RPF-1

# A MODEL FOR EVALUATING THE COSTS AND BENEFITS OF RAILROAD ELECTRIFICATION

## VOLUME I - MODEL DESCRIPTION AND APPLICATION

TRANSPORTATION SYSTEMS CENTER
CAMBRIDGE, MA 02142

MARCH 1983

FINAL REPORT

PREPARED FOR THE
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
OFFICE FOR INTERCITY PROGRAMS
Washington, D.C. 20590

13 - Electrification

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A model has been developed to evaluate the economic benefits of large scale railroad electrification. Site specific factors which have a major impact on the rate-of-returns are included as input data, thus providing a procedure for comparing the economics of individual routes in a uniform and expeditious manner. The model is a before tax analysis in which relative inflation of energy alternatives can be specified as well as a general inflation rate. As an option, any portion of the initial investment can be paid from borrowed funds that are subsequently repaid.

The results of application to a hypothetical U.S. network of 29,000 miles are included. The predominant electric locomotive type for the network is a 6 axle, 6000 rail horsepower unit.

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## PREFACE

The Railroad Electrification Assessment Model was developed by the U.S. Department of Transportation, Transportation Systems Center (TSC) for the Federal Railroad Administration (FRA), Office of Intercity Programs. The model was formulated to assist the joint railroad/government planning committee that was convened by Louis S. Thompson, Associate Administrator of the Office of Intercity Programs, to evaluate large scale electrification in the U.S. Railroad members of the planning committee included:

R.M. CHAMPION, JR. — ATCHISON, TOPEKA AND SANTA FE
Assistant to the President - Staff Studies and Planning

S.R. JOHNSON — FAMILY LINES
Assistant Vice President of Operations Planning

E.R. LICHTY — CHESSIE SYSTEM
General Manager - Operations Planning

J.R. MARTIN — SOUTHERN RAILWAY
Assistant Vice President - Transportation Planning

J.R. OSMAN — MISSOURI PACIFIC RAILROAD
Director of Profit Planning

J.H. REBENSDORF — UNION PACIFIC RAILROAD
Assistant Vice President - Planning and Analysis

F.E. SULLIVAN — BURLINGTON NORTHERN, INC.
Manager, Economic Research

J.H. WILLIAMS — CONRAIL
Assistant Vice President - Strategic Analysis

The FRA project manager responsible for directing model development was Gordon B. Mott, who assumed the additional responsibilities of developing the network and obtaining the traffic and route characteristics required.

The model was developed by Dr. C.H. Spenny of TSC with the assistance of J. Smith, a consultant to the FRA, who developed the cash flow related to the transfer of diesel locomotives and specified the sensitivity study, and S. Prensky of TSC who developed traffic level for each route segment. The model was programmed for digital computation and operated by N. Smith and R. Shay of Systems Development Corporation. Input data for the hypothetical network was prepared by F. Hafer of Input Output Computer Services, Inc., under contract to TSC.

This two-volume report has been arranged with different readers in mind. A general description of the model and its capabilities can be obtained by reading Volume I. Readers interested in the results of application of the model to a U.S. network, need only read Section 2 of Volume I. For those interested in the details of the model, Volume II, entitled "User's Guide," describes the format of the input and output data and computational algorithms used in the model. Volume II also contains a listing of the program.

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## EXECUTIVE SUMMARY

Prior to onset of the "energy crisis", reduced locomotive maintenance and improved traction capability were considered to be the major advantages of electrification when compared to operation with diesel motive power. In recent years, instability in the price of diesel fuel relative to electric energy and uncertainty in its availability have made energy a significant consideration.

The Federal Railroad Administration had conducted two major studies of electrification prior to that documented by this report: (1) A government/industry task force concluded in 1974 that electrification was the only viable alternative to liquid petroleum fuel for intercity movement of goods and people, and (2) A 1977 study, mandated by the Railroad Revitalization and Regulatory Reform Act of 1976, concluded that while electrification of certain routes would be beneficial to the owning railroad, the national benefits were not sufficient to warrant government assistance beyond the commitment of the 4-R Act. An update of the second study in 1980 concluded that a marginal improvement in the rate of return had resulted from relative inflation of cost factors over the three year period and from projections of further increase in the price of diesel fuel relative to other costs. The network results in these studies were based on average costs and typical route characteristics.

At a joint conference of the FRA and several major railroads in Kansas City in October, 1980, a commitment was made to proceed jointly with a more in-depth study that considered the effect of route specific factors. Three committees were formed with objectives as follows:

1. Planning Committee - Establish a procedure for determining which routes should be electrified and in what order;

2. Finance and Administration Committee - Evaluate alternative means for financing the initial investment;

3. Technical and Operations Committee - Identify and assess issues which represent risk to the successful implementation of electrification.

The Railroad Electrification Assessment Model described herein was developed by TSC to provide information for the Planning Committee on the relative economics of route segments, thereby permitting evaluation of large scale electrification in more detail and with a higher level of confidence in the results than had previously been possible using "average" or "typical" characteristics. The model was formulated to apply route-specific values of critical design and operating variables. It is a differential, discounted cash flow analysis based on identical traffic, freight rates, and quality of service for diesel and electric operation.

The model has been used to analyze the economics of an electrified U.S. freight hauling network consisting of 96 route segments for 16 railroads totaling nearly 29,000 route miles. For the base case analyzed, the rate of return for the network was substantially greater than predicted by previous FRA studies. Considerable variation of rate of return between route segments was found depending on the combination of critical site-specific factors that exist. The factors found to have major influence on the rate of return were traffic density, type of diesel locomotive being replaced, type of electric locomotive, dispatch policy, catenary cost and differential cost of fuel compared to electricity. The best single surrogate to these factors was found to be annual fuel consumption per route-mile. However, there is still sufficient dependency on variables uncorrelated with fuel consumption (e.g., bridge clearance and signal and communication compatibility) to require computation of the rate of return.

Sufficient study was performed to conclude that the economic advantage of electrification over diesel operation is real and in many cases substantial. The next logical step would be for the railroads to initiate more detailed studies of routes that show a favorable rate of return. It may be desirable to make additional evaluations using the Railroad Electrification Assessment Model prior to initiating more detailed studies in order to better scope that work. One particular aspect that should be examined is the impact of the timing of conversion on the cash flow of the railroad involved.

# 1. INTRODUCTION

Railroad electrification has proven to be economically viable in many countries over the past several decades. Excluding the United States, nearly 20 percent of all track in the world is presently electrified.[1]*

In the United States, less than one percent of the track is presently electrified. There have been numerous studies of mainline electrification in the U.S., most concluding that the rate of return is positive but that the capital cost of conversion is too great to justify the risk. The only electrification installed in the last forty years has been limited to a few hundred miles of private coal hauling and commuter operations.

Prior to onset of the "energy crisis" reduced locomotive maintenance and improved traction capability were considered to be the major advantages for electrification when compared to diesel motive power. In recent years, instability in the price of diesel fuel relative to electric energy and uncertainty regarding its availability have made energy a significant consideration. Traction advantages have become less significant with the introduction of diesel locomotives with higher adhesion.

*Numbers in brackets indicate references listed in Section 6.

The Federal Railroad Administration (FRA) had conducted two major studies prior to that documented by this report:

1. A government/industry task force concluded in 1974 that electrification was the only viable alternative to liquid petroleum fuel for intercity movement of goods and people[2];

2. A 1977 study mandated by the Railroad Revitalization and Regulatory Reform Act of 1976 (4-R Act) concluded that while electrification of certain routes would be beneficial to the owning railroad, national benefits were not sufficient to warrant government assistance beyond the commitments of the 4-R Act[3].

An update of the second study was completed in 1980[4], which concluded that a marginal improvement in the rate of return had resulted from relative inflation of cost factors over the three year period and from projections of further increase in the price of diesel fuel relative to other costs. At a joint conference of the FRA and several major railroads in Kansas City in October, 1980, a commitment was made to proceed jointly with a more in-depth study. Three committees were formed with objectives as follows:

1. Planning Committee - Establish a procedure for determining which routes should be electrified and in what order;

2. Finance and Administration Committee - Evaluate alternative means for financing the initial investment;

3. Technical and Operations Committee - Identify and assess issues which represent risk to the successful implementation of electrification.

A list of participants in each of these committees is included as Appendix A. The Railroad Electrification Assessment Model, described herein, was developed to provide information for the Planning Committee on the relative economics of route segments. The Planning and the Technical and Operations Committees made recommendations for refinement and assisted in identifying and obtaining route-specific input data for the model. The model was subsequently endorsed by the Planning Committee as the recommended procedure for initial planning of large scale electrification.

All committee activity has been completed. Appendix B summarizes the recommendations of the Planning and the Technical and Operations Committees that were integrated into the model, and summarizes the recommendations made by the Finance and Administration Committee.

# 2. MODEL APPLICATION TO A HYPOTHETICAL NETWORK

The Railroad Electrification Assessment Model was used to evaluate the costs and benefits expected from an electrified U.S. network of freight-hauling railroads. A network consisting of ninety-six route segments belonging to sixteen private railroad companies was examined. The results presented in this section are the aggregated statistics for the entire network. Results on a route and railroad basis are regarded as proprietary data and are not presented in this report. The route-specific results are available from the participating railroads at their discretion. One of the route segments was selected to illustrate use of the model and is introduced in Section 4 of this volume and in Volume II without disclosing its identity.

In several of the tables and charts which follow, comparison is made to previous FRA cost/benefit studies. These studies were performed in 1977[3] and 1980[4], and are based on average costs and route characteristics, the costs being for the year of the study. The study being reported herein uses 1980 costs and route-specific characteristics. Therefore, comparison of this study with the 1977 study reveals changes resulting from cost escalation as well as refinement in route and operating characteristics, refinement of the costs attributed, and an increase in the price of fuel. Differences between the present study and the 1980 study do not include a cost escalation factor.

