West 700/track mile Similar to tunnels, average regional alterations costs per mile of roadway were used.
Diesel-Electric Shops & Engine Houses	$9,000/locomotive unit (130) Information was obtained from Transportation Statistics, 1969, Investment in Road and Equipment. It had to be assumed that the depreciated investment figures for shops and engine houses are representative of a steady state service level. An investment figure per serviceable road locomotive was calculated.

EXHIBIT 5-2 (cont.)

INVESTMENT PRICES

INVESTMENT ITEM	PRICE, REFERENCE AND COMMENTS
Electric Shops & Engine Houses	$1,800/locomotive unit (130) No data could be obtained from the literature on shops and engine house investment for electric locomotives. In the following section on maintenance a maintenance ratio for Electric locomotive: Diesel Locomotive of approximately 0.4 was determined. Taking into account that the numerical ratio of diesel locomotives to electric locomotives is approximately 2/1 by our assumptions and as calculated elsewhere, the requirement for electric shops and engine houses was calculated.
Diesel-Electric Shop Equipment	$3,500/locomotive unit (130) Similarly to Shops and Engine houses for Diesel, this figure was calculated from Transportation Statistics data, investment in road and equipment.
Electric Shop Equipment	$1,800/locomotive unit (130) The investment figure for electric shop equipment, which is approximately half of that required for diesel maintenance, was adopted by the Standards Committee.

Exhibit 5-3

ECONOMIC LIFETIMES

ITEM	ECONOMIC LIFETIME	COMMENTS AND REFERENCES
Diesel-Electric Locomotive	15 yrs.	The Standards Committee of the Task Force agreed upon a practical lifetime for diesel-electric locomotives of fifteen years.
Electric Locomotive	30 yrs.	Documented foreign experience shows a sharp rise in maintenance costs after 30-35 years (95). Literature tends to set the lifetime of electric locomotives at twice that of the diesel-electric locomotives. Some manufacturers maintain that future locomotives may have longer economic lifetimes. The Standard Committee suggested a value of 30 yrs.
Freight Cars	25 yrs.	The operating lifetime of freight cars was calculated from data given in ICC Transport Statistics (130)
Catenary	45 yrs.	(56)
Substations	50 yrs.	(130)
Electrical Distribution Lines	65 yrs.	(195)
Signaling	40 yrs.	(130)
Communications	40 yrs.	(130)
Tunnels & Subways	65 yrs.	(130)
Bridges, Trestles & Culverts	65 yrs.	(130)
Shops & Engine Houses	65 yrs.	(130)
Shop Equipment	40 yrs.	(130)

Exhibit 5-4

OPERATING COST FACTORS

SOCIAL RESOURCE COSTS

OPERATING COST ITEM	COST FACTOR, REFERENCE AND COMMENTS
Locomotive, Diesel-Electric	$22,000/unit (130) Average maintenance cost for diesel-electric locomotives (Account 311) were provided by railroads through the AAR Ad Hoc Committee on Railroad Electrification.
Locomotive, Electric	$9,000/unit (130) Literature values for relative maintenance costs of electric versus diesel vary from 1:2 to 1:3. A factor of 0.4 was adopted and approved by the Standards Committee of the Task Force.
Catenary	$1,000/track mile (56) Based on the assumption of simplified catenary construction, the Standards Committee of the Task Force adopted this average maintenance cost for all regions.
Substations	$50/track mile (56)
Shops & Engine Houses, Diesel-Electric	$900/locomotive unit (130)
Shops & Engine Houses, Electric	$200/locomotive unit (130) Calculated by multiplying the corresponding Diesel Engine House Maintenance value of $900 by the maintenance ratio of diesel-electric versus electric locomotives (0.4).

EXHIBIT 5-4 (cont.)

OPERATING COST FACTORS

SOCIAL RESOURCE COSTS

COST ITEM	COST, REFERENCE AND COMMENTS
Shop Equipment, Diesel	$1,100/locomotive unit (130) Maintenance costs assumed to be 1% of investment in shop machinery.
Shop Equipment, Electric	$600/locomotive unit (130) Maintenance costs assumed to be 1% of investment in shop machinery
Fuel & Lubricants, Electric	$.015/kwh
Fuel & Lubricants, Diesel	$.148/gal (9,197) Fuel and energy costs are calculated on the basis of current costs. Projections to 2005 were made on best available information on energy projections. See section 5.3.2 for discussion.

Exhibit 5-5

OPERATING COST FACTORS

ADDITIONAL INPUT DATA FOR CALCULATIONS OF PRIVATE MONEY COSTS

OPERATING COST ITEM	COST FACTOR, REFERENCE AND COMMENTS
State Taxes and Local	East 2.6% (200) South 2.3% Midwest 2.5% West 3.5% Rates were obtained from analysis of Commerce Clearing House data and through appropriate regional averaging. Total taxes are calculated annually on the depreciated property value of the respective system components.

5.3.6 Inflation Factors. It is current practice to evaluate government programs in terms of constant dollars. That is, no inflation factors are utilized to adjust the prices of goods or services over the length of the study period. This standard practice allows the evaluation of programs in terms of their social costs, relative to other government programs. Because there would be substantial relative-price changes during the study period, a series of price inflators were used in making price projections for use in estimating Social Resource Costs. In order to yield a present value which did not include the effects of general price inflation, the discount rate was increased from the recommended 10 percent to 13 percent. The additional 3 percent counteracts the general price impact of the inflators on total present value, giving a present value comparable to the constant dollar present values yet reflecting relative price changes.

In order to develop prices for the base year, 1975, available prices were inflated from their year of reference to 1975. Figures from the Bureau of Labor Statistics were analyzed for past inflation trends for different commodities in the period 1961 to 1970. Documented costs and prices derived from the literature, ICC Statistics and manufacturer's information were then inflated at these rates to the base year of 1975.

Exhibit 5-6 lists inflation factors which were derived from BLS Statistics. Inflation rates for fuel and electricity were discussed in more detail in Section 5.3.2.

The same inflation factors were used for estimating both Social Resource Costs and Private Money Costs. Railroads would actually see the impact of inflation on their cash flows. Electrification would substitute immediate but non-inflating investment costs for the constantly inflating operating costs of diesel. Higher inflation would tend to favor electrification. This fact, in addition to the importance of relative price shifts, makes the use of inflated prices important in considering Private Money Costs. The way in which these inflated costs were treated in discounting is discussed in the next section.

5.3.7 Discount Rate. In converting the cost streams into present value, a discount rate was applied to both the Social Resource Costs and the Private Money Costs. The discount rate used for Social Resource Costs was the 10 percent standard for most government programs increased to 13 percent to offset the general effects of inflation in

Exhibit 5-6

Inflation Factors Prior to 1975

Locomotives	5.0 %
Catenary	5.0 %
Substations	5.0 %
Supply lines	5.0 %
Signal system	5.0 %
Communication system	5.0 %
Tunnels	5.0 %
Bridges	5.0 %
Elev. structures	5.0 %
Shops and engine houses	5.0 %
Shop Equipment	5.0 %
Maintenance	2.7 %

Inflation Factors 1975 - 2005

Locomotives	2.6 %	
Catenary	2.6 %	
Substations	2.6 %	
Supply lines	2.6 %	
Signal system	2.6 %	
Communication system	2.6 %	
Tunnels	2.6 %	
Bridges	2.6 %	
Elev. structures	2.6 %	
Shops and engine houses	2.6 %	
Shop equipment	2.6 %	
Diesel fuel	5.6 %	(1975-1980)
	0.0 %	(1980-1995)
	3.6 %	(1995-2005)
Electric energy	3.6 %	
Maintenance Costs	2.6 %	

the prices used. The 10 percent discount rate reflects judgment as to the average returns on resources in the private sector. It is the rate prescribed for use in evaluating public investments.

The choice of a discount rate for analysis of Private Money Costs is a difficult matter. There is no authority in the railroad industry to settle, by proclamation, the question of the cost of capital or the opportunity costs in the railroad industry. Because the 10 percent government rate is intended to reflect the time value of resources in the private economy as a whole, it represents an average that should be available to the railroad industry. Nevertheless, the specific economic and financial conditions of the industry or of individual railroads could cause deviation from this average. For the purposes of this study, the 10 percent rate was used, plus the additional 3 percent to offset the general price inflation built in. Use of the same discount rate facilitates comparison between social and private costs. It does not imply an intent to counteract the effects of inflation as viewed by industry. Nor does it imply any judgment as to the rate of return in the railroad industry. In addition, the costs were discounted at various rates between 5 percent and 15 percent to allow analysis at some other rate if a case was made that it was representative of conditions within the railroad industry.

5.3.8 Cost Estimating Relationships. In order to calculate total differentiating system costs, cost estimating relationships have been developed by which prices and cost factors were applied to transportation input requirements to develop investment or annual operating costs. The employment of such estimating relationships has a long history in the railroad industry. The relationships used in this study are linear in form, and represent first order approximations, suitable to identify and differentiate major costs for obtaining an overall insight into the value of electrification. Availability and accuracy of data do not seem to warrant more complicated equations at this level of analysis.

In building and refining the cost estimating sub-program all equations were written on the basis of locomotive units or track miles. Consequently, cost parameters (prices, maintenance cost factors, etc.) have been expressed as dollars per locomotive unit or dollars per track mile. All costs were estimated on an annual basis.

For estimation of Social Resource Costs, the investment costs were entered as a lump sum payment in the year of purchase. For estimation of Private Money Costs, however, it was assumed that all investments were made by "direct reduction" loan resulting in equal annual payments over the lifetime of the equipment. These payments covered both the principal of the investment and the interest on the loan. A 7.5% interest rate was used for these calculations. Sensitivity tests were conducted at 5% and 10%.

Cost input parameters are calculated for five-year intervals, 1975-2005. The evaluation program (EVAMEA), which is described in the following section, was set up to interpolate between these points.

The symbols and cost estimating relationships are given in Exhibits 5-7 through 5-11. For calculations on the computer, some equations were programmed in slightly different form.

5.3.9 Evaluation and Cost Comparisons

5.3.9.1 Use of Evaluation Program. At the Transportation Center at Northwestern University in Evanston, Illinois, a computer program (EVAMEA) (110) was available to analyze alternative transportation programs suggested for construction between two points. The program permits a comparison of alternative projects using present value, rate of return, and pay-back evaluation techniques. With some adaptations this program was used for the present study.

The present value technique of the program was used as originally designed. The rate of return and pay back techniques were not appropriate for use in this study, because no attempt was made to estimate total benefits or revenues. In addition, the technique of annualizing investment outlays is not compatible with rate of return or pay-back techniques, as embodied in the Transportation Center's EVAMEA Computer program. In place of the latter two, we substituted the present value of private money cost approach.

5.3.9.2 EVAMEA Program and Its Modification. EVAMEA is a computer program for evaluating the economy of mutually exclusive alternatives. The program takes cost and benefit streams for up to 10

Exhibit 5-7

LIST OF TRANSPORTATION INPUT VARIABLES

LEN	Electric Locomotives, New
LER	Number of Electric Locomotives in 2005
LDU	Diesel-Electric Locomotives Entering in 1975
LDN	Diesel-Electric Locomotives, New
LDR	Number of Diesel-Electric Locomotives in 2005
FC	Freight Cars
TRE	Tracks, Electric Service
TRD	Tracks, Diesel-Electric Service
FUE	Number of KWH
FUD	Gallons of Diesel Fuel
TAF	Tax Rate

Exhibit 5-8

LIST OF COST FACTORS

Item	Price	Maintenance Factors	Operating Life	Prices in 2005	Average Age in 2005
Locomotive:					
Electric	PA	MA	OA	PAA	AA
Diesel-Electric, Used	PB			PAB	
Diesel-Electric, New	PC	MC	OC	PAC	AC
Freight Cars, Used	PD	MD	OD	PAD	AD
New	PE	--	OE	PAE	AE
Catenary	PF	MF	OF	PAF	AF
Substations & Switching Stations	PG	MG	OG	PAG	AG
Electrical Distribution Lines	PH	MH	OH	PAH	AH
Signaling	PI	MI	OI	PAI	AI
Communications	PJ	MJ	OJ	PAJ	AJ
Tunnels	PK	--	--	PAK	AK
Bridges	PL	--	--	PAL	AL
Elevated Structures	PM	--	--	PAM	AM
Shops:					
Diesel-Electric	PN	MN	ON	PAN	AN
Electric	PO	MO	OO	PAO	AO
Shop Equipment:					
Electric	PP	MP	OP	PAP	AP
Diesel-Electric	PQ	MQ	OQ	PAQ	AQ
Tracks:					
Electric Service	--	MR	--	---	--
Diesel-Electric Service	--	MS	--	---	--
Fuel & Lubricants					
Electric	PT	--	--	---	--
Diesel-Electric	PU	--	--	---	--

Exhibit 5-9

COST ESTIMATING RELATIONSHIPS

	Equations	Comments
INVESTMENT COSTS		
Locomotives		
Electric	LEN x PA - LDU x PC	Investment in electric locomotives and disinvestment of diesel locomotives replaced by electric units. As electrification is only possible on a percentage of lines, it is assumed that the diesel units will be sold to the general diesel pool at current (1975) market value.
Diesel-Electric	LDN x PC	On the diesel side no charges are entered for the existing locomotive pool.
Freight Cars	FC x PD	Because of slightly increased speeds in the electric operation, fewer cars need to be in circulation, or, alternatively, more cars are required under diesel operation. The difference is entered as a cost on the diesel side. The value of FC designates the car inventory difference. PD is the average value for cars entering in 1975.
Catenary	TRE x PF	Catenary costs over total track (link) length.
Substations & Switching Stations	TRE x PG	Cost of substations over link. PG = f (voltage).

Exhibit 5-9 (cont.)

Equations

Electrical Distribution	TRE x PH	Cost of electrical distribution lines, i.e., high tension lines to substation. PH calculated on per track mile basis.
Signaling	TRE x PI	Total cost of required signal system changes for adaptation to electric operation.
Communications	TRE x PJ	Shielding and adaptation of railroad communication equipment.
Tunnels & Subways	TRE x PK	Average total cost required for modification of the tunnels.
Bridges, Trestles & Culverts	TRE x PL	Average total cost of adapting bridges.
Shops & Engine Houses:		Investment in new engine houses or adaptation of existing engine houses for electric locomotive maintenance. Disinvestment in discontinued diesel engine houses. On diesel side: cost equation to accommodate growth and replacement requirements of diesel shops.
Electric	-(LDU x PN) + (LEN + PO)	
Diesel-Electric	LDN x PN	
Shop Equipment:		Calculation of shop equipment costs in similar fashion.
Electric	-(LDU x PQ) + (LEN x PP)	
Diesel-Electric	LDN x PQ	

OPERATING COSTS

Maintenance

Locomotives:		Total locomotive maintenance costs calculated on a locomotive unit basis. Although a cost-per-mile variable could be more sensitive, the structure of the analysis required costs per locomotive unit.
Electric	LEN x MA	
Diesel-Electric	(LDU + LDN) x MC	The diesel equation calculates maintenance cost for locomotives entering in 1975 (LDU) and locomotives bought subsequently.

Exhibit 5-9 (cont.)

Equations		Comments
Catenary	TRE x MF	Total catenary maintenance cost per link.
Substations & Switching Stations	TRE x MG	Cost of maintaining substations and switching stations.
Electrical Distribution Lines	TRE x MH	
Signalling	TRE x MI	This equation calculates the total incremental signal system maintenance cost. That is that increment of maintenance cost due to the adaptation of the original system. (Estimates are difficult and MI is thought to be small to negligible).
Communications	TRE x MJ	
Tunnels & Subways	--	No or negligible differential maintenance costs will be incurred.
Bridges, Trestles & Culverts	--	No or negligible differential maintenance costs will be incurred.
Elevated Structures	--	No or negligible differential maintenance costs will be incurred.
Shops & Engine Houses:		Differences occur in the number of engine houses required. Maintenance of electric engine houses may be low due to difference in type of maintenance operations.
Electric	LEN x MO	
Diesel-Electric	(LDN + LDU) x MN	
Shop Equipment:		Less complex maintenance operations for the electric locomotive differentiate the two sides.
Electric	LEN x MP	
Diesel-Electric	(LDN + LDU) x MQ	

Exhibit 5-9 (cont.)