## 2.1 MAJOR FINDINGS

Application of the assessment model to a hypothetical network produced the following results and conclusions:

1. The initial capital investment in the fixed plant and locomotives to electrify 29,000 miles of high density mainline, in constant 1980 dollars, is 18 billion dollars, offset by a credit of four billion dollars for diesel locomotives that would otherwise have been required, leaving a net investment of 14 billion dollars;

2. For the base case analyzed, the pre-tax rate of return for the network is 19 percent, a substantial increase over the previously reported FRA results;

3. Variation in the rate of return between route segments of similar traffic density can be large, depending on the combination of other significant factors that exist;

4. A number of factors influence the rate of return, notably the traffic density, gradient, type of locomotives, dispatch policy, and to a degree locomotive-miles. A surrogate for all of these factors may be found in the annual fuel consumption per route-mile, which shows a high correlation with the rate of return;

5. The estimated annual diesel oil saving is 51 million barrels, 10 percent less than previously reported;

6. The base case rate of return is reduced to 14 percent when it is assumed that the relative costs of diesel fuel and electricity remain constant;

7. The use of some outside financing by the railroad at commercial long-term interest rates would reduce the railroad's own initial investment and improve the rate of return so long as it exceeds the rate of interest to be paid.

## 2.2 ROUTE DEFINITION

Traffic density has generally been used as the principal criterion for route selection. A report published in 1977 under the sponsorship of FRA's Office of Research and Development[5], and which became the data base for all subsequent FRA analyses up to the present one, established 40 million gross ton-miles per mile (MGTM/M) as the minimum for inclusion in their Service Level One, a basic network of nearly 10,000 route-miles. Service Level Two included other high density routes, generally with a traffic density of 20 to 40 MGTM/M, that could be suitably operated as electrified lines. Together with Level One, this totalled nearly 40,000 route-miles.

The present analysis also began by identifying line segments based on their traffic density, using 1978 data. As a rule, 30 MGTM/M was used as the minimum for inclusion in the study, though this selection was modified to provide a limited number of necessary connecting links and to make each railroad's electrified segments cohesive from an operating standpoint. The result gave a national network of about 26,000 route-miles. Within this network, a smaller more heavily used core of about 10,000 route-miles was also identified, primarily on the basis of each link carrying at least 40 MGTM/M. The remainder of the 40,000 route-miles was dropped as being unlikely to meet the financial criteria needed for electrification.

This original 10,000/26,000 route-mile network was used for the initial economic analysis, but subsequently it was modified for a variety of reasons. For example:

1. 1978 was the year of a strike against the Norfolk and Western, and consequently its traffic for that year was abnormally low. Several links that had not

originally been included were added when an average of 1977 and 1979 densities was substituted;

2. Traffic patterns had been, or are expected to be, changed because of intervening mergers such as CSX;

3. Some railroads requested deletion for operational considerations of certain segments that from a density standpoint had been included; for example, Longview-Fort Worth on Missouri Pacific and Denver-Pueblo on Burlington Northern;

4. Traffic growth since 1978, primarily coal, has resulted in new lines being added such as Salt Lake City-Los Angeles on Union Pacific and Elkhorn City-Spartanburg on Clinchfield;

5. Two links originally included, Fullerton-San Diego on Santa Fe and Albany-Croton/Harmon on Conrail, are predominantly passenger routes and were dropped when the study became more commercially-oriented.

The map shown in Figure 2-1 depicts the final network which was analyzed for electrification.* Consisting of ninety-six route segments belonging to sixteen railroads, it is a truly national network which links most major traffic centers. Route segments range in size from 36 to 1,035 miles in length and typically connect endpoints that are existing yards or crew change points.

*A table listing the individual links included in the network is given in Appendix C.

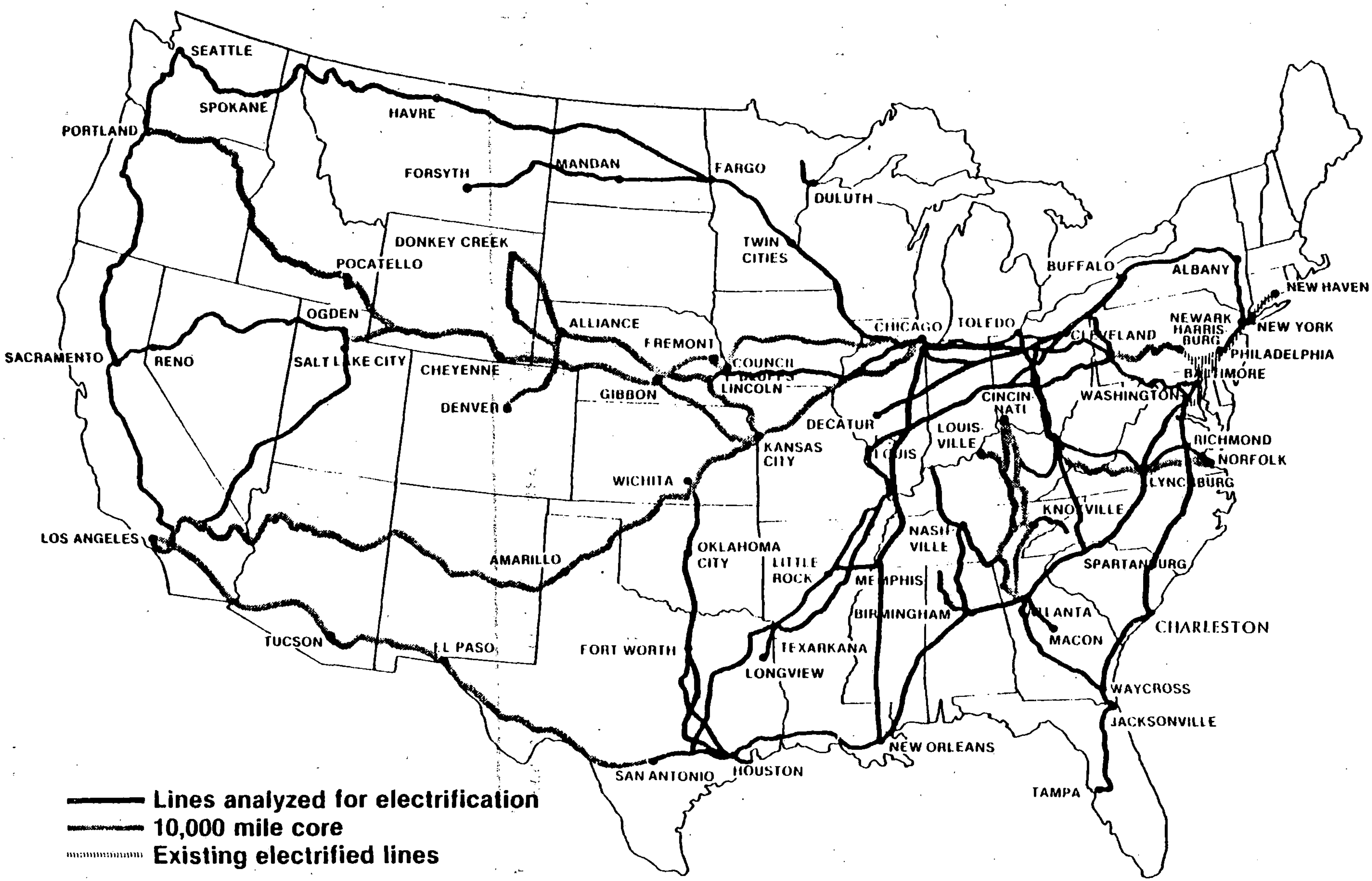


FIGURE 2-1. HYPOTHETICAL 29,000 MILE NETWORK STUDIED

The percentage of total traffic on a route segment that would actually be hauled by electric locomotives varies from virtually 100 percent down to slightly over 50 percent, depending on factors such as the amount of local switching service and the presence of traffic moving to and from non-electrified lines at intermediate points. Table 2-1 defines how the potential volume of electrically-hauled traffic is distributed over the mileage of the network.

A significant percentage of the route-miles in the network actually consist of more than one track, and all routes include some amount of yard trackage and sidings that for operating purposes would need to be electrified. These numbers are broken out in Table 2-2, which also indicates the relative curvature, a factor affecting the cost of construction.

## 2.3 CONSTRUCTION SEQUENCING

The initial planning phases of the FRA electrification initiative were designed around the concept of a federally-assisted program that would promote the rapid electrification of a network consisting of segments of several different railroad companies. An early question which needed to be answered was the time required to complete such a program. With the help of Electrack, Inc., a hypothetical construction schedule was devised which included an arbitrary constraint that for planning purposes construction would be limited to 1,000 route-miles in any year. This rate is less than the nearly 1200 miles per year achieved in the USSR during a 15 year period from 1955 to 1970[6] and could reasonably be accomplished with an acceptable level of service disruption by

TABLE 2-1. DISTRIBUTION OF ELECTRICALLY-HAULED TRAFFIC

| TRAFFIC DENSITY RANGE | PERCENT OF ROUTE MILEAGE |
|---|---|
| Greater than 40 MGTM/M | 41.0 |
| 30 - 40 MGTM/M | 28.6 |
| 20 - 30 MGTM/M | 27.0 |
| Less than 20 MGTM/M | 3.4 |

TABLE 2-2. TRACK CHARACTERISTICS

| CURVATURE CATEGORY | ROUTE MILES | | | | |
|---|---|---|---|---|---|
| | 1-TRACK | 2-TRACK | 3-TRACK | 4-TRACK | TOTAL |
| Tangent to Light Curvature (0-1° Avg.) | 14,930 | 9,473 | 289 | 82 | 24,774 |
| Medium Curvature (1° to 3° Avg.) | 2,172 | 1,162 | 85 | 41 | 3,460 |
| Heavy Curvature (>3° Avg.) | 287 | 154 | 6 | 1 | 448 |
| | 17,389 | 10,789 | 380 | 124 | 28,682 |
| Track-Miles | 17,389 | 21,578 | 1,140 | 496 | 40,603 |
| | | | Sidings & Yards | | 9,575 |
| | | | Total Track-Miles | | 50,178 |

a half-dozen design/construct teams operating simultaneously under the following conditions:*

1. Standard catenary and substation designs;

2. Coordinated deployment of design/construct teams to minimize relocation time;

3. Prior definition of lines to be electrified;

4. Availability of engineering data from the railroads.

While it was necessary to demonstrate that a program of this magnitude could be carried out within a reasonable period of time, our use of arbitrarily-assigned starting times for the electrification of individual links resulted in distortions in the economic analysis because of the effects of traffic growth on those links begun later in the program. Therefore, in our final analyses we established the Begin Design Engineering date of the first link of each railroad as January 1, 1982. Each individual link would still require the same length of time for design and construction as estimated earlier, and those railroads with fewer miles to be electrified would complete their program sooner, but by establishing a uniform starting date the economic returns to the individual railroads would be more nearly comparable. Table 2-3 compares the route-miles placed in service annually under each of the two schedules. It is recognized that the uniform schedule results in the theoretical construction of greater than 1,000 route-miles annually in the early years of the program. <u>The results presented in this report are for the uniform schedule</u>.

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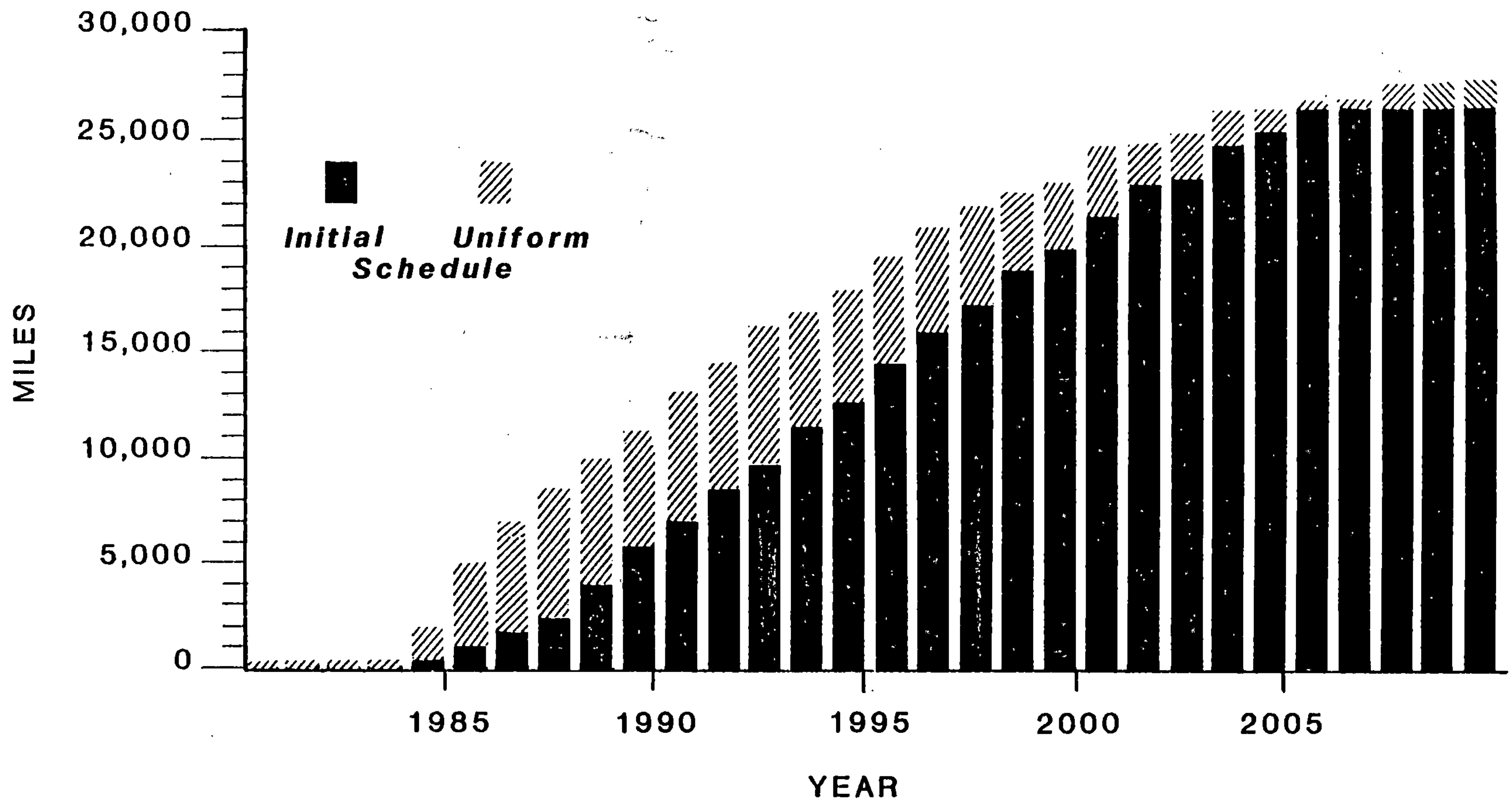
*See Appendix D for a more thorough discussion of the assumptions made in developing the construction schedule.

TABLE 2-3. CONSTRUCTION SEQUENCE ROUTE MILES PLACED IN SERVICE*




Note: Total miles electrified for the two schedules differ because additional segments were added to the network for study under the uniform schedule.

## 2.4 TRAFFIC LEVELS

Table 2-4 summarizes the characteristics of the traffic hauled in three types of service on the 10,000 mile core and the full 29,000 mile network. While a majority of the traffic is hauled as "normal" traffic with no special operational procedures, roughly 25 percent is hauled in "expedited" service with additional motive power used to reduce running time. The term "bulk" service, as applied to this analysis, refers to certain unit trains carrying coal, ore or grain. The run time of these trains often differs from that for normal service as a result of several factors: (1) dispatch at levels approaching the minimum traction requirement of the ruling grade, (2) bypassing of intermediate yards, and (3) speed restrictions on open-top hopper cars. Not all railroads operate unit trains significantly different from "normal" traffic and therefore made no distinction in reporting the operating parameters. Thus only eight percent of the traffic in this study is

TABLE 2-4. TRAFFIC CHARACTERISTICS FOR THE 10,000-MILE CORE AND 29,000-MILE NETWORK

| | TYPE OF SERVICE | | | |
|---|---|---|---|---|
| | BULK | NORMAL | EXPEDITED | ALL TRAFFIC |
| 10,000-Mile Core | | | | |
| 1980 Traffic (BGTM/YR)* | 38 | 351 | 135 | 524 |
| Route Miles Served | 1,075 | 9,860 | 8,750 | 9,860 |
| 1980 Traffic Density (MGT/YR)** | 36 | 36 | 15 | 53 |
| Annual Growth Rate Through 1990 | 4.8% | 3.7% | 1.3% | 3.2% |
| 29,000-Mile Network | | | | |
| 1980 Traffic (BGTM/YR) | 76 | 788 | 265 | 1,129 |
| Route Miles Served | 3,485 | 28,680 | 26,790 | 28,680 |
| 1980 Traffic Density (MGT/YR) | 22 | 27 | 10 | 39 |
| Annual Growth Rate Through 1990 | 4.8% | 2.9% | 1.2% | 2.6% |

*Billion gross ton-miles per year.
**Million gross tons per year.

identified as moving in bulk service. This number is expected to grow, however, based on current trends in many railroad operating departments and as a result of anticipated large increases in the movement of coal.

The composite traffic density of all categories is 39 million gross tons for the network as a whole, and 53 million for the 10,000 mile core, essentially unchanged from the levels of 1977* which is in agreement with the traffic statistics of the entire U.S. rail system[7][8].

## 2.5 MOTIVE POWER REQUIREMENTS

The basic performance requirements of a locomotive consist are: (1) sufficient traction to climb the ruling grade on the route, and (2) sufficient power to move the train over the route in a specified time. A consist is ideally matched to these basic requirements when it has just sufficient power and traction capability.

The range of power and traction capabilities of the diesel locomotive types now in service is quite diverse. Table 2-5 identifies the characteristics of representative diesel road locomotives in service on the network. Tractive effort is related to the weight on drivers, number of traction motors, and the power output of the prime mover. For a given train weight, the continuous tractive effort required becomes greater as the gradient increases, but a relatively fixed amount per axle is available at a given adhesion rate. Over heavy grades, therefore, the tendency will be to use six-axle locomotives to increase tractive effort. However, where there are few or no

*See Reference 3, Table C-2, an FRA staff study supporting Reference 3.

TABLE 2-5. DESIGN CHARACTERISTICS AND COST IN 1980 FOR DIESEL LOCOMOTIVE TYPES USED IN THE NETWORK STUDY

| | | TYPE 1 | TYPE 2 | TYPE 3 | TYPE 4 | TYPE 5 | TYPE 6 | TYPE 7 |
|---|---|---|---|---|---|---|---|---|
| TYPICAL MFRS. MODEL NO.: | | | | | | | | |
| GEN. MOTORS | | GP-38 | SD-38 | GP-40 | SD-40 | SD-45 | GP-50 | SD-50 |
| GEN. ELECTRIC | | U-23B | U-23C | U-30B | U-30C | | B-36-7 | C-36-7 |
| Rated Horsepower* | | 2,000 | 2,000 | 3,000 | 3,000 | 3,600 | 3,500 | 3,500 |
| Rail Horsepower** | | 1,700 | 1,700 | 2,550 | 2,550 | 3,060 | 3,000 | 3,000 |
| No. of Axles* | | 4 | 6 | 4 | 6 | 4 | 4 | 6 |
| Weight/Axle* | | 64,000 | 59,300 | 64,000 | 61,300 | 61,300 | 65,000 | 65,000 |
| Adhesion Capability | | .18 | .18 | .18 | .18 | .18 | .25 | .25 |
| Cont. Tractive Effort at Adhesion Limit* | | 46,000 | 64,100 | 46,000 | 66,200 | 66,200 | 65,000 | 97,500 |
| RHP/lb of T.E. | | .037 | .027 | .055 | .039 | .046 | .046 | .031 |
| COST | $/Unit | 630K | 730K | 660K | 760K | 830K | 700K | 820K |
| | $/RHP | 371 | 429 | 259 | 299 | 272 | 233 | 273 |
| | $/lb of T.E. | 13.75 | 11.50 | 14.25 | 11.75 | 12.50 | 10.75 | 8.50 |

*Source: Reference[9].
**Rail horsepower = RHP = 0.85 x rated horsepower (assumed).

gradients, a four-axle locomotive will provide adequate continuous tractive effort at lower cost. In a fleet required for work with both types of need, the final choice is of necessity a compromise to avoid too great a number of locomotive types, and the result is neither full utilization of tractive effort or power rating. There will be similar compromises when considering the type of electric locomotive to be used.