	Equations	Comments
Other Operating Costs		
Fuel & Lubricants		
Electric	FUE x PT	Calculation of respective energy costs.
Diesel	FUE x PU	
Taxes	TAF x (depreciated investment costs)	Tax assessment and rates vary widely between states. An average value was calculated and applied annually.

Exhibit 5-10

RESIDUAL VALUES OF INVESTMENT PROCUREMENTS

The period considered in this study is from 1975 to 2005. At the end of this interval, some equipment purchased in 1975 or before 2005 will have a residual value, depending on its operating lifetime. Residual values will be calculated as follows:

Electric Locomotive $\quad LER \frac{(OA - AA)}{OA} PAA$

Diesel-Electric $\quad LDR \frac{(OC - AC)}{OC} PAC$

Freight Car $\quad FC \frac{(OC - AD)}{OD} PAE$

Catenary $\quad TRE \times PAF \times \frac{(OF - AF)}{OF}$

Substations & Switching Stations $\quad TRE \times PAG \times \frac{(OG - AG)}{OG}$

Electrical Distribution Lines $\quad TRE \times PAH \times \frac{(OH - AH)}{AH}$

Signaling $\quad TRE \times PAI \times \frac{(OI - AI)}{OI}$

Communications $\quad TRE \times PAJ \times \frac{(OJ - AJ)}{OJ}$

Tunnels $\quad TRE \times PAK \times \frac{(OK - AK)}{OK}$

Bridges $\quad TRE \times PAL \times \frac{(OL - AL)}{OL}$

Exhibit 5-10 (cont.)

Equations

Electric Shops	$LER \times PAO \times \frac{(OO - AO)}{OO}$
Diesel-Electric	$LDR \times PAN \times \frac{(ON - AN)}{ON}$
Electric Shop Equipment	$LER \times PAP \times \frac{(OP - AP)}{OP}$
Diesel- Electric Shop Equimment	$LDR \times PAQ \times \frac{(OQ - AQ)}{OQ}$

Exhibit 5-11

Summary of Physical Input Data

Regional Characteristics

	Load Factors		Grade and Curvature Resistance
	$f_{Electric}$	f_{Diesel}	lbs/ton R_{gc}
Region 1 - East	.586	.545	3.64
Region 2 - South	.693	.644	3.81
Region 3 - Mid West	.605	.561	4.29
Region 4 - West	.669	.621	4.29

	Typical Ruling Grades percent g
Eastern Mountain	1.60
Midwestern & Flat	1.00
Western Mountains	1.75

Locomotive Characteristics

	Electric	Diesel
Rail Horsepower	5300	2800
Adhesion Factor	.25	.18
Weight, tons	180	180
Number of axles	6	6
Availability	.95	.84
Overload (one hour capacity)	10%	

car utilization A=.10
car weight W_c = 72 tons, gross

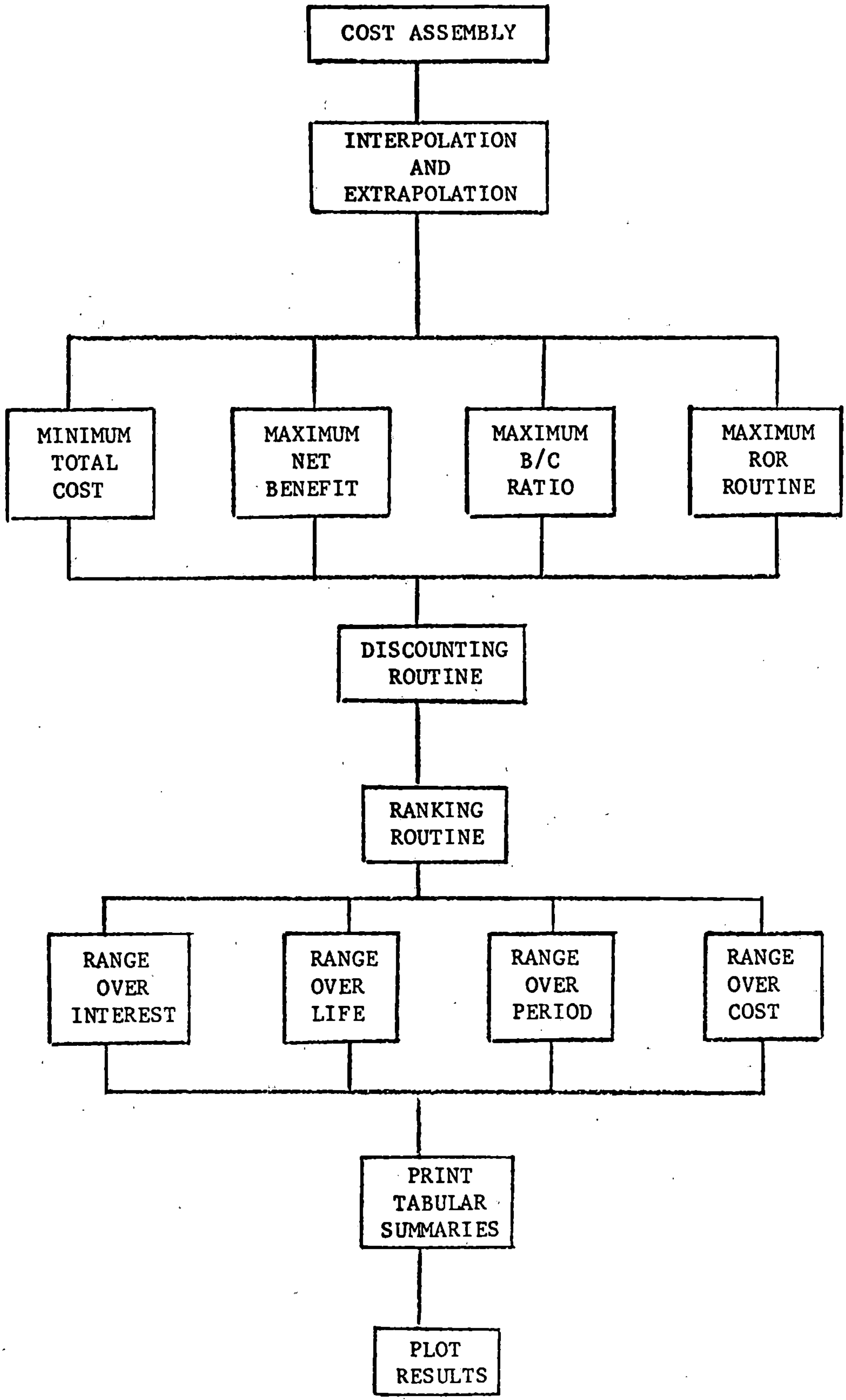
investment alternatives and computes any of four evaluation criteria. The four criteria are minimum total discounted costs, maximum net benefits, maximum benefit:cost ratio, and maximum internal rate of return.

The program is set up as a series of linked subprograms in Fortran IV for a CDC-6400 computer. The user specifies cost and benefit streams over the life of each alternative, selects from the four criteria available and chooses interest rates and analysis periods. EVAMEA is capable of interpolating and extrapolating cost data for all periods from as few as two points or from functional relationships. The basic flow diagram of EVAMEA is shown in Exhibit 5-12.

For the purposes of this study, EVAMEA was linked with the three preprograms discussed in the previous sections, one to extrapolate traffic from FRA traffic projections, a second to compute basic transportation inputs and a third to compute costs from physical inputs. These preprograms are set up to repeat the physical and cost computations for each route in the skeleton network.

Care was taken in constructing the pre-programs to maintain the identity and accessibility of each parameter, relationship, and data point. Although this has resulted in a less than optimal program from the viewpoint of programming and computational efficiency, it permitted exceptional flexibility for changing inputs, assumptions, and relationships. This flexibility was used in sensitivity tests or for modifying the analysis as better data and relationships became available.

EVAMEA's outputs included the interpolated costs for each year in the thirty-year study period, their discounted present value, the sum of the total discounted costs, and a ranking of alternatives from minimum total discounted costs to maximum. EVAMEA is also capable of producing a sensitivity analysis of the alternatives at different discount rates and plotting the results.



EVAMEA Program Structure

Exhibit 5-12

5.4 MODIFICATIONS TO THE BASIC MODEL STRUCTURE

A number of inputs were offered by the railroad industry during the course of the study, particularly following the presentation of the draft report. These inputs came in the form of verbal comments at the October 1972 Task Force Meeting, in letters from carriers to the AAR's Ad Hoc Committee on Railroad Electrification and in other conversations between members of the study committee and railroaders. In broad terms, these inputs suggested a re-examination analysis in the following areas:

1. The cost savings achieved in electric drag service due to reduced freight car fleet requirements that result from increases in over-the-road speeds in drag service;

2. The service availability of locomotives;

3. The effective utilization rate or load factor in the application of motive power in hauling trains;

4. The maintenance costs of locomotives.

These areas were made the subject of additional study by the DOT and PanTek study team. In addition, the DOT determined at this point that it would be useful to make the model operational "in-house." In the course of operating the model at DOT, a technique was developed using a Train Performance Calculator which allows for making more reasonable estimates of the values used for the highly interrelated variables "load factor," "average grade and curvature resistance" and "manifest or drag speed." The use of this technique should also allow individual railroads to use the present model to reflect not national averages but, with proper substitutions, their own effective profiles and cost experiences and projections.

5.4.1 Revised Locomotive Inventory Computations. Much of the re-examination focused on the techniques for sizing the locomotive inventories involved, among other variables, the following:

- Average velocities in manifest and drag service;

- Rolling resistance according to the Davis formulae;

- Average resistance due to grades and curves;

- Load factor, representing the fraction of rated motive power actually applied;
- Availability factor, representing the fraction of time a locomotive is hauling trains; and
- Rated rail horsepower per unit.

Values for these variables were originally drawn from the literature or specified under the assumption that they were not strongly correlated except as expressed in the equations used in computing locomotive inventories. The re-examination addressed both the values and the interdependencies between these variables. The assumptions of cause and effect were reconsidered and, in mathematical terms, the resulting distinctions between independent variables, dependent variables and constants were revised.

Particular attention was focused on the average velocities for drag service because of the substantial savings of electrification originally estimated due to this factor. Railroads run drag trains due to several operating considerations originally extraneous to the model. These considerations can directly and indirectly impose low speed limits on the trains. Drag trains must, of course, have enough power to breast the ruling grade, but additional power may not lead to higher speeds, as was previously assumed in the model, if the trains are already at the speed limit most of the time. Thus, drags are often underpowered because they are slow, rather than the other way around.

In the equation for locomotive inventories, the way in which "extra" horsepower is converted to higher drag speeds depends on the load factor, f. If load factor is not affected by changes in rated horsepower on the train, then more power yields higher speeds. If, on the other hand, speeds are limited for reasons other than power, then the load factor must drop as rated horsepower increases and as a result, velocities may increase little. Thus, the load factor should not be treated as a regional constant, as was the original case, but as a variable that is highly sensitive to route profile, operating conditions, and rated horsepower.

Since the problem of calculating load factor is difficult and closely tied to the specific route involved, it was estimated by using a Train Performance Calculator program to simulate the operation and energy consumption of several trains over a variety of sample routes. These runs helped to determine the relationship between rated horsepower, load factor, average velocities, and grade and curvature resistance. The new values used for these variables reflect these relationships.

The re-examination also clarified the meaning and relationship between load factor, f, and availability factor, A, in representing the way in which the power capacity of locomotive inventory is actually utilized in moving freight. The product of f and A gives the fraction equal to the energy actually produced by a locomotive in a year divided by the energy it would produce if it ran full throttle all year long. The two factors together must account for all of the time spent in activities other than full power output, such as:

1. Out of service due to repairs or slack traffic periods;

2. In terminal yards, waiting for a train, fueling, inspection;

3. Waiting at intermediate yards (without change of locomotives);

4. In delays on the road (due to meets and equipment failures);

5. On a moving train, at less than full throttle (limited by adhesion or speed limit).

The availability factor represents the fraction of time an engine is "available," that is, not in state 1. or 2. Correspondence with railroads from several regions indicated approximately 55% availability rather than the 84% and 95% values originally used for diesel-electric and electric respectively. The difference between the two locomotives reflects the fact that electrics spend less time in maintenance, inspection and fueling. The new values used reflect the same proportional difference as the old: the new availability values were set at .58 for electric and .52 for diesel-electric.

The load factor is then defined using the TPC runs, as

$$f = \frac{\text{TPC horsepower-hours consumed}}{(\text{TPC running time + time in states 3 \& 4}) \times \text{rated Hp on train}}$$

The resistance due to grades and curves, Rgc, can also be evaluated from the TPC runs. This factor actually represents all energy consumption not explained by the Davis formulae evaluated at the average speeds. While long non-momentum grades and curves account for part of this resistance, much of it stems from the acceleration-deceleration cycles that arise in maintaining average speeds in the face of speed restrictions and delays.

Hence

$$Rgc = \frac{\text{TPC energy consumption in mile-pounds-R (average speed)}}{\text{gross ton miles}}$$

where average speed = miles (TPC time + time in states 3 and 4). Rgc computed in this fashion was found to be noticeably higher for manifest than for drag service. This illustrates the necessity of defining these variables in a manner consistent with their interdependencies: e.g., if locomotives in state 3 were considered to be "unavailable" it would lower A and raise f, and by raising the average speed, would lower Rgc.

An inspection was made of the way this approach to f, A, and Rgc affects the sensitivity to other variables in sizing the locomotive fleet. It was found that ruling grade has a strong inverse effect on drag service load factors and, in extreme cases, on manifest load factors. This makes electrification appear most desirable in mountainous regions. Rgc, on the other hand, appears less sensitive to ruling grade. Using locomotives having more horsepower per ton will almost proportionally lower the load factor for drag and, in extreme cases, will also give diminishing returns for manifest. The use of slug units, on the other hand, can pay off for drag but not for manifest service. In view of this, the model was modified to permit locomotives to be used for the two services.

In addition, higher adhesion strongly increases load factor and the sensitivity tests show the resulting large payoff. Because of these sensitivities, all region and ruling grade combinations, eleven in all, were run as separate "sensitivity tests" to find crossover points.

The locomotive inventory determined by this approach was compared to the actual road freight and road switcher ownership of two large railroads. The model produced inventories with about two-thirds as much locomotive horsepower per gross ton as these roads actually used.

Since the study only considered operations on important mainlines, as opposed to railroad systems with secondary line service and road switchers doing extensive yard and transfer work, the 33% better locomotive utilization appears to be quite plausible.

5.4.2 Locomotive Maintenance Costs. Additional input on the subject of diesel maintenance costs was supplied by a number of railroads to the Ad Hoc Committee of the AAR and made available to the study. These inputs indicated that annual maintenance costs for a high horsepower diesel-electric unit are in the vicinity of $46,000 when inflated to 1975 prices. Since these cost number represent the results of a concerted effort to develop a cost base for railroad maintenance, they are believed to be more representative of reality than the prior figure of $22,000. The new value was, therefore, inserted in the base case; electric maintenance costs were held at 40% of the diesel-electric cost.

6. RESULTS

This section presents the results and conclusions drawn from the costs estimated for diesel-electric and electric operations. Two major indicators have been used to express the results. The first is the crossover point, the percentage of practical single track capacity (61.5 million gross tons per mile of track per year) at which the electric system becomes less costly than the diesel-electric. The second is the total incremental costs discounted to present value for each of the routes in the skeleton network. In addition to estimating costs for the skeleton network, sensitivity tests were made using a special test region. The results of these tests yield the crossover points assuming various input values.

6.1 RESULTS BASED ON EVALUATION OF SOCIAL RESOURCE COSTS

The original results showed a crossover point at 0.63 of practical single track capacity or about 39 million gross tons per mile of track per year (see Exhibit 6-1). This corresponded to electrification of 14,290 miles of mainline track in the skeleton network at a savings of $1.1 billion in total incremental costs (discounted).

The subsequent re-examination led first to a change in the computation of the freight car inventory. This limited the savings from more rapid movement of freight cars (due to higher electric drag speeds) to only the fraction of the car inventory that is en route. A programing error in the computation of average speeds was also identified and corrected. The results from this version of the model with no other changes in inputs or equations showed diesel-electric to be less costly at all traffic densities under 246 million gross tons per year (see Exhibit 6-2).

After the revisions discussed in section 5.4 were made, new inputs for each of the regions of the skeleton network were derived. These are summarized in Exhibits 6-3 and 6-4. The crossover points were then derived separately for each region and ruling grade. These computations reflect the need to specify consistent values for average speed, average grade and curvature resistance, load factor and ruling grade. The resulting crossover points are shown in Exhibit 6-5. A separate set of crossover points was derived under the assumption that the route was double track and would be electrified with a double track catenary. It is important to note that these results show no crossover (that is, no potential for cost savings with electrification) below 246 million gross tons per year on routes of 1.0% ruling grade, except in the South. This highlights the over-importance of grade to economical electrification.

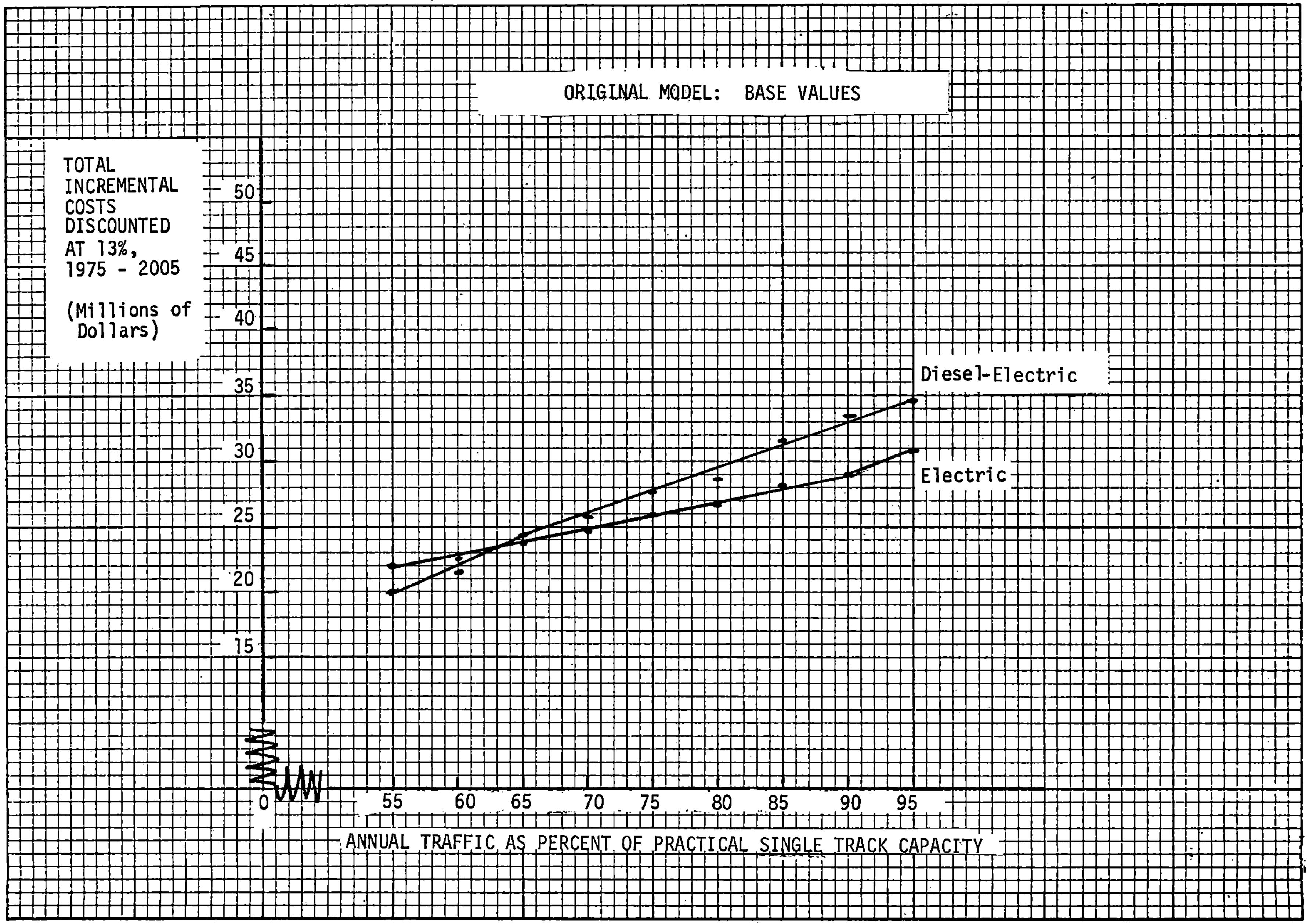

ORIGINAL MODEL: BASE VALUES
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975 - 2005
(Millions of Dollars)
50
45
40
35
30
25
20
15
0
55
60
65
70
75
80
85
90
95
Diesel-Electric
Electric
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY

Exhibit 6-1

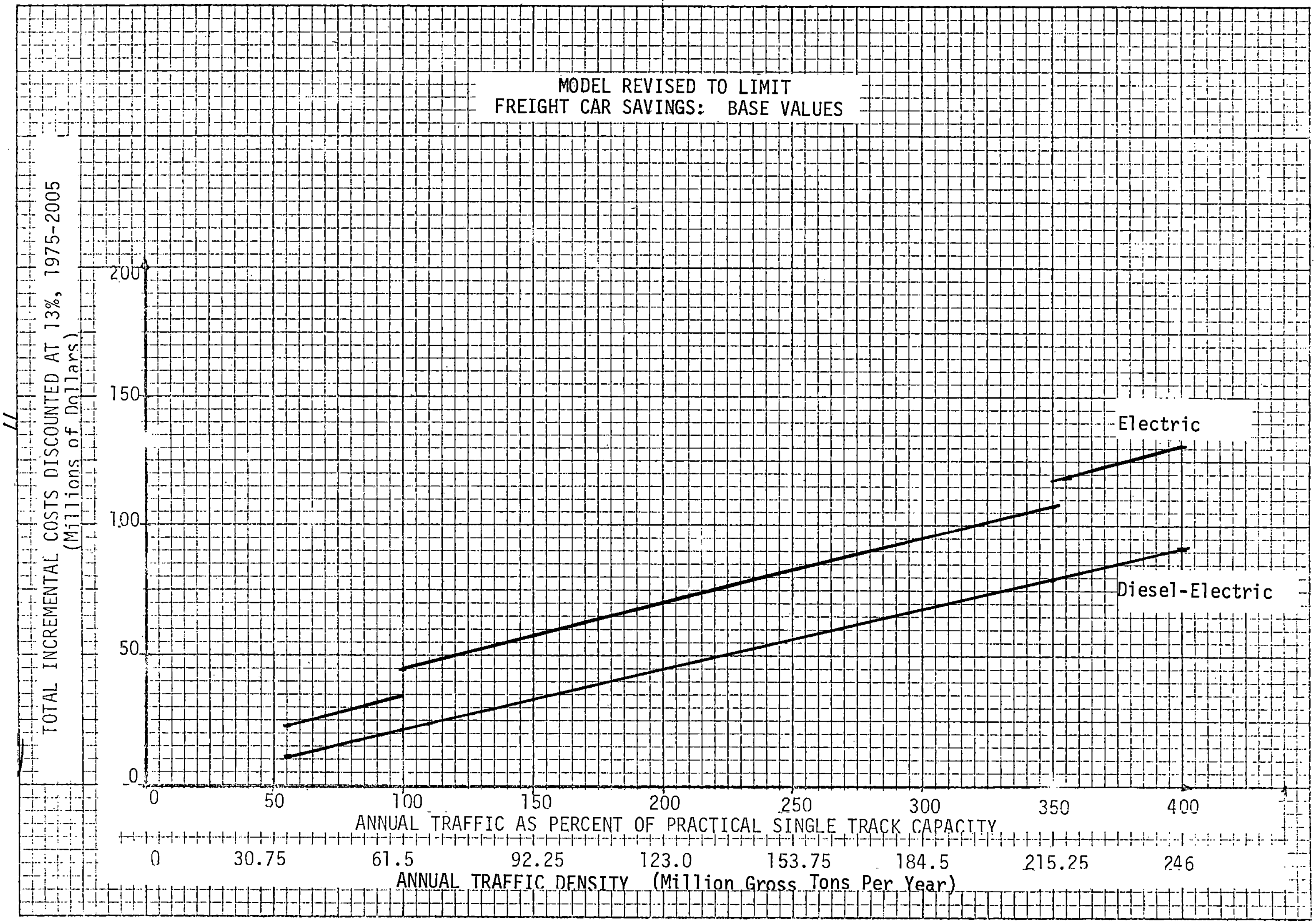

MODEL REVISED TO LIMIT
FREIGHT CAR SAVINGS: BASE VALUES
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005
(Millions of Dollars)
200
150
100
50
0
Electric
Diesel-Electric
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-2

EXHIBIT 6-3

SUMMARY OF PHYSICAL INPUT DATA - REVISED

- REGIONAL CHARACTERISTICS -

	Load Factor		Grade and Curvature Resistance (lbs/ton)	Load Factors						Grade and Curvature Resistance (lbs/ton)
	Electric	Diesel-Electric		Electric		Diesel-Electric	Electric		Diesel-electric	
				without slug	with slug		without slug	with slug		
Region 1-East	.6	.5	5.5	.18	.31	.23	18.6	16.3	17.2	3.64
Region 2-South	.4	.4	5.5	.19	.33	.25	19.6	17.3	18.2	3.81
Region 3-Midwest	.4	.4	5.5	.34	.60	.46	21.0	18.7	19.6	4.29
Region 4-West	.4	.4	5.5	.20	.35	.26	21.6	19.3	20.2	4.29
Region 5-Sensitivity Tests	.4	.4	5.5	.20	.35	.26	19.6	17.3	18.2	4.29

TYPICAL RULING GRADES (percent)

Eastern Mountain	1.60
Midwestern: Flat	1.00
Western Mountain	1.75

- LOCOMOTIVE CHARACTERISTICS -

	Electric	Electric plus slug	Diesel-electric
Rail Horsepower	5300	5300	2800
Adhesion	.25	.25	.18
Weight(tons)	180	360	180
Axles	6	12	6
Availability	.58	.58	.52
Overload Capacity(1 hr)	10%	10%	——

EXHIBIT 6-4

SUMMARY OF REGION INPUT DATA
MANIFEST SERVICE

REGION	AVERAGE SPEED (miles per Hour)	AVERAGE GRADE AND CURVATURE RESISTANCE (pounds per ton)	RULING GRADE (percent)	LOAD FACTORS Electric	LOAD FACTORS Diesel-electric
1. EAST	36	5.5	1.0	.49	.46
			1.6	.36	.36
			1.75	.36	.36
2. SOUTH	40	5.5	1.0	.53	.5
			1.6	.4	.4
			1.75	.4	.4
3. MIDWEST	40	5.5	1.0	.53	.5
			1.6	.4	.4
			1.75	.4	.4
4. WEST	42	5.5	1.0	.55	.52
			1.75	1.42	.42
5. SENSITIVITY TESTS (base)	40	5.5	1.6	.4	.4

EXHIBIT 6-4 (cont.)

SUMMARY OF REGION INPUT DATA
DRAG SERVICE

REGION	AVERAGE SPEEDS (miles per hour)			AVERAGE GRADE AND CURVATURE RESISTANCE (pounds per ton)	RULING GRADE (percent)	LOAD FACTORS		
	Electric		Diesel-electric			Electric		Diesel-electric
	without slug	with slug				without slug	with slug	
1. EAST	18.5	16	17	3.64	1.0	.29	.52	.39
					1.6	.18	.31	.23
					1.75	.17	.29	.21
2. SOUTH	19.5	17	18	3.81	1.0	.31	.55	.42
					1.6	.19	.33	.25
					1.75	.18	.31	.23
3. MIDWEST	21	18.5	19.5	4.29	1.0	.34	.60	.46
					1.6	.22	.36	.28
					1.75	.20	.34	.26
4. WEST	21.5	19	20	4.29	1.0	.35	.61	.47
					1.75	.20	.35	.26
5. SENSITIVITY TESTS (base)	19.5	17	18	4.29	1.6	.20	.35	.26

EXHIBIT 6-5

SUMMARY OF CROSSOVER POINTS BY REGION

Levels of traffic density at which it becomes economical to electrify a link of a given region and ruling grade

REGION	RULING GRADE (PERCENT)	SINGLE TRACK DENSITY (million gross tons/yr.)	SINGLE TRACK Percent of practical single track capacity	DOUBLE TRACK DENSITY (million gross tons/yr.)	DOUBLE TRACK Percent of practical single track capacity
1. EAST	1.0	None	None	None	None
	1.6	None	None	169.6	275%
	1.75	70.0	114%	140.0	227%
2. SOUTH	1.0	75.9	123%	151.7	246%
	1.6	52.5	85%	104.9	170%
	1.75	47.5	77%	95.0	154%
3. MIDWEST	1.0	None	None	212.8	345%
	1.6	63.6	103%	127.1	206%
	1.75	61.76	100%	123.2	200%
4. WEST	1.0	None	None	None	None
	1.75	65.4	106%	130.7	212%
5. SENSITIVITY TESTS (base)	1.6	62.9	102%	125.9	204%

The appropriate crossover points from Exhibit 6-5 were then entered along with the other regional inputs in making runs of the model for the skeleton network. The results are summarized in Exhibits 6-6 and 6-7. Under these conditions, electrification yields savings for 18 routes comprising 6,171 miles. The savings in total incremental costs, discounted to present value, is $360 million or about 9% of the total incremental discounted costs under diesel-electric operation.

6.2 SENSITIVITY TESTS

A special region comprised of 70 routes with traffic density ranging from 55% to 400% of practical single track capacity in 1975 (and not growing over time) was the basis for the sensitivity tests. The diesel-electric costs for these routes can be interpolated to obtain a very nearly straight line graph with traffic density as the independent variable. For the sensitivity tests, the model is programed so that the "electric alternative" is immediate electrification regardless of traffic density; the graph of these costs is also nearly linear except for substantial step increases at the densities for which an additional electrified track is required. As a result of these discontinuities, the diesel-electric graphs may intersect in up to three places. For a route with traffic growing from year to year, the model would electrify the first, second, and third tracks, respectively, when the densities corresponding to the related crossover points are attained.

It is important to distinguish between the two types of sensitivity tests: the sensitivity of the <u>system</u> is tested when it is assumed that the model is simulating a real railroad to estimate the cost-effectiveness of a specified change in a variable of the system. In performing a systems test, all of the input variables affected by the simulated change must also be adjusted. The sensitvity of the <u>model</u> itself is tested if a variable is changed without further changes in the underlying system. For example, raising the speed of manifest trains by 10 mph probably cannot be accomplished in a railroad system without affecting characteristics measured by other variables. Hence, running the model with only the manifest speed changed would not be a realistic simulation of increased speeds in an actual railroad system. Model tests, nevertheless, are of interest because they help identify the potential errors that could arise if erroneous input data are used in estimating total costs.