When considering the use of a single locomotive type against the use of two or more types more closely related to exact needs, there are two questions to be answered: (1) does the inherent higher power-to-tractive effort capability of the electric locomotives warrant more widespread use of multiple types on a route segment or railroad, and (2) what is the optimum ratio of power-to-tractive effort capability for the type or types that predominate?

This study resulted in most cases in a single electric locomotive type for each segment, optimizing use of its traction and power capabilities. In some cases marginally better results might be obtained from using two or more types of electric locomotives but such considerations are more appropriate to a detailed study.

Three electric locomotive types were defined with the characteristics listed in Table 2-6. The Type One electric is a four-axle unit similar to the General Electric E-25 now in service at the Texas Utilities Company. The Type Two is a six-axle unit with an intermediate power rating. It is not represented by any unit currently marketed. The Type Three is also a six-axle unit, but with a higher power rating. It is a slightly more powerful version of GE's E-60 and EMD's GM-6.

The factor of adhesion for all electrics was assumed to be 25 percent. The Types Six and Seven diesels have improved wheel-slip controls giving them also an assumed 25 percent factor of adhesion. All other diesels are assumed to have an 18 percent factor of adhesion. Since fewer than one percent of the diesel units in service have improved adhesion, in essence <u>the study compares electric locomotives having 25 percent adhesion factors to diesel locomotives having 18 percent adhesion factors</u> and, as such, estimates the benefits for conversion from the <u>existing</u> diesel fleet to electric traction. In any detailed financial evaluation for investment

TABLE 2-6. DESIGN CHARACTERISTICS AND COST IN 1980 FOR ELECTRIC LOCOMOTIVE TYPES USED IN THE NETWORK STUDY

| LOCOMOTIVE TYPE | | TYPE 1 | TYPE 2 | TYPE 3 |
|---|---|---|---|---|
| Rail HP | | 2,500 | 4,000 | 6,000 |
| Number of Axles | | 4 | 6 | 6 |
| Wt./Axle (lb) | | 65,000 | 65,000 | 65,000 |
| Adhesion Capability | | .25 | .25 | .25 |
| Cont. Tractive Effort at Adhesion Limit | | 65,000 | 97,500 | 97,500 |
| RHP/lb of Tractive Effort | | .038 | .041 | .062 |
| Cost | $/Unit | 720K | 1.2M | 1.4M |
| | $/RHP | 360 | 300 | 233 |
| | $/lb of T.E. | 11.10 | 12.30 | 14.40 |

purposes it would be prudent also to compare the replacement of existing diesels with improved diesels. From such studies it would be possible to decide whether to electrify or to evolve to improved diesel traction at lower benefit but much lower capital investment.

Table 2-7 presents the locomotive requirements of the 29,000 mile network. The 2,550 rail horsepower, six-axle diesel dominates the existing service while the 6,000 rail horsepower, six-axle electric would be expected to be the successor. The selection procedure adopted was to replace diesel units on a segment with electric units that have precisely the traction capability required on the ruling grade and a minimum of power in excess of the current diesel dispatch level. This assured that the current operational capability was maintained. Working strictly on a comparison of the ratios

TABLE 2-7. CALCULATED LOCOMOTIVE REQUIREMENTS FOR A 29,000-MILE NETWORK

| DIESEL LOCOMOTIVE TYPE | QUANTITY REQUIRED BY TYPE OF SERVICE | | | |
|---|---|---|---|---|
| | BULK | NORMAL | EXPEDITED | TOTAL |
| Type 1: 4-Axle 1,700 Rail Horsepower | 19 | 632 | 121 | 772 |
| Type 2: 6-Axle 1,700 Rail Horsepower | 0 | 21 | 0 | 21 |
| Type 3: 4-Axle 2,550 Rail Horsepower | 0 | 499 | 270 | 769 |
| Type 4: 6-Axle 2,550 Rail Horsepower | 137 | 1,755 | 728 | 2,620 |
| Type 5: 6-Axle 3,060 Rail Horsepower | 0 | 408 | 242 | 650 |
| Type 6: 4-Axle 3,000 Rail Horsepower | 13 | 21 | 7 | 41 |
| Type 7: 6-Axle 3,000 Rail Horsepower | 0 | 0 | 0 | 0 |
| TOTALS | 169 | 3,336 | 1,368 | 4,873 |
| **ELECTRIC LOCOMOTIVE TYPE** | | | | |
| Type 1: 4-Axle 2,500 Rail Horsepower | 0 | 30 | 0 | 30 |
| Type 2: 6-Axle 4,000 Rail Horsepower | 100 | 247 | 26 | 373 |
| Type 3: 6-Axle 6,000 Rail Horsepower | 0 | 1,245 | 502 | 1,747 |
| TOTALS | 100 | 1,522 | 528 | 2,150 |

of rail horsepower to tractive effort in Tables 2-5 and 2-6, diesels would be replaced by electric types as follows:

| Diesel Type | Electric Type |
|---|---|
| 1, 2, 7 | 1 |
| 4 | 2 |
| 3, 5, 6 | 3 |

If the type four diesel were ideally matched to the power and traction requirements on a route, the type two electric would be expected to be predominant. Such is not the case. Diesel consists are dispatched with considerably more tractive effort than required for the ruling grade in order that the power rating be sufficient for schedule requirements. Thus, with the replacement philosophy adopted, the type three electric actually predominates.

Based on the distribution in Table 2-7, the optimum electric locomotive, capable of providing service equivalent to the present diesel fleet while simultaneously making fullest utilization of power and traction capability, has a power rating in excess of 4,000 rail horsepower; possibly even greater than 6,000 horsepower but this is conjecture because no greater horsepower unit was included in the evaluation. Detailed studies of a much more technical nature (including research into the best ways of exploiting what is quite a different power supply demand) would be required before the decisions on electric locomotive size and types were made. The present study suggests that a locomotive in the 4,000 rail horsepower range would be needed for "bulk" haul where the prime criterion is adhesion, but that for "normal" and "expedited" service locomotives of higher horsepower would be more economical.

## 2.6 ENERGY CONSUMPTION AND ENERGY COST PROJECTIONS

Figure 2-2 shows the consumption of electrical energy on the rail network through the 28 year period of construction. The change in slope in 1990 is the result of assuming all traffic growth terminates in that year. Hence, when construction is completed in the year 2010, railroad energy consumption becomes constant at 30 million megawatt-hours per year. The corresponding consumption of diesel fuel on the rail network in the year 2010, assuming electrification does not occur, is 2200 million gallons or 52 million barrels per year. This fuel consumption is less than one percent of the total petroleum products consumed in the U.S. in 1980[10].

Table 2-8 shows railroad energy consumption by Bureau of Census region and the percent of 1980 regional electric utility energy production that railroad electrification represents. The total electric energy consumed by the completed rail network based on 1980 traffic levels is approximately one percent of total 1980 electric utility energy production. The Bureau of Census region which has the largest railroad energy consumption in percent of 1980 electric utility energy production is the Mountain region with 2.7 percent followed by the West North Central region with 2.4 percent. In the previous FRA study[4], the Mountain region was identified as possibly having inadequate electric generating capacity to handle railroad electrification.

Total electric utility energy production in the U.S.A. is projected to increase by 3.6 percent per year from 1980 to 1990[11]. By Bureau of Census region, the projections are 4.7 percent per year for the Mountain region and 3.8 percent per year for the West North Central region. If electrification of the network were accelerated and completed uniformly over the 1980-1990 period, then the projected total utility energy