The inputs for each of the sensitivity tests are shown in Figure 6-8 and the results are summarized in Figure 6-9. Three indicators are shown in Exhibit 6-9 for evaluating sensitivities. The first is the additional cost as compared to the cost estimated using the base values. At 58.6 gross tons per year, the traffic density chosen for summarizing sensitivity test results, the base costs are $37.1 million for electric and $36.0 million for diesel-electric. (Costs at other traffic densities are shown in Exhibit 6-10

EXHIBIT 6-6

COST SAVINGS ON
ECONOMICALLY ELECTRIFIABLE ROUTES

ROUTE NUMBER (by Rank in Skeleton Network)	REGION	TOTAL DISCOUNTED COSTS (millions of dollars)		SAVINGS WITH ELECTRIFICATION	
		Diesel-Electric	Electric	Cost Savings (millions of dollars)	Percent Savings
1	East	389.8	369.4	20.4	5
2	East	533.9	508.5	28.4	5
3	South	128.9	110.0	18.9	15
4	Mid-West	340.5	313.7	26.8	8
5	Mid-West	75.3	69.3	6.0	8
6	East	105.6	83.3	72.3	21
7	West	381.2	379.6	1.6	0
9	East	173.8	152.1	21.7	12
10	South	55.4	45.6	9.8	18
14	Mid-West	270.4	267.8	2.6	1
18	East	146.7	128.5	18.2	12
24	South	41.6	39.1	2.5	6
26	West	379.2	334.5	44.7	12
28	West	128.7	113.9	14.8	11
30	South	31.3	29.7	1.6	5
32	West	399.6	353.0	46.6	12
37	West	392.7	371.9	20.8	5
53	South	37.8	35.9	1.9	5
TOTALS		4012.4	3705.8	359.6	9

EXHIBIT 6-7

REGIONAL COMPARISON OF COST SAVINGS
UNDER ELECTRIFICATION

REGION	ROUTE MILES	TOTAL DISCOUNTED COSTS (millions of dollars) Diesel-electric	Electric	COST SAVINGS WITH ELECTRIC (millions of dollars)	COST SAVINGS PER ROUTE MILE (Millions of dollars per mile)
EAST	1550	2218.6	2107.6	161.0	.104
SOUTH	531	486.0	451.3	34.7	.065
MIDWEST	1015	1911.2	1875.8	35.4	.035
WEST	3075	1809.4	1680.9	128.5	.042
TOTALS	6171	6425.2	6115.6	359.6	.053

EXHIBIT 6-8

SUMMARY OF SENSITIVITY TEST INPUTS

TEST(Model or System)	Main Variable(s) Under Consideration	Base Value	Test Value	Accompanying Changes in Other System Inputs
1. BASE				For base values of system see Exhibits through
2. Electric locomotive life 40 (system)	Electric locomotive life	30 years	40 years	None
3. Diesel-electric locomotive life 20 (system)	Diesel-electric locomotive life	15 years	20 years	None
4. Electric life 40/ Diesel life 20 (system)	Electric life; Diesel-electric life	30;15	40;20	None
5. Bigger manifest electric (system)	Horsepower of manifest electric Price of manifest electric	5300 Hp $575,000 in 1975	8000 Hp $867,000 in 1975	f Manifest electric = .333
6. Bigger manifest diesel-electric (system)	Horsepower of manifest diesel-electric Price of manifest diesel-electric	2800 Hp $391,000 in 1975	3570 Hp $421,000 in 1975	None
7. Bigger diesel-electric for both services (system)	Horsepower of manifest & & drag-diesel electric Price of manifest & drag diesel-electric	2800 $391,000	3570 $421,000	f Drag, diesel-electric = .222
8. Slugs for electric drag service (system)	Weight of drag electric locomotives Axles of drag electric locomotives Price of drag electric locomotives Maintenance of drag electric locomotives	180 tons/unit 6 axles/unit $575,000 in 1975 $ 18,400/unit-year in 1975	360 12 $805,000 in 1975 $ 35,880 in 1975	f Drag, electric = .35

EXHIBIT 6-8 (cont.)

SUMMARY OF SENSITIVITY TEST INPUTS

TEST(Model or System)	Main Variable(s) Under Consideration	Base Value	Test Value	Accompanying Changes in Other System Inputs
9. All adhesion up 20% (system)	Electric factor of adhesion Diesel-electric factor of adhesion	.25 .18	.30 .216	[f] Drag, electric = .229 [f] Drag,diesel-electric = .30
10. Diesel-electric adhesion = .25 (system)	Diesel-electric factor of adhesion	.18	.25	[f] Drag, diesel-electric = .347
11. A mountain railroad (system)	Ruling grade Average manifest speed	1.6% 40 mph	2.5% 30 mph	[f] Manifest, electric = .3 [f] Manifest, diesel-electric = .3 [f] Drag,electric = .114 [f] Drag,diesel-electric = .15
12. A flat railroad (system)	Ruling grade	1.6%	1.0%	[f] Manifest, electric = .53 [f] Manifest,diesel-electric = 5.0 [f] Drag,electric = .34 [f] Drag,diesel-electric = .46
13. Ruling grade up 20% (model)	Ruling grade	1.6%	1.92%	——
14. Ruling grade down 20% (model)	Ruling grade	1.6%	1.28%	——
15. "Average grade and curvature resistance" up 20% (system)	"Average Grade & curve resistance," manifest "Average Grade & curve resistance," drag	5.5 pounds/ gross ton 4.29 pounds/ gross ton	6.6 5.15	——

EXHIBIT 6-8 (cont.)

SUMMARY OF SENSITIVITY TEST INPUTS

TEST(Model or System)	Main Variable(s) Under Consideration	Base Value	Test Value	Accompanying Changes in Other System Inputs
16. "Average grade and curvature resistance" down 20% (model)	"Grade & curve resistance," manifest	5.5	4.4	——
	"Grade & curve resistance,"drag	4.29	3.43	
17. Freight cars: invest only in 1975 (system)	Price of freight cars, after 1975	$22,600 in 1980	Free	None
18. Catenary cost lower(system)	Price of catenary per track mile	$50,000 in 1975	$33,000 in 1975	None
19. Higher locomotive maintenance (system)	Maintenance of electrics/ unit-year	$18,400 in 1975	$24,000 in 1975	None
	Maintenance of diesel-electric/unit-year	$46,000 in 1975	$60,000 in 1975	
20. Lower locomotive maintenance (system)	Maintenance of electrics/ unit-year	$18,400	$ 9,000	None
	Maintenance of diesels/ unit-year	$46,000	$22,000	
21. Lower electric power cost (system)	Price of a Kilowatt-hour	1.3¢ in 1975	1.1¢ in 1975	None
22. Lower diesel fuel cost (system)	Price of a gallon of diesel fuel	14.2¢ in 1975	12.3¢ in 1975	None
23. Electric power and diesel fuel costs lower (system)	Electric power cost; Diesel fuel cost	1.3¢; 14.2¢	1.1¢; 12.3¢	None

EXHIBIT 6-8 (cont.)

SUMMARY OF SENSITIVITY TEST INPUTS

TEST(Model or System)	Main Variable(s) Under Consideration	Base Value	Test Value	Accompanying Changes in Other System Inputs
24. Lower locomotive availability (system)	Electric locomotive availability	58%	38%	None
	Diesel-electric locomotive availability	52%	32%	
25. Higher locomotive availability (system)	Electric locomotive availability	58%	78%	None
	Diesel-electric locomotive availability	52%	72%	
26. 35% Drag traffic (model)	Drag Gross Ton-Miles/ Total GTM	.65	.35	___
27. 100% Drag traffic (model)	Drag GTM/Total GTM	.65	1.00	___
28. 100% Manifest traffic (model)	Drag GTM/Total GTM	.65	0.00	___
29. Manifest speed 50 mph (model)	Average manifest speed	40 mph	50 mph	___
30. Best electric case (system)	Combination: Electric locomotive life = 40 years; Use of slug unit for drag; Mountain railroad grades; lower catenary cost; higher locomotive maintenance costs; lower electric power costs; lower locomotive availability; lower load factor.			
31. Best diesel-electric case (system)	Combination: Diesel-electric locomotive life = 20 years; bigger manifest diesel-electric; diesel-electric adhesion = 25%; lower maintenance; lower diesel fuel cost; higher availability.			

EXHIBIT 6-9

SUMMARY OF SENSITIVITY TEST RESULTS

TEST	VARIABLE (Used to calculate elasticity)	ADDITIONAL COSTS* (millions of dollars) Electric	Diesel-electric	ELASTICITY** Electric	Diesel-electric	CROSSOVER POINTS (million gross tons/year) First Track	Second Track	Third Track
1. BASE						Diesel-elec.	126	Electric
2. Electric locomotive life 40 (system)	Locomotive life	-0.1	0	-0.008	.0	Diesel-elec.	121	Electric
3. Diesel-electric locomotive life 20 (system)	Locomotive life	0	-1.0	0	0.083	Diesel-elec.	147	Electric
4. Electric life 40/ Diesel life 20 (system)	Locomotive life	-0.1	-1.0	-0.008	0.083	Diesel-elec.	140	Electric
5. Bigger manifest electric (system)	Locomotive horsepower	0.4	0	0.021	0	Diesel-elec.	128	Electric
6. Bigger manifest diesel-electric (system)	Locomotive horsepower	0.3	- 0.8	0.029	0.081	Diesel-elec.	146	Electric
7. Bigger diesel-electric for both services (system)	Locomotive horsepower	-0.9	- 1.0	- 0.087	0.10	Diesel-elec.	141	Electric

* Additional costs estimated with the test values as compared with the base values, for operations at 58.6 million gross tons per year.

** Elasticity = $\frac{\text{change in costs}}{\text{base costs}} \div \frac{\text{change in variable}}{\text{base value of variable}}$ for operations at 58.6 million gross tons per year.

EXHIBIT 6-9 (cont.)

SUMMARY OF SENSITIVITY TEST RESULTS

TEST	VARIABLE (Used to calculate elasticity)	ADDITIONAL COSTS (millions of dollars)		ELASTICITY		CROSSOVER POINTS (million gross tons/year)		
		Electric	Diesel-electric	Electric	Diesel-electric	First Track	Second Track	Third Track
8. Slugs for electric drag service (system)	Locomotive horsepower	-1.6	-0.2	-0.086	-0.011	56	109	Electric
9. All adhesion up 20% (system)	Adhesion	-1.1	-1.9	-0.15	-0.26	Diesel-elec.	141	Electric
10. Diesel-electric adhesion = .25 (system)	Adhesion	1.0	-3.5	0.069	-0.25	Diesel-elec.	Diesel	Diesel-elec.
11. A mountain railroad (system)	Ruling grade	5.0	12.0	0.25	0.59	38	76	Electric
12. A flat railroad (system)	Ruling grade	-3.2	-7.1	0.23	0.53	Diesel-elec.	213	Diesel-elec.
13. Ruling grade up 20% (model)	Ruling grade	0.2	1.2	0.027	0.17	Diesel-elec.	120	Electric
14. Ruling grade down 20% (model)	Ruling grade	-0.3	-0.2	0.04	0.03	Diesel-elec.	129	Electric

EXHIBIT 6-9 (cont.)

SUMMARY OF SENSITIVITY TEST RESULTS

TEST	VARIABLE (Used to calculate elasticity)	ADDITIONAL COSTS (millions of dollars) Electric	Diesel-electric	ELASTICITY Electric	Diesel-electric	CROSSOVER POINTS (million gross tons/year) First Track	Second Track	Third Track
15. Average grade and curvature resistance up 20% (system)	Average grade	1.9	5.0	0.26	0.69	54	106	Electric
16. Average grade and curvature resistance down 20% (model)	Average grade	-1.3	-2.9	0.18	0.40	Diesel-elec.	153	225
17. Freight cars: invest only in 1975(system)	———	.0	-0.1	———	———	Diesel-elec.	128	Electric
18. Catenary cost lower (system)	Catenary Cost	-1.8	0	0.15	0	54	104	Electric
19. Higher locomotive maintenance (system)	Locomotive maintenance	1.0	4.5	0.074	0.34	46	92	Electric
20. Lower locomotive maintenance (system)	Locomotive maintenance	-1.6	-7.8	0.083	0.42	Diesel-elec.	Diesel	Diesel-elec.
21. Lower electric power cost (system)	Fuel	-2.6	0	0.46	0	49	98	Electric

EXHIBIT 6-9 (cont.)

SUMMARY OF SENSITIVITY TEST RESULTS

TEST	VARIABLE (Used to calculate elasticity)	ADDITIONAL COSTS (millions of dollars) Electric	Diesel-electric	ELASTICITY Electric	Diesel-electric	CROSSOVER POINTS (million gross tons/year) First Track	Second Track	Third Track
22. Lower diesel fuel cost (system)	Fuel	0	-2.1	0	0.44	Diesel-elec.	157	231
23. Electric power and diesel fuel costs lower (system)	Fuel	-2.6	-2.1	0.46	0.44	Diesel-elec.	116	Electric
24. Lower locomotive availability (system)	Locomotive Availability	4.7	15.0	-0.35	-1.14	Electric	64	Electric
25. Higher locomotive availability (system)	Locomotive Availability	1.4	5.9	-0.10	-0.45	Diesel-elec.	206	Diesel-elec.
26. 35% Drag traffic (model)	____	0.3	2.0	____	____	60	121	Electric
27. 100% Drag traffic (model)	____	-0.2	0.7	____	____	Diesel-elec.	123	Electric
28. 100% Manifest traffic (model)	____	1.7	3.2	____	____	58	116	Electric

EXHIBIT 6-9 (cont'd.)

SUMMARY OF SENSITIVITY TEST RESULTS

TEST	VARIABLE (Used to calculate elasticity)	ADDITIONAL COSTS* (millions of dollars) Electric	Diesel-electric	ELASTICITY** Electric	Diesel-electric	CROSSOVER POINTS (million gross tons/year) First Track	Second Track	Third Track
29. Manifest speed 50 mph (model)	Manifest speed	1.2	2.0	0.13	0.22	Diesel-elec.	123	Electric
30. Best electric case(system)	____	6.9	45.0	____	____	Electric	Electric	Electric
31. Best diesel-electric case (system)	____	1.8	-16.0	____	____	Diesel-elec.	Diesel	Diesel-elec.

for the base values). The additional costs shown in Exhibit 6-8 are changes to these base costs.

A second indicator is the elasticity. This represents the magnitude of the sensitivity of costs to the test variable. The higher the absolute value of the elasticity, the stronger the sensitivity. The third indicator is the change in crossover points. For the base values the crossover occurs at about 126 gross tons per year or slightly greater than 200% of practical single track capacity, as shown in Exhibit 6-10. The crossover points in Exhibit 6-9 show the impact of the changed inputs on the traffic density at which electrification is economical. Changes making electrification more economical reduce the traffic density at which crossover occurs.

Graphs of the estimated total discounted costs for a selected number of the sensitivity tests are provided in Exhibits 6-11 through 6-23. The significance of key sensitivity tests is discussed briefly in the following paragraphs.

6.2.1 <u>Locomotive Characteristics</u>. The variables relating to locomotives are obviously important, but especially for diesel-electric, where locomotives are the principal continuing investment item. Tests 2-4 show that extension of locomotive life by a third is over ten times as beneficial to a diesel-electric route. Tests 5-8 show that electric locomotives have so much horsepower per ton that further power, even when restricted to manifest (Test 5), is largely wasted except on the flattest and fastest roads. Higher horsepower diesel-electrics, on the other hand, pay off fairly well in manifest service (Test 6) (because there are fewer units to maintain) but the power cannot be put to use for drag (Test 7). Turning to less powerful locomotives, the tests show that the use of electric slug units would yield good savings in drag service (Test 8).

Increases in adhesion,in the case of drag service, show nearly proportional gains in utilization. This leads to dramatic savings, especially if it can be achieved for diesel-electric (Tests 9 & 10).

6.2.2 <u>Grades</u>. It has long been known that electrification is more desirable in rough terrain. In the "mountain railroad" sensitivity test (Test 11), the load factor is cripplied by the ruling grade for drag and by the slow going for manifest. Hence more locomotives are needed, and this increases diesel-electric costs about twice as much as electric. The reverse effect helps the diesel-electric more on the flat railroad (Test 12).

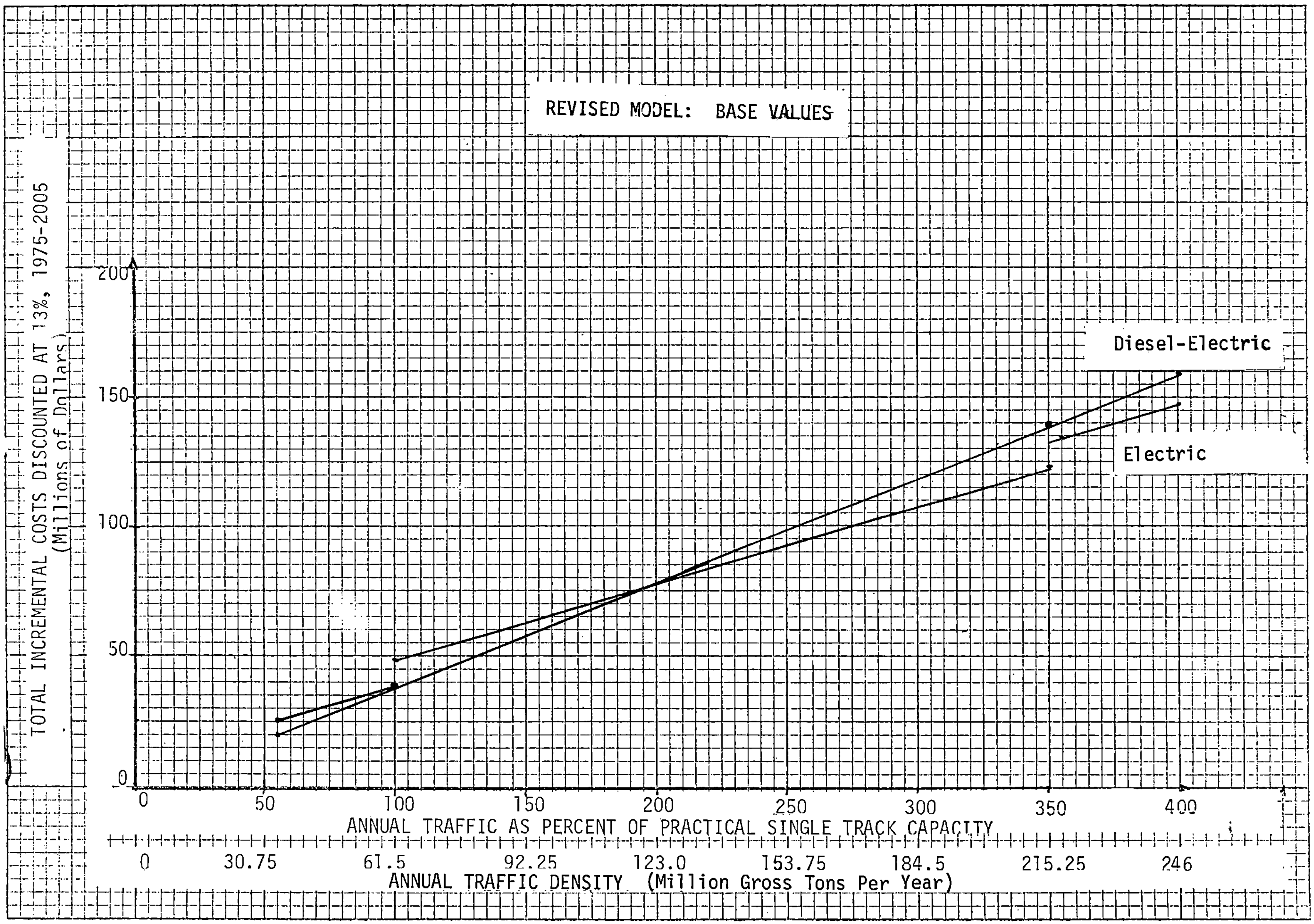

REVISED MODEL: BASE VALUES
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005
(Millions of Dollars)
200
150
100
50
0
Diesel-Electric
Electric
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-10

The sensitivity of the model to variations in the resistance due to ruling and "average" grades (Tests 13-16) was also tested. The great sensitivity shown to average grade and curvature resistance confirms the need for TPC runs and consistency with other variables in estimating its value correctly.

6.2.3 Investment and Operating Costs. The greater power of electrics expedites only part of the road operations and none of the yard operations, so the savings from more rapid over-the-road movement of freight cars is negligible (Test 17). Catenary, on the other hand, is a big part of the cost of electrification (Test 18) and the total costs are quite sensitive to catenary costs.

Sensitivity tests 19 and 20 show that the cost of maintaining locomotives can make or break the diesel-electric alternative. This cost item, above all others, must be carefully ascertained and its trend astutely forecast. Fuel costs are also a major cost under either alternative (Tests 21-23) and are unfortunately subject to considerable uncertainties.

6.2.4 Operations. Locomotive availability is a very important variable and, as usual, it affected diesel-electric costs three or four times as much as the electric (Tests 24 & 25). Low locomotive availability due to such factors as seasonal peaking of traffic strongly favors electrification.

The sensitivities of the model with respect to traffic composition (Tests 26-28) and manifest speed (Test 29) were also tested. Fairly small changes in total cost arise within the plausible domains of these fairly uncertain inputs.

6.2.5 Composite Tests. Clearly, the system has sufficiently complex interrelationships that the effect of two simultaneous changes is not necessarily the sum of their separate effects. In particular, changes that decrease locomotive utilization will increase the importance of locomotives in the total costs and thereby augment the sensitivity of costs related to locomotive fleet size. Changes that increase resistance and energy consumption will not only increase the sensitivity of costs to variables related to locomotive inventory, but will also raise fuel consumption.

The "best electric" and "best diesel-electric" cases (Tests 30 & 31) display these synergistic effects on total costs, especially in the diesel-electric alternative.

They also reveal the wide variation in total costs that is possible within reasonable bounds for the inputs.

6.2.6 Discount Rate. In addition to the tests shown in Exhibits 6-8 and 6-9, the sensitivity of costs to discount rate was tested. Exhibit 6-21and 6-22 show that at 10% and 16%, the crossover points are of approximately 80% or 135% (for first or second tracks) and 300%, respectively. Exhibit 6-23 shows that the electric system becomes lower in total incremental discounted costs at about 12% discount rate. Recalling that these discount rates have been increased by 3% to offset the general inflation reflected in the prices used, it can be concluded that electrification is economical at base values for other inputs for social rates of discount below 9%.

6.3 RESULTS BASED ON PRIVATE MONEY COSTS

Private money costs differ from social costs through the inclusion of annualized investment costs, interest charges, taxes, and equity calculations (instead of the simple calculation of residual economic life used in social resource costing).

Under private money costing, it was assumed that all investment items were paid on an annual basis, not as a lump sum at time of purchase. The results of tests made with the original model show only a modest change in the crossover point from diesel-electric to electric in terms of percent of practical single track capacity.

Even though private money costs were not estimated using the revised model, nor developed for each of the high-density routes used in the skeleton network, it seems reasonable to conclude that electrification is favorable to approximately the same extent for private as for social resource costs.

It is important to emphasize the conclusion drawn from the composite sensitivity tests of best electric and best diesel-electric situations. Individual railroads will undoubtedly experience combinations of conditions that differ from the average values assumed for both social resource cost and private money cost estimates. As a result, railroad companies evaluating electrification for specific routes will find situations both more and less favorable for electrification than the base cases assumed here. It is particularly important that conclusions drawn from such particularized analysis be kept in proper perspective when considering the national analyses conducted in this study.

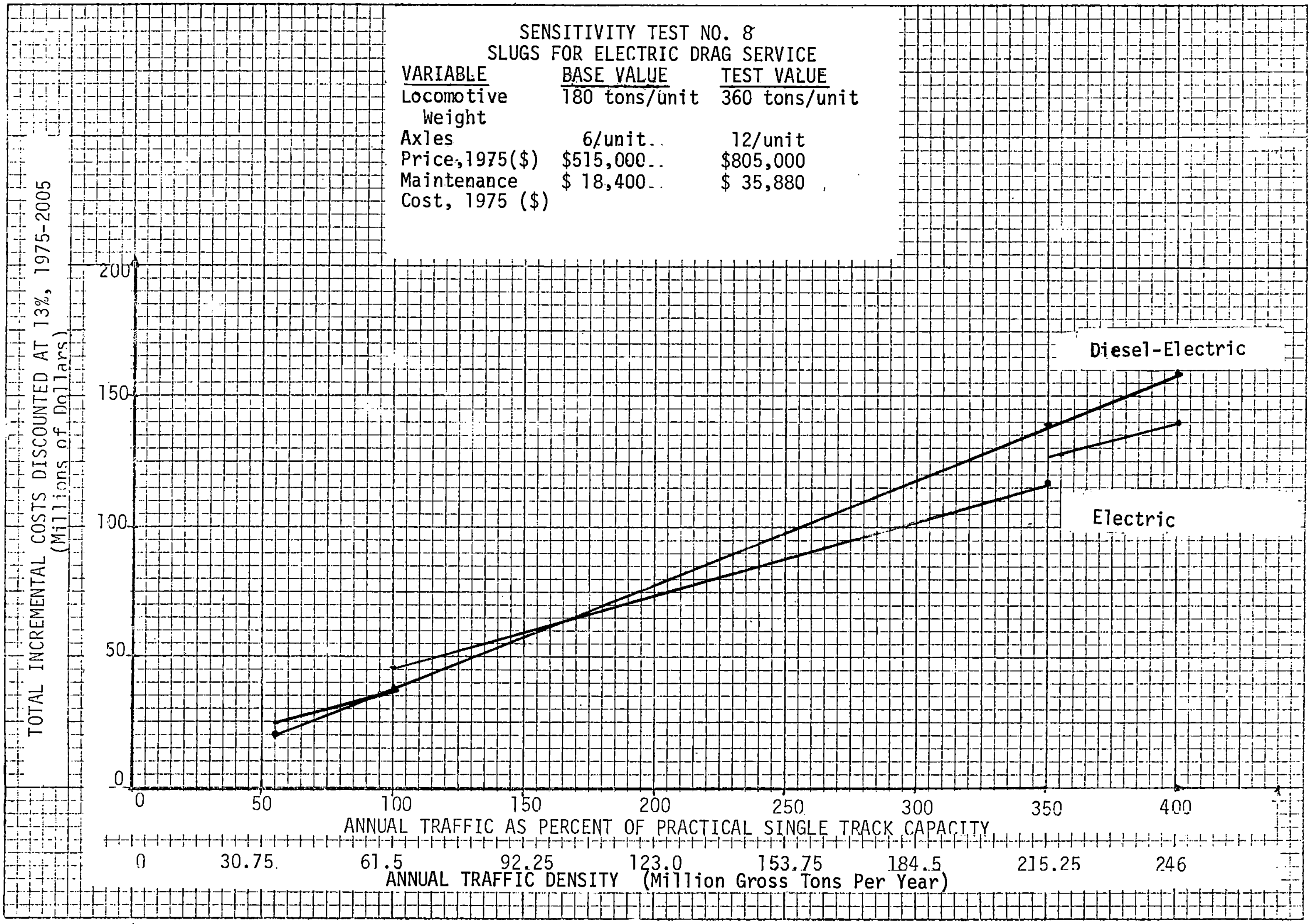

SENSITIVITY TEST NO. 8
SLUGS FOR ELECTRIC DRAG SERVICE
VARIABLE
BASE VALUE
TEST VALUE
Locomotive Weight
180 tons/unit
360 tons/unit
Axles
6/unit
12/unit
Price, 1975 ($)
$515,000
$805,000
Maintenance Cost, 1975 ($)
$ 18,400
$ 35,880
Diesel-Electric
Electric
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005 (Millions of Dollars)
0
50
100
150
200
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-11

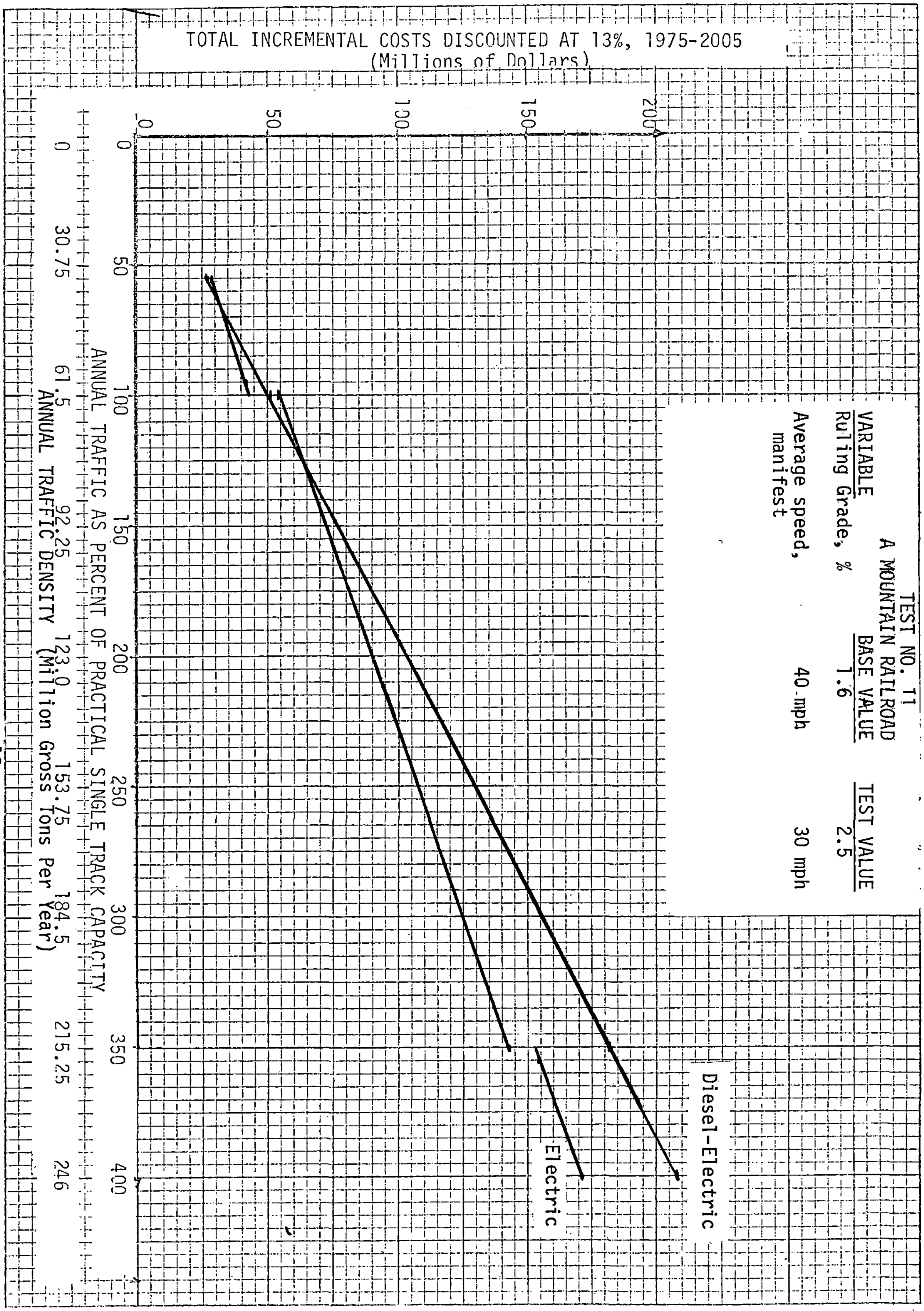

TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005
(Millions of Dollars)
0
50
100
150
200
TEST NO. 11
A MOUNTAIN RAILROAD
VARIABLE
BASE VALUE
TEST VALUE
Ruling Grade, %
1.6
2.5
Average speed, manifest
40 mph
30 mph
Diesel-Electric
Electric
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246