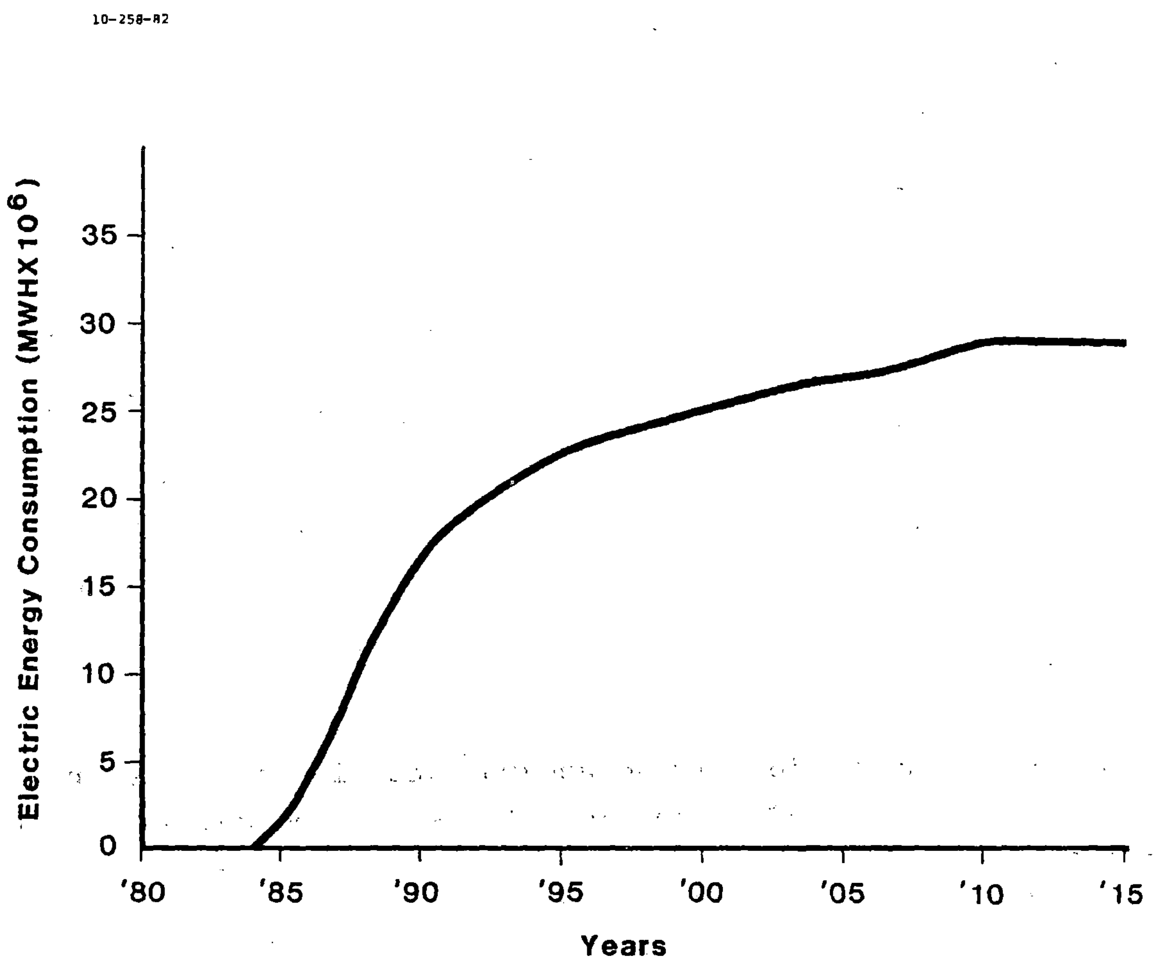
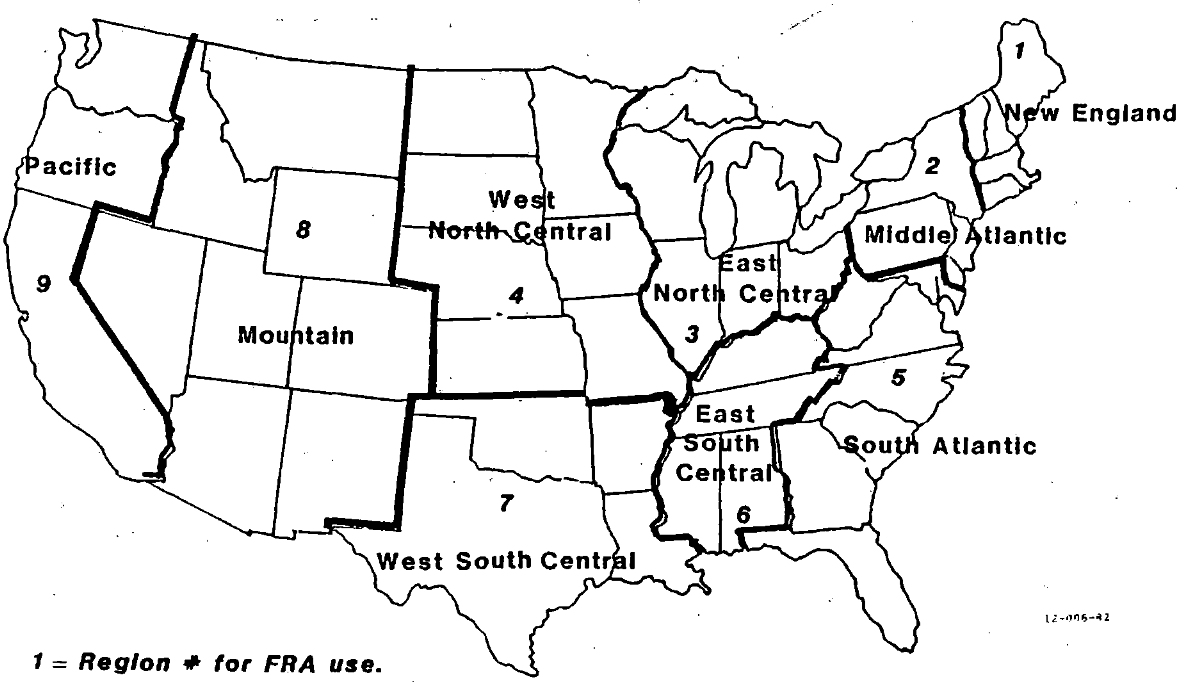



FIGURE 2-2. ELECTRIC ENERGY CONSUMPTION ON THE 29,000 MILE NETWORK

TABLE 2-8. RAILROAD ENERGY CONSUMPTION AND COST OF ELECTRICITY BY BUREAU OF CENSUS REGION

| BUREAU OF CENSUS REGION | RAILROAD ENERGY CONSUMP.* | 1980 ELECTRIC UTILITY ENERGY PRODUCTION[11] | RAILROAD ENER. CONSUMP. PER ELEC. UTILITY ENERGY PRODUC. | 1980 COST OF ELECTRICITY** |
|---|---|---|---|---|
| | MWH x 1,000,000 | | PERCENT | ¢/kWh |
| 1. New England | 0 | 78 | 0 | 5.3 |
| 2. Middle Atlantic | 1.4 | 261 | 0.6 | 4.5 |
| 3. East North Central | 2.4 | 397 | 0.6 | 4.1 |
| 4. West North Central | 3.9 | 168 | 2.3 | 4.1 |
| 5. South Atlantic | 3.3 | 418 | 0.8 | 3.6 |
| 6. East South Central | 2.1 | 214 | 1.0 | 3.6 |
| 7. West South Central | 1.9 | 313 | 0.6 | 2.9 |
| 8. Moutain | 5.5 | 159 | 3.5 | 2.8 |
| 9. Pacific | 2.6 | 269 | 1.0 | 2.5 |
| TOTAL | 23.2 | 2,277 | 1.0 | 3.4 Avg. |

*Based on 1980 traffic levels for a 29,000 route-mile electrified network.
**Industrial rates.




1 = Region # for FRA use.

production would increase by less than 0.1 percent per year.* By Bureau of Census region, the projections would increase from 4.7 to 4.9 percent per year for the Mountain region and from 3.8 to 4.0 percent per year for the West North Central region.

Table 2-9 shows the power line required to connect traction substations to the existing utility substations and power line. The new power line voltage is 115, 230, or 345 KV depending on the closest existing power line. The average number of circuit miles installed annually by the utility industry is just over 10,000[11], so that if the 2400 miles required for the electrification network were installed over 25 years, the installation rate would be increased by less than one percent.

The cost of electric energy and diesel fuel are expected to rise at a rate faster than general inflation. For the base case, electric energy cost is assumed to increase by two percent per year and diesel fuel by three percent per year above general inflation until year 2000. This is handled in the model by an annual increase of 2.3 percent in diesel fuel cost and no escalation in the cost of electricity in excess of general inflation. The procedure for developing the relative escalation from various forecast data is described in Section 4.1.2. Beyond year 2000, no relative escalation is assumed.

## 2.7 NETWORK INVESTMENTS

Tables 2-5 and 2-6 contain the unit cost of each locomotive type considered in the study. Table 2-8 contains the cost of

*Railroad growth is not included here.

TABLE 2-9. MILES OF NEW POWER LINE REQUIRED FOR RAILROAD ELECTRIFICATION

| BUREAU OF CENSUS REGION | NEW POWER LINE REQUIRED FOR RAILROAD ELECTRIFICATION (MILES) |
|---|---|
| 1. New England | 0 |
| 2. Middle Atlantic | 74 |
| 3. East North Central | 297 |
| 4. West North Central | 375 |
| 5. South Atlantic | 374 |
| 6. East South Central | 244 |
| 7. West South Central | 320 |
| 8. Mountain | 425 |
| 9. Pacific | 277 |
| TOTAL | 2,386 |

*Based on a 29,000 route-mile U.S. Electrified Network.

electricity for each Bureau of Census region. These two sets of unit cost factors illustrate the manner in which costs are developed as a function of critical design and operating variables. Further discussion of cost dependency on critical variables is contained in Section 4.1.1. In this section the weighted average costs, as derived from the study results, are compared with costs appearing in the previous FRA studies. Column C of Table 2-10 summarizes the weighted average cost factors.

TABLE 2-10. COMPARISON OF AVERAGE ELECTRIFICATION COST FACTORS

| CATEGORY | A* (1977 DOLLARS) AVERAGE COSTS (THOUSAND $) | B* (1980 DOLLARS) AVERAGE COSTS (THOUSAND $) | C (1980 DOLLARS) WEIGHTED AVERAGE COSTS (THOUSAND $) |
|---|---|---|---|
| Capital Costs (per route mile): | | | |
| Catenary - Single Track | 103.5 | 175.0 | 141.3 |
| - Double Track | 190.5 | 318.0 | 279.6 |
| Substations - Single Track | 34.0 | 87.0 | 34.1 |
| - Double Track | 62.0 | 158.0 | 48.2 |
| Signal and Communications | | | |
| - Single Track | 52.5 | 142.0 | 100.0 |
| - Double Track | 77.5 | 210.0 | 100.0 |
| Civil Reconstruction | | | |
| - Single Track | 27.5 | 53.7 | 31.7 |
| - Double Track | 41.25 | 78.9 | 31.7 |
| Utility Connection Costs | 10.0 | 15.0 | 17.5 |
| Operating Costs: | | | |
| Diesel Energy (¢/gallon) | 42.0 | 85.0 | 100.0 |
| Electric Energy (¢/kWh) | 2.7 | 4.23 | 3.4 |
| Diesel Loco. Maint. (¢/unit-mile) | 68.0 | 133.0 | 133.0 |
| Elect. Loco. Maint. (¢/unit-mile) | 29.0 | 65.0 | 85.0 |
| Catenary Maint. - Double Track ($/route-mile/year) | 2.0 | 4.4 | 5.0 |
| Locomotive Costs (thousand $ per unit: $ per rail hp): | | | |
| Diesel | 500 : 196 | 791 : 264 | 732 : 295 |
| Electric | 1,000 : 200 | 1,540 : 302 | 1,360 : 243 |

*Taken from Table 1, Ref. 4. A refers to 1977 FRA study (Ref. 3); B refers to 1980 FRA study (Ref. 4); C refers to present study.

The basic change with respect to the "B" results is a reduction in the capital cost factors as a result of several changes:

1. Separate itemization of fees for design and construction engineering that were previously included as part of each fixed plan investment;

2. Revised unit cost estimates;

3. Revised estimates of design complexity based on route-specific data.

Table 2-11 compares the net investments and net annual savings for the 29,000 mile network and 10,000 mile core ("C") with those of the previous FRA studies of 10,000 and 26,000 mile networks ("A" and "B"). The net investment in the "C" network is nine percent less than in the "B" network even though it is 3,000 route-miles longer. This results primarily from the factors as described in the previous paragraph which are discussed in more detail below.

TABLE 2-11. NET INVESTMENTS AND NET ANNUAL SAVINGS DUE TO ELECTRIFICATION

| | A* (1977 DOLLARS) | | B* (1980 DOLLARS) | | C (1980 DOLLARS) | |
|---|---|---|---|---|---|---|
| CATEGORY | 10,000-MI NETWORK | 26,000-MI NETWORK | 10,000-MI NETWORK | 26,000-MI NETWORK | 10,000-MI CORE | 29,000-MI NETWORK |
| Route-miles: | 10,000 | 26,000 | 10,000 | 26,000 | 9,860 | 28,681 |
| Traffic: | 502,470 | 945,800 | 502,470 | 945,800 | 484,035 | 1,044,751 |
| Investments ($M): | | | | | | |
| Catenary | 1,660.6 | 3,595.8 | 2,646 | 6,040 | 2,605.2 | 7,592.2 |
| Substations | 516.4 | 1,175.2 | 1,320 | 3,000 | 522.9 | 1,534.3 |
| Utility Connections | 100.0 | 260.0 | 150 | 390 | 167.7 | 513.6 |
| Signals & Communications | 682.5 | 1,625.0 | 1,850 | 4,400 | 1,032.4 | 2,924.9 |
| Civil Reconstruction | 361.6 | 858.0 | 696 | 1,660 | 216.5 | 909.4 |
| Design Engineering | - | - | - | - | 454.5 | 1,347.4 |
| Construction Engineering | - | - | - | - | 68.2 | 202.1 |
| Electric Locos Purchased | 1,800.0 | 3,400.0 | 2,770 | 5,240 | 1,835.8 | 3,604.1 |
| Diesel Loco Purchase Avoided | - | - | - | - | -2,271.2 | -4,346.8 |
| Diesel Locos Released | -1,700.0 | -3,200.0 | -2,690 | -5,060 | 0 | -9.9 |
| Net Investments | 3,420.9@ | 7,714.0 | 6,740 | 15,700 | 4,632.0 | 14,271.4 |
| Annual Costs and Credits ($M): | | | | | | |
| Electric Energy | 381.0 | 706.1 | 597 | 1,110 | 354.0 | 708.0 |
| Electric Loco Maintenance | 96.6 | 182.4 | 217 | 409 | 166.4 | 302.0 |
| Wayside Maintenance | 20.0 | 52.0 | 44 | 114 | 43.6 | 122.8 |
| Diesel Fuel | -398.8 | -739.2 | -807 | -1,500 | -760.9 | -1,500.0 |
| Diesel Loco Maintenance | -370.0 | -696.3 | -724 | -1,360 | -542.2 | -1,050.0 |
| Diesel Loco Purchases | -94.0 | -178.0 | -149 | -281 | -55.7 | -67.9 |
| Electric Loco Purchases | - | - | - | - | 51.3 | 60.7 |
| Net Annual Savings | 365.2 | 673.0 | 822 | 1,508 | 743.5 | 1,424.4 |

*Taken from Table C-2, Appendix C of DOT/FRA Report (Ref. 1)
@See Appendix 1 - Errata for Appendix C of Ref. 1.

There is a 25 percent increase in the cost of catenary construction for the network despite a reduction in cost per unit-mile as indicated in Table 2-10. The increase is the result of a 3000 mile increase in network size and inclusion of 9600 miles of sidings and yards in the estimate (see Table 2-2). This increase was offset by the reduction in substation cost, which resulted from downward revision of both unit cost and quantity of substations.

A number of alternative methods of calculating costs of signaling were explored, but in the absence of detailed examination of the existing equipment on each segment it was considered prudent to continue to use a flat cost per mile except where route-specific data were available, accepting that this method may under or overstate the costs according to the age and condition of the equipment in use. The reduction in cost is the result of a downward revision in the cost per mile.

The number of locomotives (diesel and electric) required was significantly less than previously estimated, thereby significantly reducing the magnitude of these investments. However, the net locomotive investment now indicates a significant credit whereas the previous studies showed an expense. This results from the difference in procedure for crediting diesel locomotives not required. In the previous studies, it had been assumed that the locomotives displaced by electrification would be a cross section of a fleet with a life of 18 years equally distributed. Credit was taken for sale or use elsewhere at a price based on straight line depreciated value in the ninth year. Credit was also taken each year thereafter for the avoidance of capital expenditure on replacing 1/18 of the diesel fleet which had been displaced by the electrification.

The capital cost of new electric locomotives was included in the capital outlay, and the cost of replacement after a 30 year life was included in the cash flow calculations.

It was considered that, for the larger railroads, these assumptions simulated the likely situation for electric locomotives, but were not realistic in portraying the capital expenditure associated with the diesel locomotives displaced. Therefore, it was assumed that the larger railroad would have a diesel locomotive replacement program based on acquiring each year new locomotives equal to 1/18 of the whole fleet. Further, that when the electric locomotives took over the work of a given number of diesels, the railroad would reduce their replacement program by an equivalent number of diesel locomotives and that there would be a credit of this amount of capital expenditure avoided to the simulation of electrification. The avoidance of a similar capital expenditure each 18 years was also credited. An estimate was made of the annual replacement need for line-haul diesel locomotives by the railroad concerned. Where this exceeded the annual building program for diesel locomotives, the credit was spread over up to three years starting with the first year of electric operation.

In comparison with the method of the previous studies, there has been a shift in the railroad cash flow; credit for the capital expenditure for diesel locomotives at the onset of electrification of any segment is greatly increased while the annual credit for diesel purchases during each year of operation has been reduced to a single credit every 18 years. For a few of the smaller railroads the proposals for electrification displaced the majority of their diesel locomotives over a relatively short period and the general method outlined above was inappropriate. In these cases the method of the previous studies was retained.

While this study did not postulate any segments in operation in 1980, the previous studies had assumed all routes in operation in their base year. For comparison of results, the annual costs and credits shown in Table 2-11 are therefore for operation of all segments at the 1980 traffic level. The net annual savings of the "C" network is six percent less than in the "B" network.

The total cost of diesel fuel is unchanged, the increased cost per gallon being offset by a reduced estimate of consumption. Electricity cost is reduced as a result reduced average costs per kilowatt-hour and reduced consumption. Both diesel and electric maintenance costs are reduced as a result of the smaller fleet sizes. Data provided by the railroads on dispatching rates were used which had the effect of reducing the energy consumption. It also reduced the number of locomotive miles and thus the locomotive maintenance costs, although the diesel maintenance cost per locomotive-mile had been held constant in the last two studies.

The significant change is the increase in percentage of net savings attributed to electric energy savings over diesel fuel. In the "A" study, energy savings accounted for five percent of the net savings. In the "B" study, it was 25 percent. In this study, it is 56 percent. Maintenance savings between electric and diesel have become increasingly less dominant, until now the energy and maintenance savings are nearly equal.

## 2.8 RATE OF RETURN CALCULATIONS

The rate of return (ROR) reflects the benefits derived from the capital expenditures, regardless of the source of funds, for each segment as it is completed. Calculated this way, changes in the provision of investment funds between the three parties concerned has no effect on the ROR for the project as a whole. No attempt has been made to evaluate the synergistic effect of multiple sectors being electrified, nor has any allowance been included for any greater attractiveness of the service offered, although these can both be significant factors for consideration in individual railroad proposals.

An alternative approach discounts the cash flow of the project at 10 percent a year and calculates the net present value surplus.

The model can calculate either of these measurements for each sector, as well as for all of the segments of a railroad and for the entire network.