Exhibit 6-12

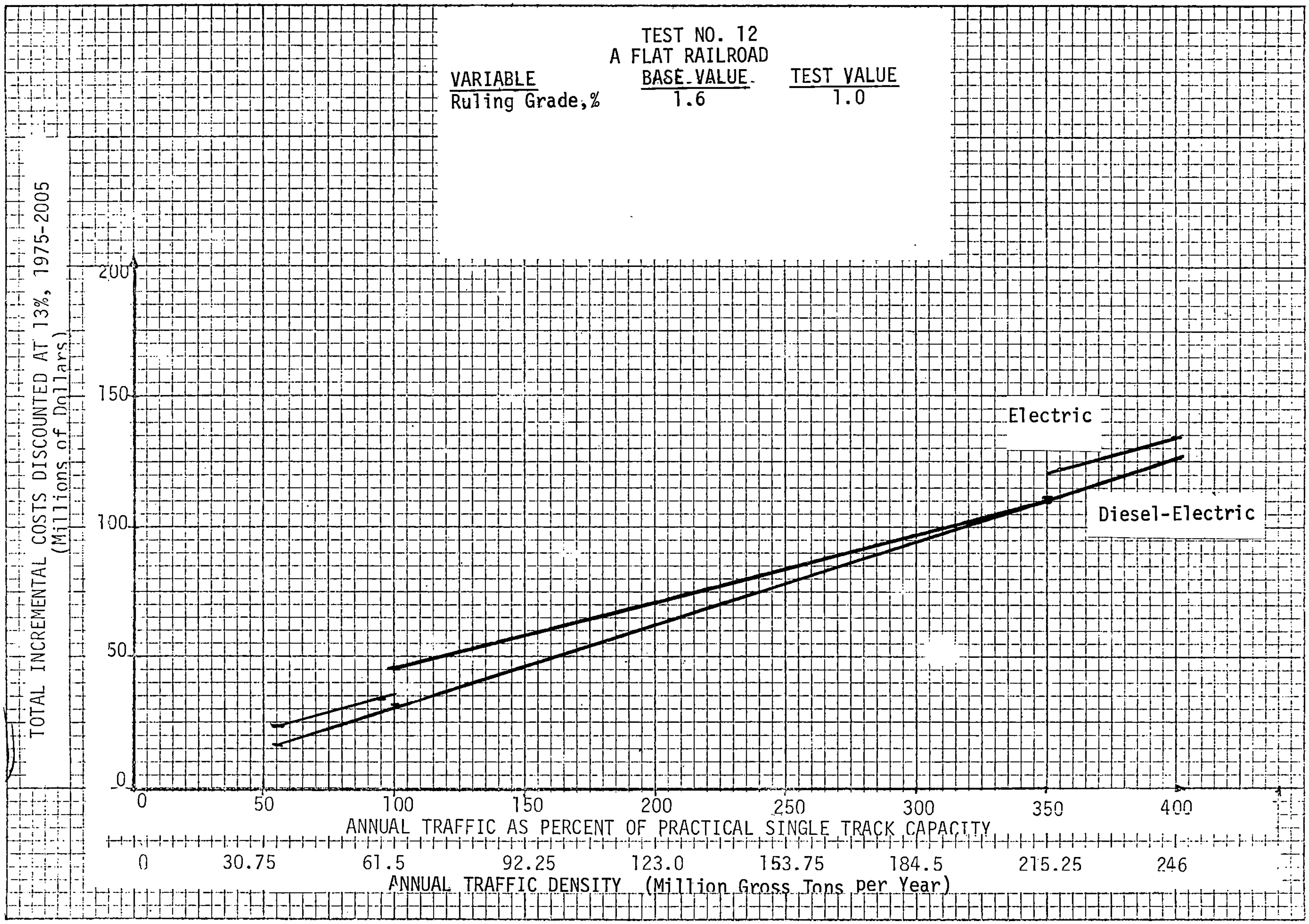

TEST NO. 12
A FLAT RAILROAD
VARIABLE
Ruling Grade,%
BASE VALUE
1.6
TEST VALUE
1.0
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005
(Millions of Dollars)
200
150
100
50
0
Electric
Diesel-Electric
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons per Year)

Exhibit 6-13

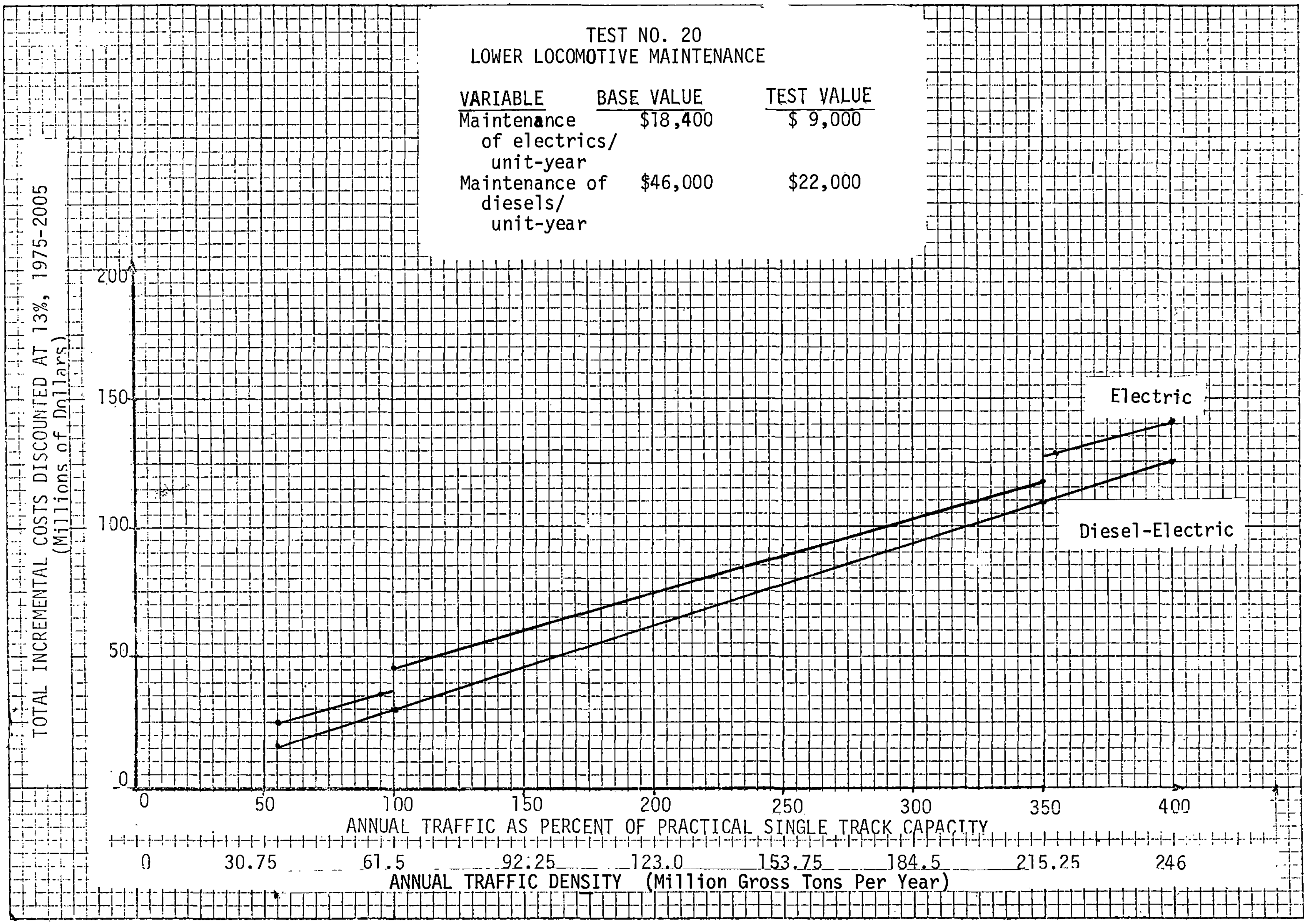

TEST NO. 20
LOWER LOCOMOTIVE MAINTENANCE
VARIABLE
BASE VALUE
TEST VALUE
Maintenance of electrics/ unit-year
$18,400
$ 9,000
Maintenance of diesels/ unit-year
$46,000
$22,000
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005 (Millions of Dollars)
200
150
100
50
0
Electric
Diesel-Electric
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-14

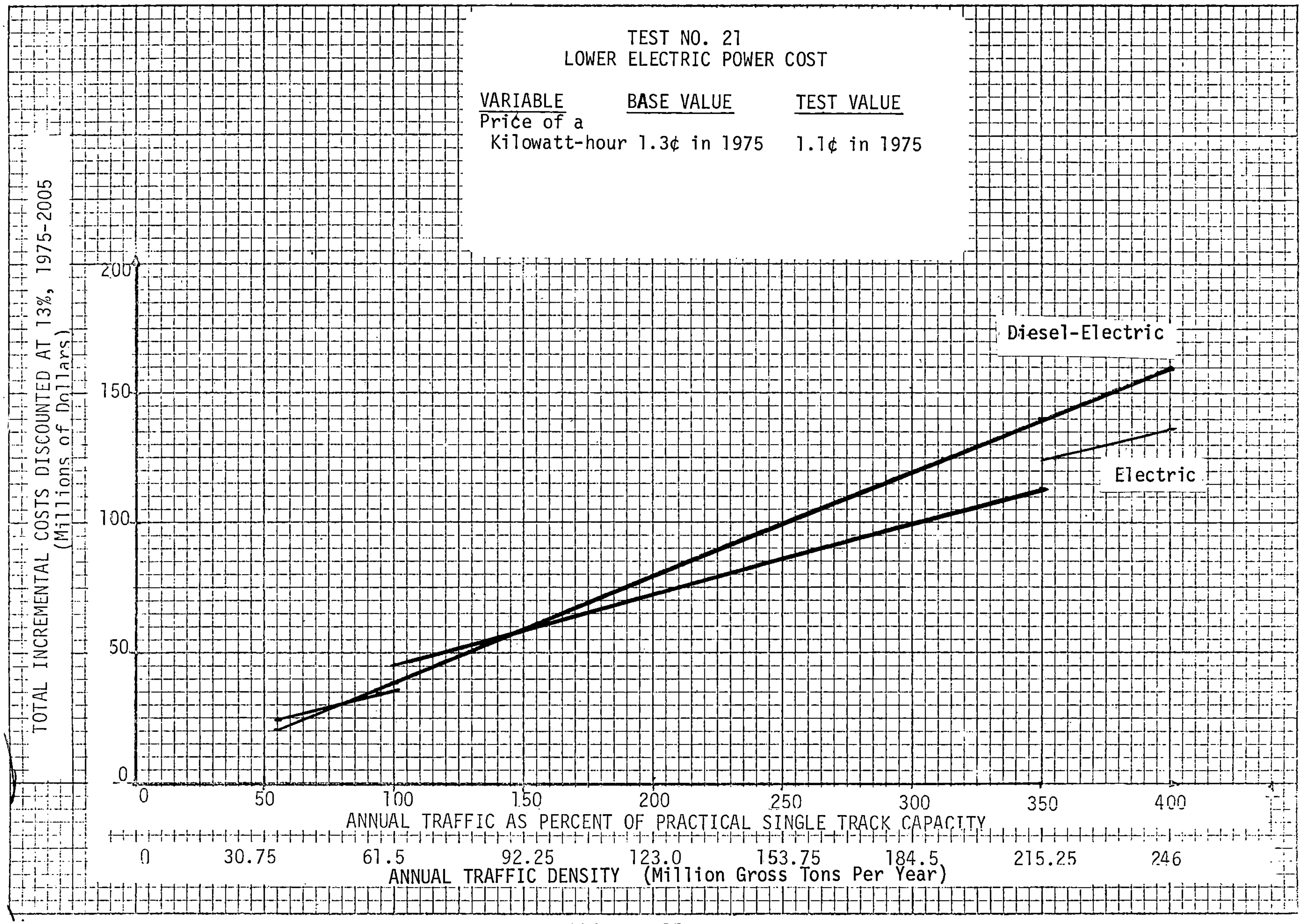

TEST NO. 21
LOWER ELECTRIC POWER COST
VARIABLE
BASE VALUE
TEST VALUE
Price of a Kilowatt-hour
1.3¢ in 1975
1.1¢ in 1975
Diesel-Electric
Electric
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005
(Millions of Dollars)
0
50
100
150
200
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-15

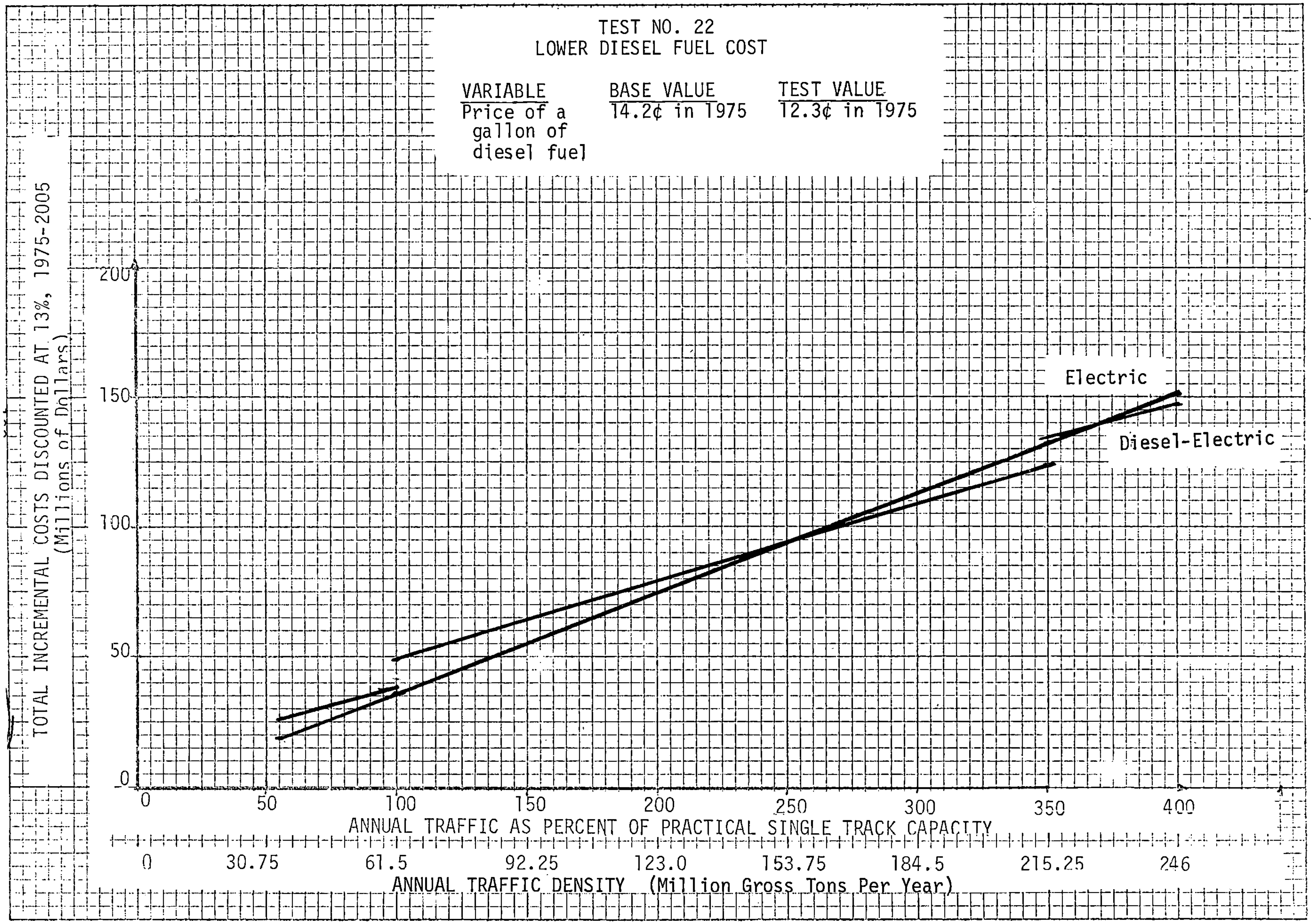
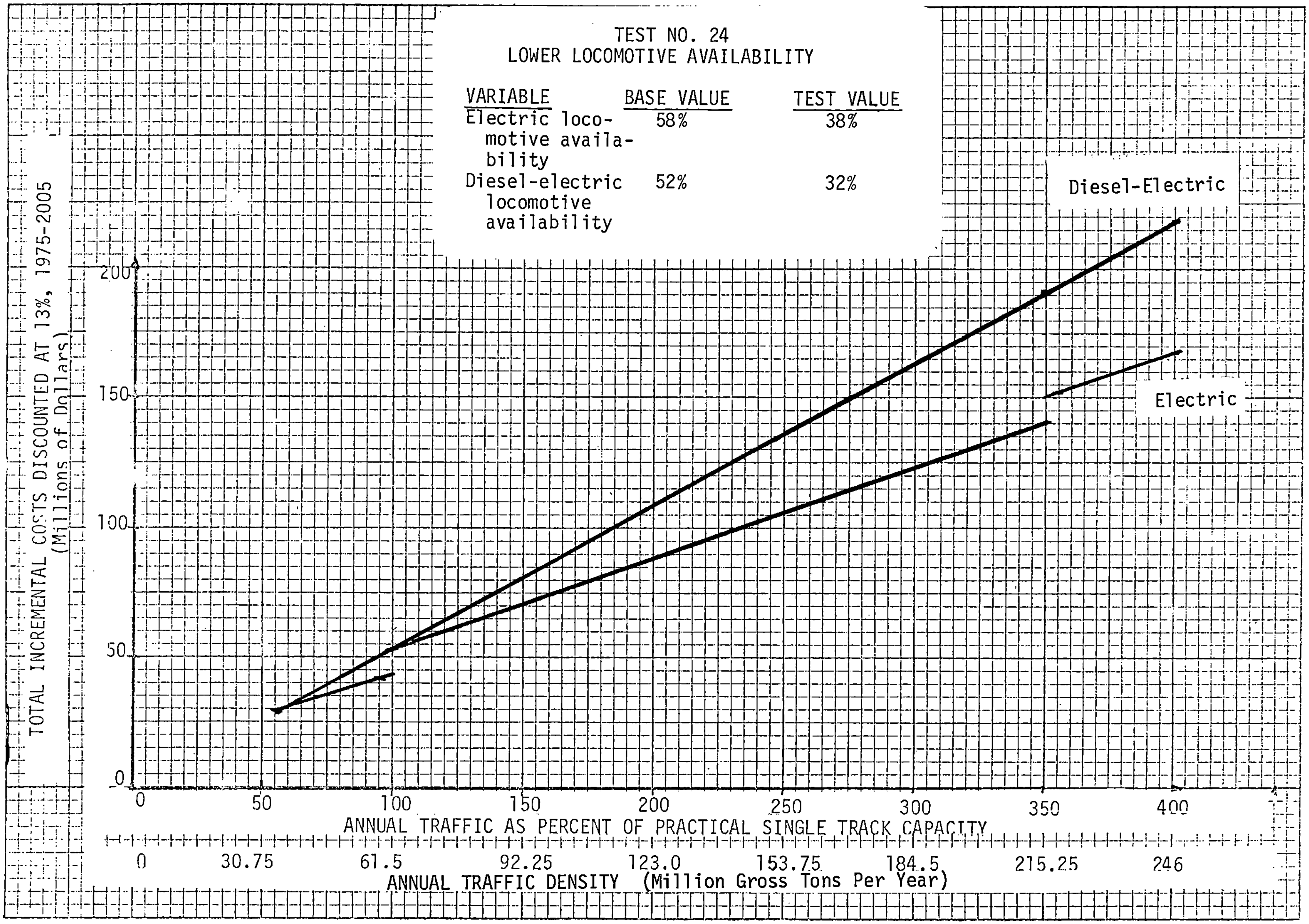