The network results are compared with previous FRA results in Table 2-12. The ROR is substantially greater, primarily because the previous studies did not consider that conversion of the network would require a finite number of years, thereby allowing traffic to build to higher levels on many of the routes before conversion. There has been a much more detailed examination of the traffic forecasts and dispatch levels, and refinement of the unit costs as discussed elsewhere in this report. In addition, avoidance of new diesel purchases during

TABLE 2-12. RATE OF RETURN FOR THE THREE NETWORK SCENARIOS (PERCENT)

| | A (1977) | | B (1980) | | C (1982) | |
|---|---|---|---|---|---|---|
| SCENARIO | W/O FUEL DIFFERENTIAL | W/FUEL DIFFERENTIAL | W/O FUEL DIFFERENTIAL | W/FUEL DIFFERENTIAL | W/O FUEL DIFFERENTIAL | W/FUEL DIFFERENTIAL |
| 10,000 Route-mi Network (Core) | 12 | 15 | 14 | 17 | 18.9@ | 25.5@ |
| 26,000* Route-mi Network | 10 | 12 | 11 | 14 | 14.4@ | 19.4 |

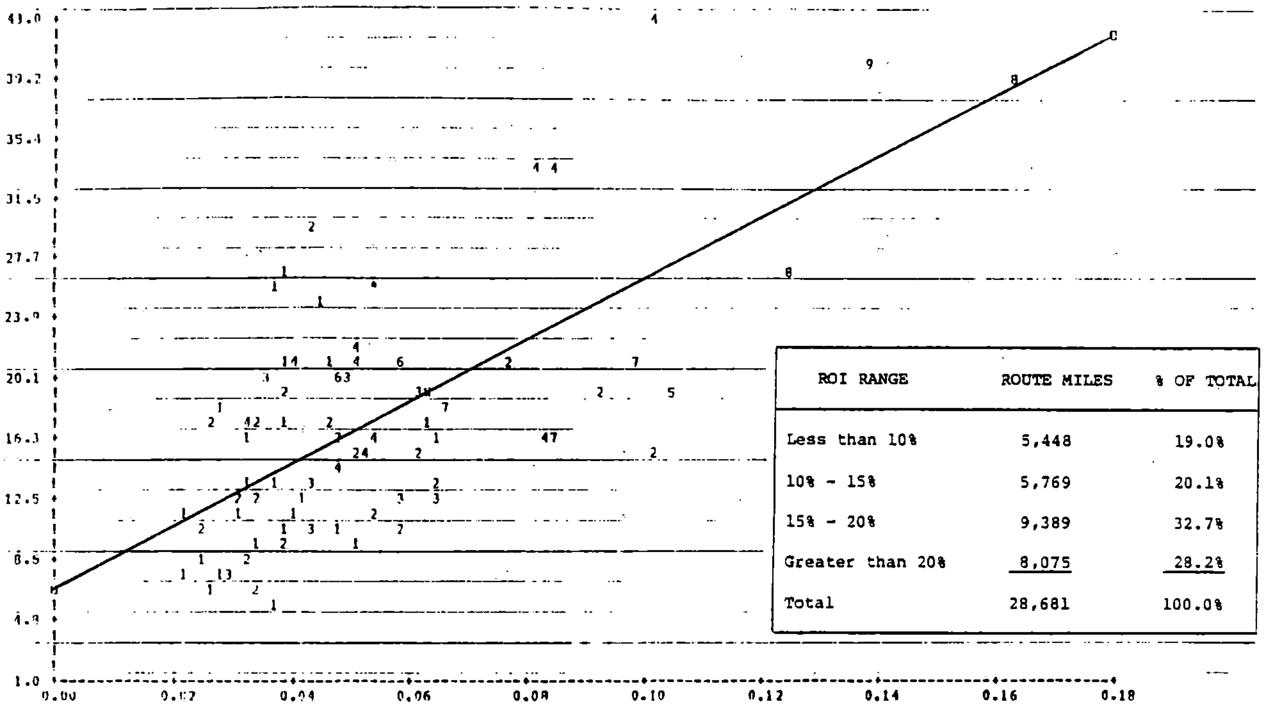
*29,000 Route-mi in C (1982) Analysis
@Constructed from other computer model runs.

the investment period produces more credit than does selling of the excess used diesels at their market value.

Of more significance is the wide variation in ROR among the 96 segments as summarized by the table inset in Figure 2-3. Analyses were made to determine the operational or performance factor most influential in establishing the ROR. The graph in Figure 2-3 is a linear regression plot of ROR versus traffic density, the traditional figure of merit used to identify routes suitable for electrification. The numbers scattered about the straight line locate the ROR and traffic density for individual route segments. The numbers (0-10) are weighting factors which indicate the relative influence of each point in establishing the regression line. The weighting factor accounts for variation in annual traffic on each route.

The straight line is a least squares fit of the points and the W on the line is the location of the mean value. If the points all fell on the straight line the correlation as measured by the R-squared computation would be 1.0[12]. The R-squared value for traffic density is 0.56.

Figure 2-4 is a linear regression plot of ROR versus diesel fuel consumption per route mile per year. This was the best single variable correlation found, the R-squared value being 0.74. Fuel consumption implicitly includes traffic density, but also brings in the effects of dispatching policy and gradient. Thus a route which is heavily graded with a high HP/ton dispatch policy will benefit more from the fuel differential and locomotive maintenance savings between diesel and electric motive power at any given traffic density.



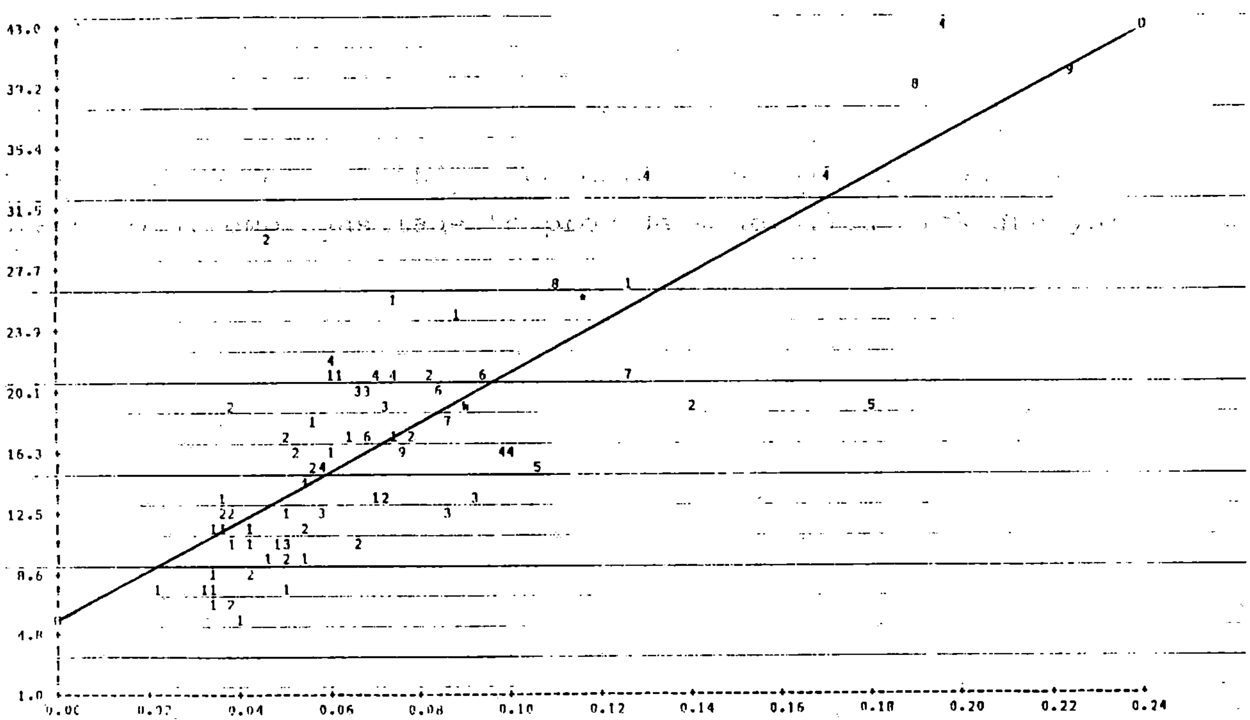

| ROI RANGE | ROUTE MILES | % OF TOTAL |
|---|---|---|
| Less than 10% | 5,448 | 19.0% |
| 10% - 15% | 5,769 | 20.1% |
| 15% - 20% | 9,389 | 32.7% |
| Greater than 20% | 8,075 | 28.2% |
| Total | 28,681 | 100.0% |

HORIZONTAL AXIS IS IN BILLION GT/YEAR IN FIRST YEAR OF OPERATION
VERTICAL AXIS IS PERCENT RATE OF RETURN

NOTE: TO CREATE LINEAR REGRESSION PLOT DRAW A STRAIGHT LINE CONNECTING THE O'S.

96 LINK EQUATION: Y = 195.22 X + 6.9872 XM = 0.063 BILLION GT/YEAR YM = 19.3% R-SQUARED = .55637

FIGURE 2-3. PLOT OF RATE OF RETURN VS. TOTAL GROSS TRAFFIC DENSITY FOR LINKS OF CASE STUDY 306AL




HORIZONTAL AXIS IS IN MILLION GAL/RM/YR IN FIRST YEAR OF OPERATION
VERTICAL AXIS IS PERCENT RATE OF RETURN

NOTE: TO CREATE LINEAR REGRESSION PLOT DRAW A STRAIGHT LINE CONNECTING THE O'S.

96 LINK EQUATION: Y = 156.0 X + 5.4581 XM = 0.089 MILLION GAL/RM/YR YM = 19.3% R-SQUARED = .73583

FIGURE 2-4. PLOT OF RATE OF RETURN VS. DIESEL FUEL CONSUMED PER ROUTE MILE FOR LINKS OF CASE STUDY 306AL

An empirical relation using the equation constants at the bottom of Figure 2-4 could be used to develop a rule of thumb for determining whether a route is suitable for electrification. While it would provide a better estimate than traffic density, there are obviously other route-specific factors which can have significant effect on the ROR. An ROR analysis assures inclusion of all such factors.

## 2.9 FINANCING ARRANGEMENTS

### Real Interest Rates

In this analysis, interest rates were divided into two components - compensation for the use of money (real interest) and compensation for inflation. The base case was calculated throughout at constant 1980 prices, and for the cost of funds for investment a "real" rate of interest was used, excluding the inflation element. Separate runs of the base case data at varying inflation rates were made to show the effect of inflation on the results.