TEST NO. 22
LOWER DIESEL FUEL COST
VARIABLE
BASE VALUE
TEST VALUE
Price of a gallon of diesel fuel
14.2¢ in 1975
12.3¢ in 1975
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005 (Millions of Dollars)
0
50
100
150
200
Electric
Diesel-Electric
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-16



TEST NO. 24
LOWER LOCOMOTIVE AVAILABILITY
VARIABLE | BASE VALUE | TEST VALUE
Electric locomotive availability | 58% | 38%
Diesel-electric locomotive availability | 52% | 32%
Diesel-Electric
Electric
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005 (Millions of Dollars)
0
50
100
150
200
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-17

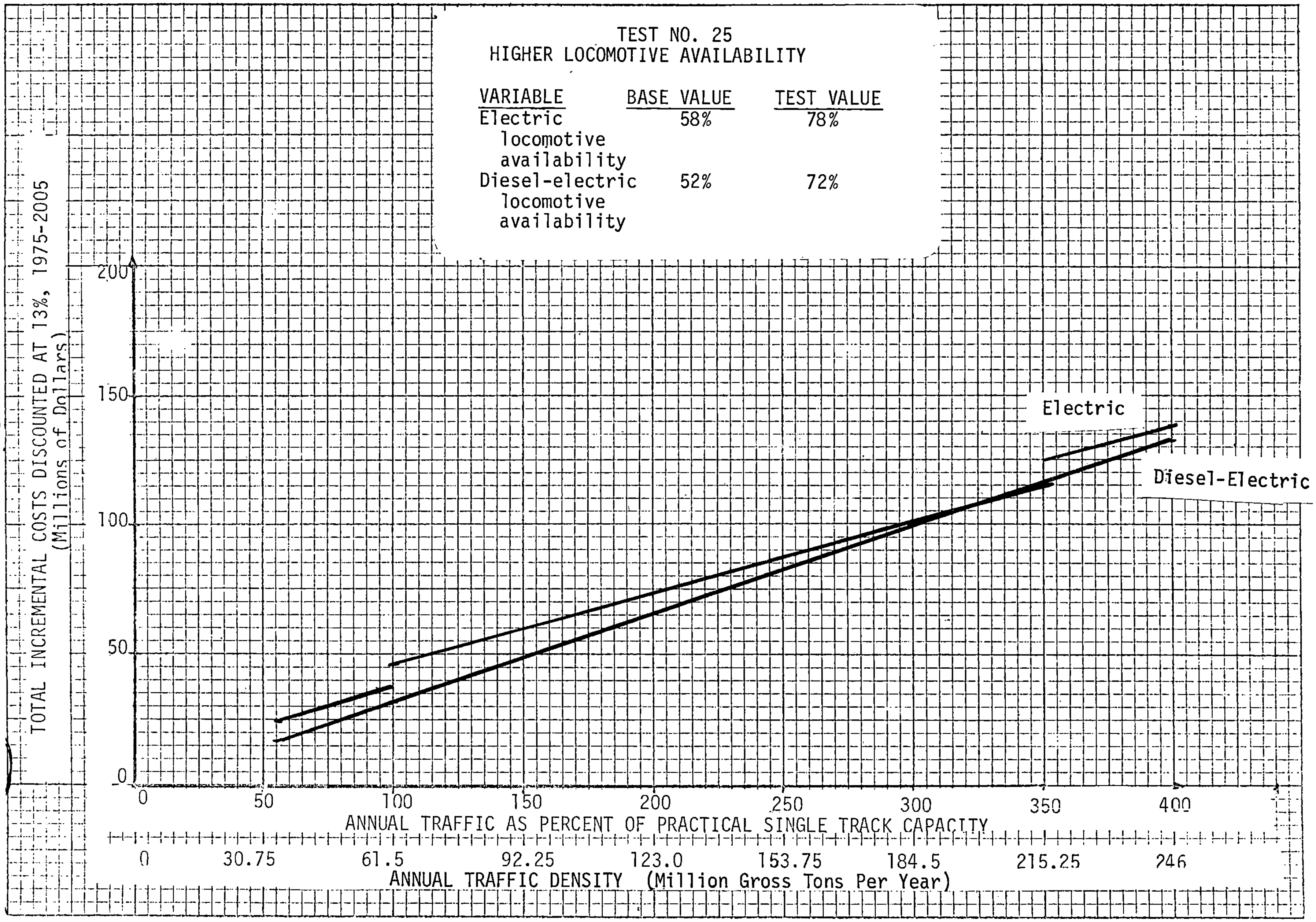
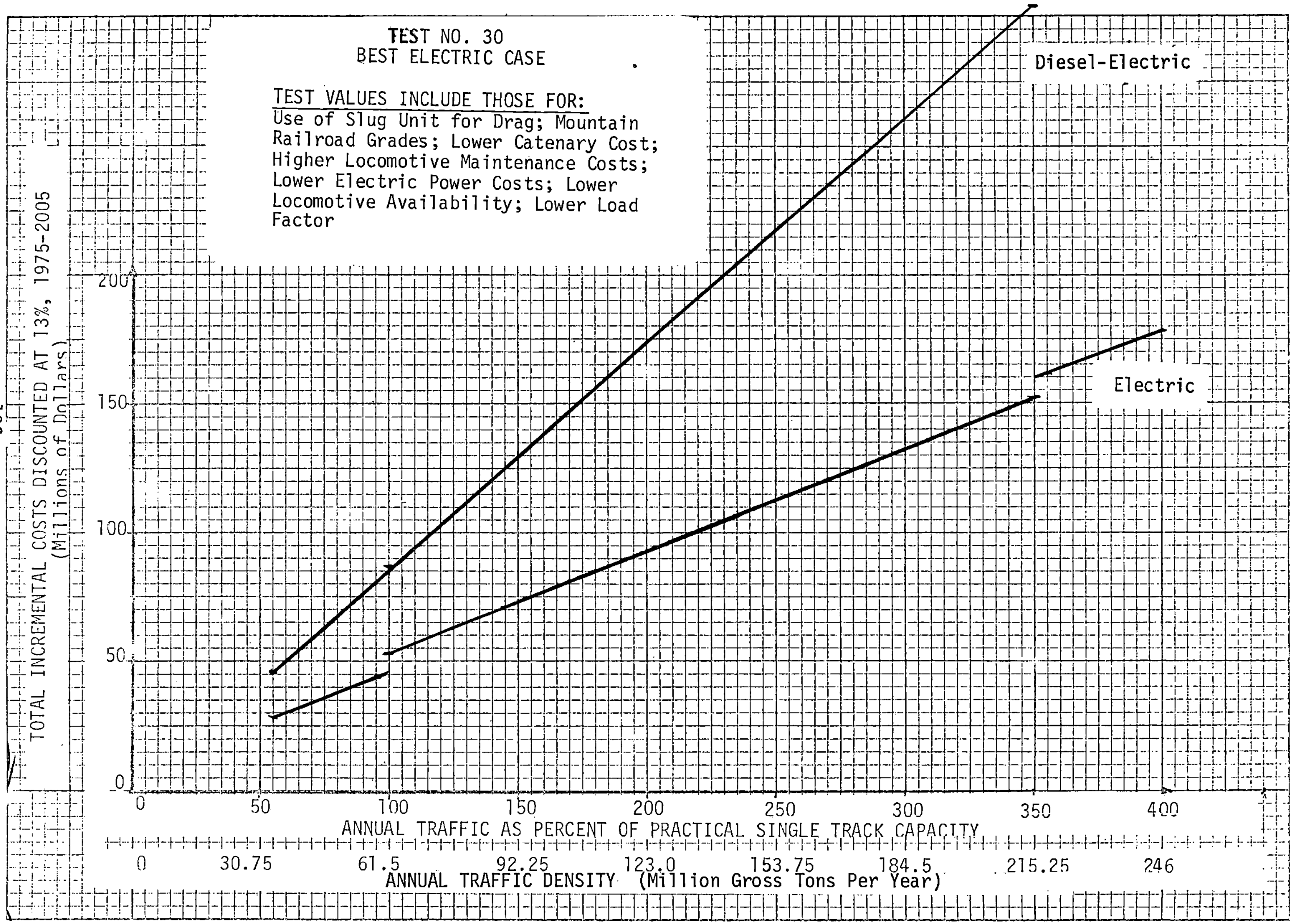

TEST NO. 25
HIGHER LOCOMOTIVE AVAILABILITY
VARIABLE | BASE VALUE | TEST VALUE
Electric locomotive availability | 58% | 78%
Diesel-electric locomotive availability | 52% | 72%
Electric
Diesel-Electric
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005 (Millions of Dollars)
0
50
100
150
200
0 50 100 150 200 250 300 350 400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0 30.75 61.5 92.25 123.0 153.75 184.5 215.25 246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-18



TEST NO. 30
BEST ELECTRIC CASE
TEST VALUES INCLUDE THOSE FOR:
Use of Slug Unit for Drag; Mountain Railroad Grades; Lower Catenary Cost; Higher Locomotive Maintenance Costs; Lower Electric Power Costs; Lower Locomotive Availability; Lower Load Factor
Diesel-Electric
Electric
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005
(Millions of Dollars)
200
150
100
50
0
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-19

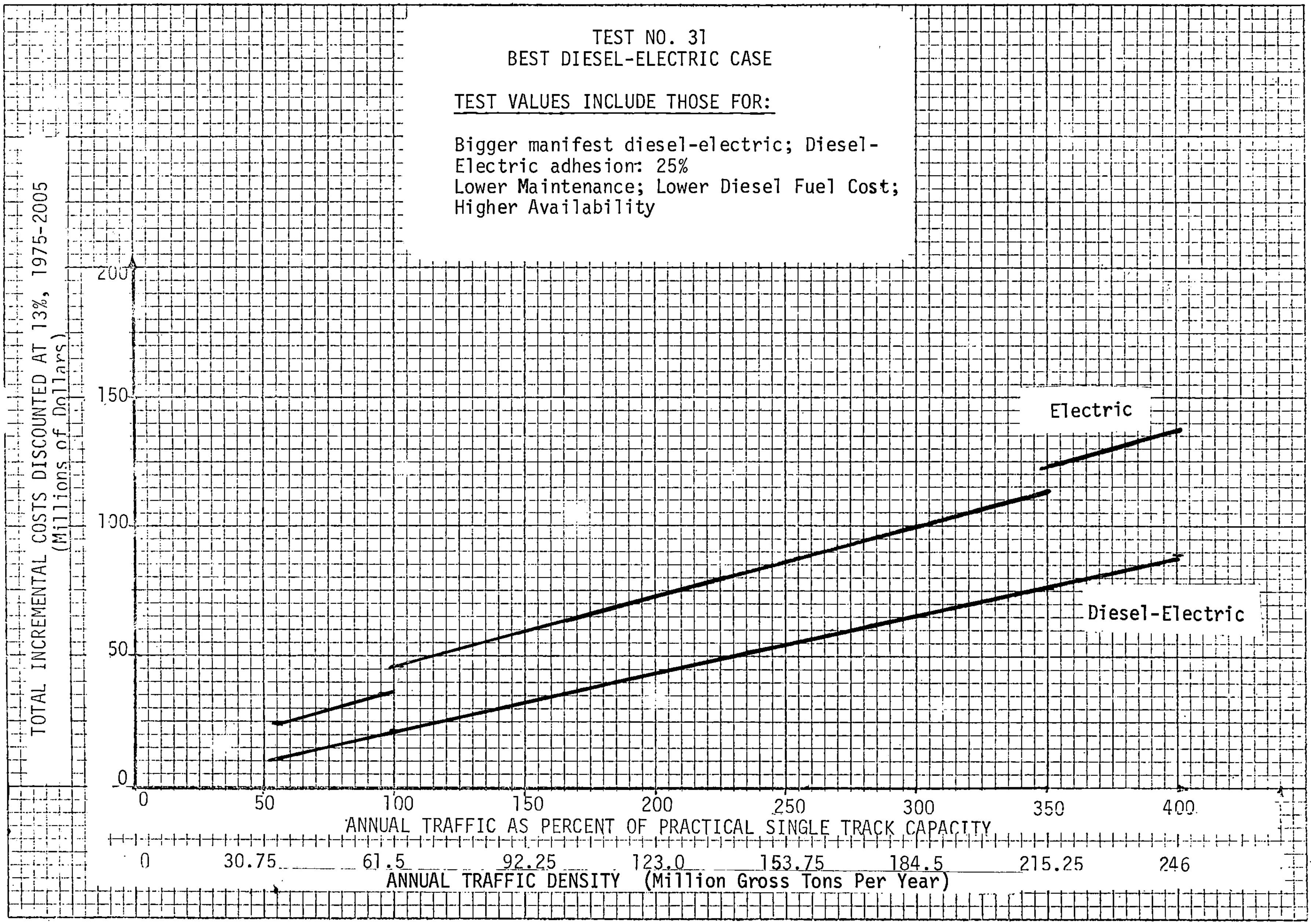

TEST NO. 31
BEST DIESEL-ELECTRIC CASE
TEST VALUES INCLUDE THOSE FOR:
Bigger manifest diesel-electric; Diesel-Electric adhesion: 25%
Lower Maintenance; Lower Diesel Fuel Cost;
Higher Availability
TOTAL INCREMENTAL COSTS DISCOUNTED AT 13%, 1975-2005
(Millions of Dollars)
200
150
100
50
0
Electric
Diesel-Electric
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-20

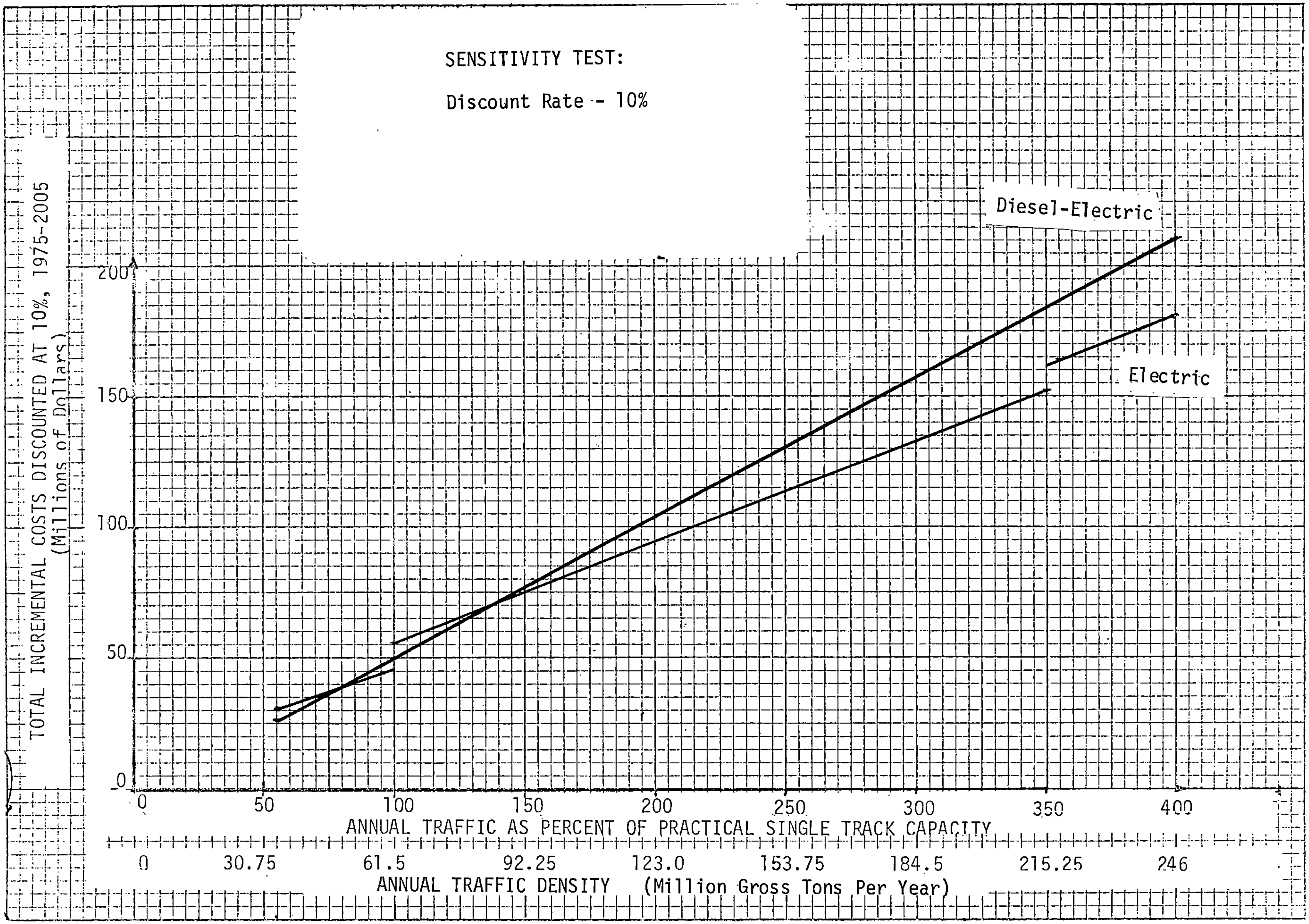

SENSITIVITY TEST:
Discount Rate - 10%
TOTAL INCREMENTAL COSTS DISCOUNTED AT 10%, 1975-2005
(Millions of Dollars)
200
150
100
50
0
Diesel-Electric
Electric
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-21

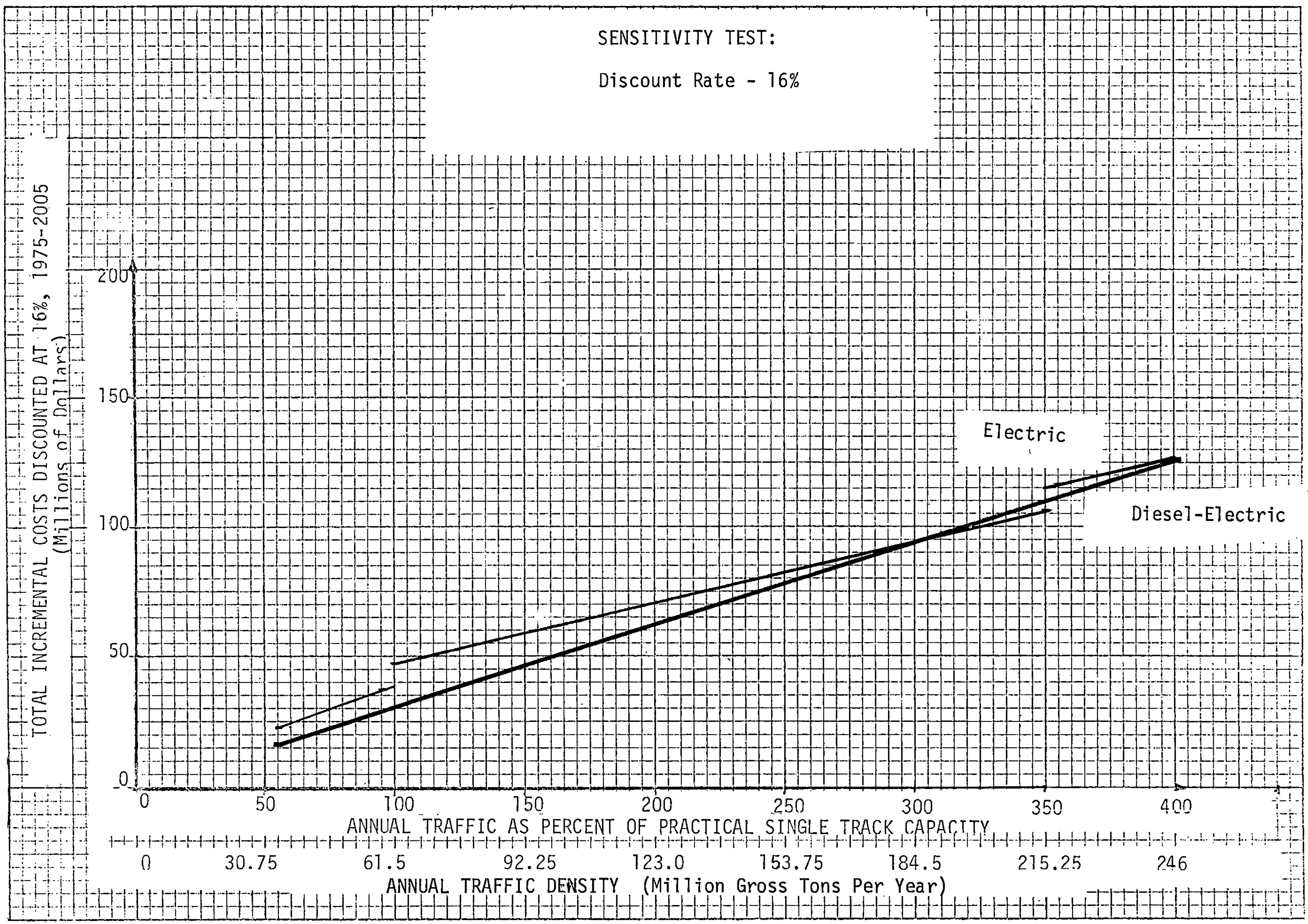

SENSITIVITY TEST:
Discount Rate - 16%
TOTAL INCREMENTAL COSTS DISCOUNTED AT 16%, 1975-2005
(Millions of Dollars)
200
150
100
50
0
Electric
Diesel-Electric
0
50
100
150
200
250
300
350
400
ANNUAL TRAFFIC AS PERCENT OF PRACTICAL SINGLE TRACK CAPACITY
0
30.75
61.5
92.25
123.0
153.75
184.5
215.25
246
ANNUAL TRAFFIC DENSITY (Million Gross Tons Per Year)

Exhibit 6-22

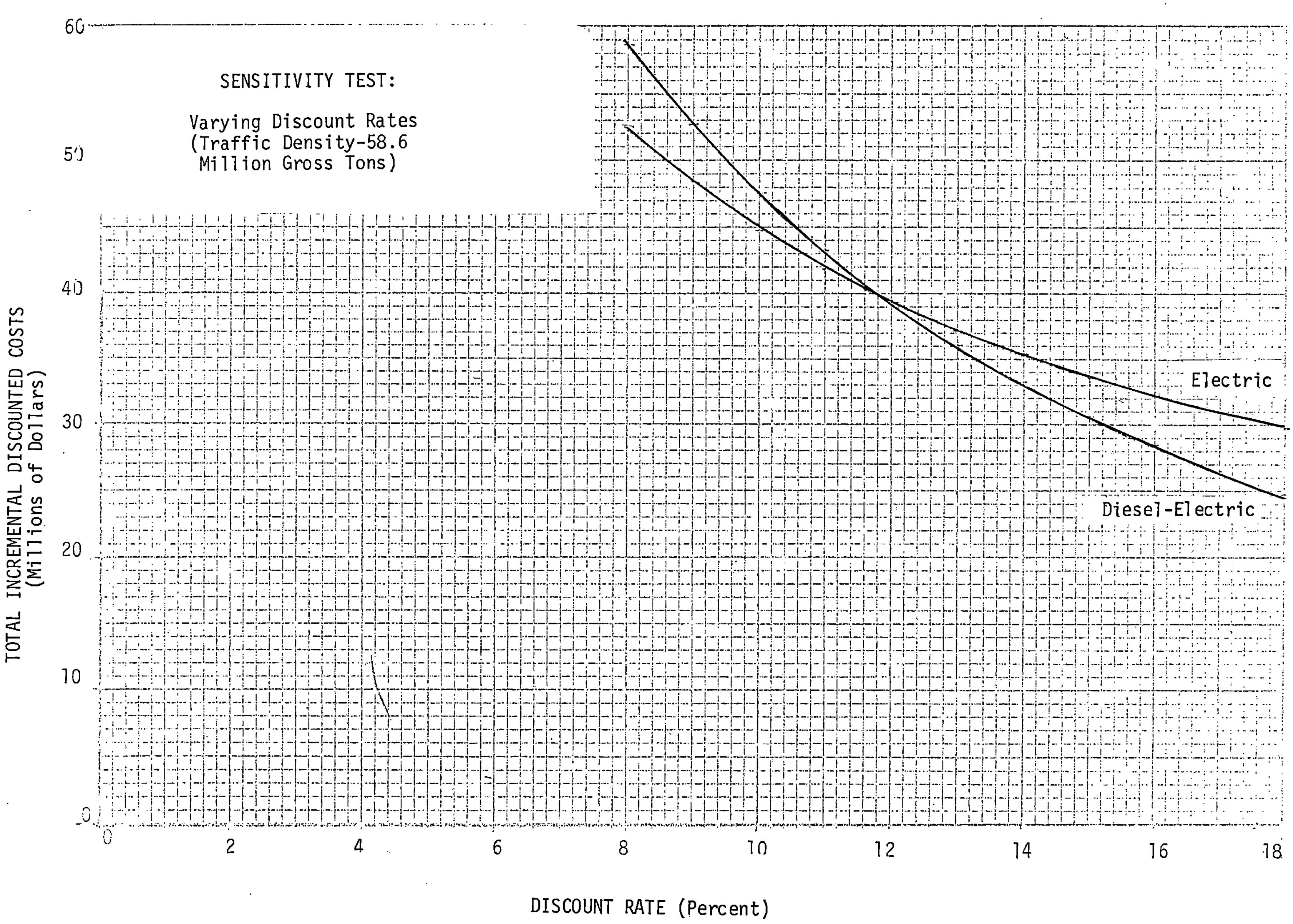

SENSITIVITY TEST:
Varying Discount Rates
(Traffic Density-58.6
Million Gross Tons)
TOTAL INCREMENTAL DISCOUNTED COSTS
(Millions of Dollars)
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
Electric
Diesel-Electric
DISCOUNT RATE (Percent)

Exhibit 6-23

7. ADEQUACY OF DATA AND METHODOLOGY

A study of the present magnitude required a definite framework for achieving the established objectives within given constraints. During the analysis, the study team expanded and refined its insights into the limitations of the framework adopted and the data on which the study rests. This section discusses the insights obtained during the course of the work as to the adequacy of the data and methodology employed.

7.1 DATA

An unavoidable uncertainty with respect to the accuracy level of numerical results is generally associated with the results of a first-level policy analysis. In a cost-effectiveness analysis, feasibility analysis or similar study, the usual means of increasing confidence in the quantitative results is to conduct the study at the next more detailed (that is, less aggregated) level. If the results, although refined and narrowed down, are essentially the same, considerable confidence can be placed on the study outcome for further action.

To give an insight into the quality of currently available and utilized data, a list of the data which would be useful to incorporate in a second more detailed level of analysis is presented. The list is not exhaustive, but representative of major components of the analysis that might reasonable be treated at a less aggregated level.

Locomotives:
- costs at various production levels
- diesel-electric costs after incorporating high adhesion characteristics
- cost of operating a family of diesel-electric or electric locomotives, including helpers

Catenary:
- designs and costs by class of terrain
- number, type and costs associated with clearance problems
- relative costs of tunnel clearance changes versus low voltage application in tunnels

Maintenance:
- improved data based on operating experience of locomotives
- costs curves as a function of locomotive age

Ruling Grades:

average (or best) values for each route

Operating practices:

- weekly scheduling inputs
- operation of mixed diesel-electric and electric locomotive fleets
- details on operating speeds
- advantages and costs of increased drag and manifest speeds

Expanded network:

- include switching and branch lines
- extend electrified network to include commuter traffic

Power costs:

- schedule power demands considering fixed and variable energy charges

There are many other areas in which more detailed data might be collected. Much of this detailed data would be appropriate for considering the implementation of electrification on specific routes and would not significantly reduce uncertainty in a national evaluation of the cost effectiveness of electrification. On the other hand, a study addressing these questions would be useful before development of specific policies for implementation.

7.2 METHODOLOGY

The cost-effectiveness methodology used in this study is appropriate to answering the basic "go-no/go" type questions, as to the attractiveness of electrification. There are some methodological issues that should, however, be noted at this point.

A number of areas in which technical dissent might be found have been resolved by using present policy positions of Federal agencies. For example, discount rates as measures of alternative investment opportunities, electric power and diesel fuel prices considering their international political aspects and pollution costs in the face of an environmental crisis, have been so resolved. There are sufficient discussions on particular aspects of these problems to warrant the guess that the ground rules will continue to be refined. Reassessment of policy position should be made at that time.

The present study was not a <u>cost-benefit</u> analysis. No effort was made to explore the demand and revenue side of railroad operations. The possible demand effects of a new locomotive system and potential changes in operating practices on freight transportation have not been estimated. Contrary to cost-effectiveness analysis, cost-benefit analysis does not require that cost or effectiveness be fixed. A cost-benefit study can be more flexible and address the problem in a more realistic manner than could be done under the assumptions of the cost-effectiveness study. It is also a more expensive study.

Basically, the methodology adopted is appropriate to the initial questions posed. If electrification were not shown by this study to be an economically attractive program vis-a-vis diesel-electric operations, then further analysis of electrification would not be appropriate. With this first question answered, others arise that need to be answered in order to move forward in a realistic manner.

8. CONCLUSIONS

This section summarizes the conclusions drawn from the cost-effectiveness review of electrification.

8.1 IS ELECTRIFICATION ATTRACTIVE IN 1975?

It has been suggested by previous analysis that electrification would be most likely to be economical for as much as 10 percent of the U.S mainline trackage carrying 50 percent of the Nation's traffic. This study compared electric and diesel-electric systems for routes carrying about 50 percent of the Nation's traffic and covering 14,290 miles of mainline routes. Electrification appears to be economical on a portion of those routes, yielding a savings of $360 million in costs discounted to 1975.

8.2 HOW MUCH ELECTRIFICATION?

The analysis shows that 18 of the 59 routes comprising 6,171 of the 14,290 route miles in the skeleton network could be economically electrified. It is important to realize that these results directly reflect the data and assumptions used and that sensitivity tests showed substantial impacts for some variables.

8.3 WHERE IS ELECTRIFICATION ECONIMICAL?

The combined use of regional values and sensitivity tests provides insight into the conditions most favorable to electrification. In addition to high traffic density, steeper and longer grades, and traffic conditions (such as seasonal peaking) that cause low locomotive utilization tend to strongly favor electrification. In addition, there are several cost parameters that have strong effects on the comparative costs. Diesel fuel and electric power costs, as expected, play a major role, as do the costs of catenary structure. Higher locomotive maintenance costs tend to favor electrification by yielding more savings. In addition, the use of slug locomotive units to make better use of the rated horsepower of electric locomotives in drag service can greatly improve the economics of electric operation.

From a regional perspective, electrification appears to offer higher savings on routes in the East and West than in the South or Mid-West. This results from the way in which factors favoring electrification combine in these regions.

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