The model will accept different rates of real interest for the two divisions of investment, utility and external funding, reflecting the differing degrees of risk associated with each.

### Variation in the Funding of the Investment

In the base case, the cash outlay for catenary, substations and utility connections was considered to be partially financed by the external funds as Table 2-13 indicates.

TABLE 2-13. BASE CASE: OUTLAY STRATEGY

| (% INVESTMENT BY) | RAILROAD | EXTERNAL FINANCE | UTILITY |
|---|---|---|---|
| Catenary | 25.0 | 75.0 | 0.0 |
| Electric Locomotives | 100.0 | 0.0 | 0.0 |
| Substations | 50.0 | 0.0 | 50.0 |
| Utility Connections | 0.0 | 0.0 | 100.0 |
| Signal & Communication Compatability | 100.0 | 0.0 | 0.0 |
| Civil Reconstruction | 100.0 | 0.0 | 0.0 |
| Systems Engineering | 100.0 | 0.0 | 0.0 |
| Construction Engineering | 100.0 | 0.0 | 0.0 |

Figures 2-5 and 2-6 show the effect in total of the financial commitment by each of the three parties cumulatively over the life of the project.

In each case, a cumulative outlay is shown which represents the gross indebtedness incurred, before considering benefits or repayment of interest or capital by another party, or benefits to the railroads from the electrification. In the cases of external and utility outlay, the total increases until all sectors have been constructed, and thereafter remains constant. In the case of railroad outlay there is a cyclic credit for avoiding investment in diesel locomotives that can be observed as a result of the different life expectancy of diesel and electric locomotives; after an initial period where the outlays exceed the negative element there is a period where the avoidance of purchase of further diesel locomotives at the end of an 18 year life is not balanced by the purchase of further electric locomotives (30 year life). Thus the cumulative outlay reduces and then increases again over cycles of about 20 years.

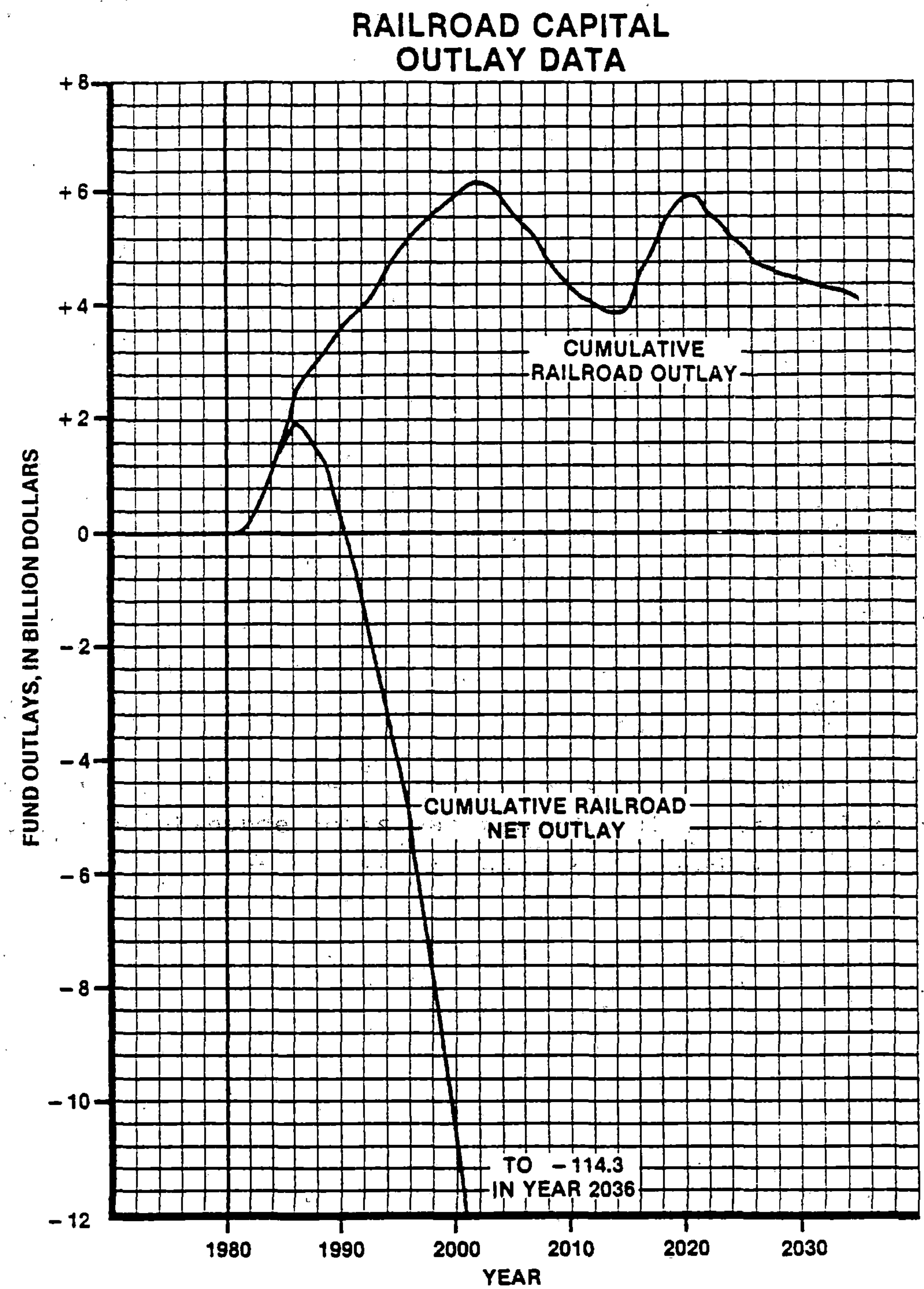



FIGURE 2-5. RAILROAD CAPITAL OUTLAY DATA

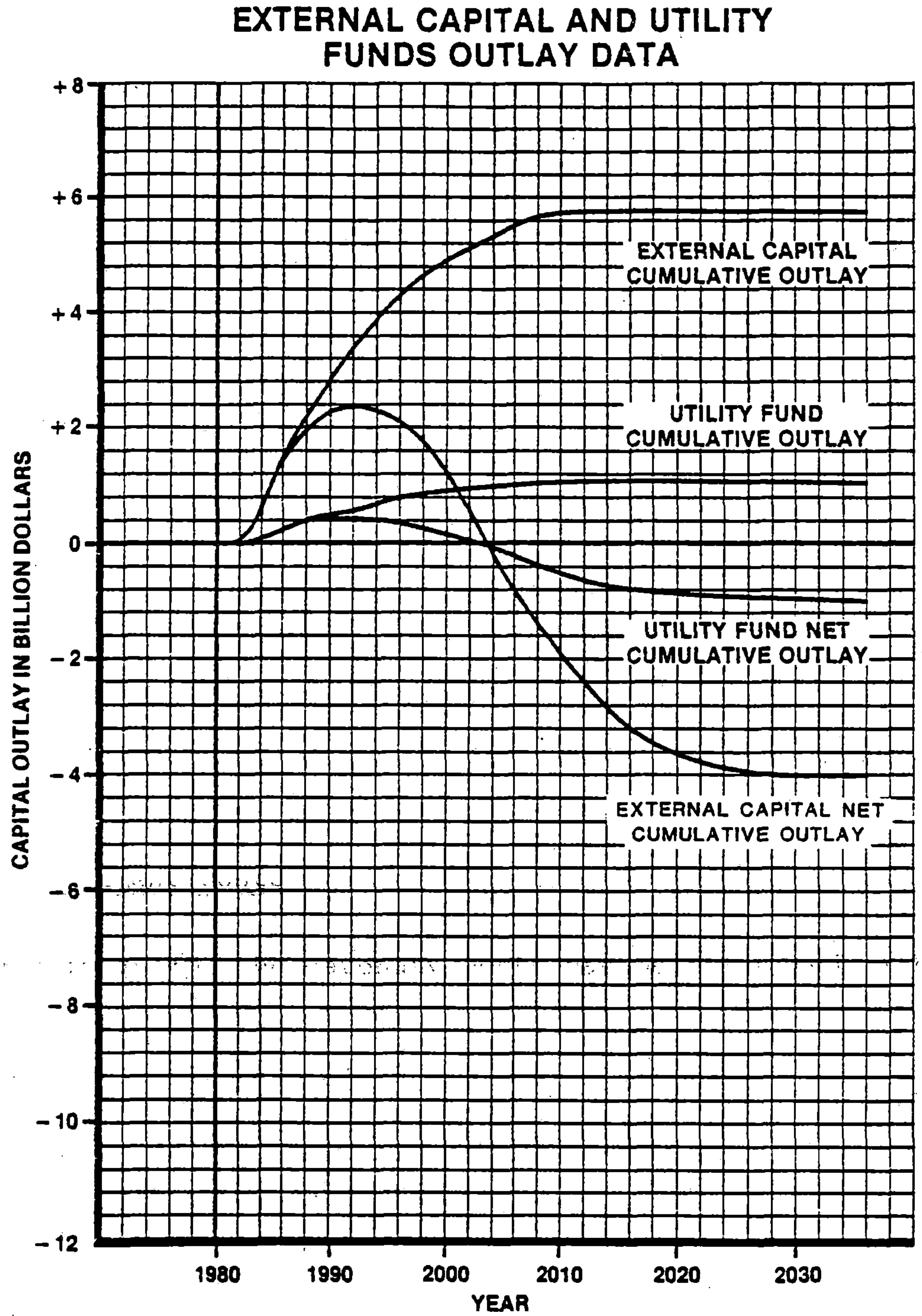



FIGURE 2-6. EXTERNAL CAPITAL AND UTILITY FUNDS OUTLAY DATA

The net cumulative outlay depicts the situation when the benefits of electrification are included. The peak outlay by the railroad and external fund is approximately $2B while for the utility industry it is $400M. The external and utility net outlay includes payments by the railroads. In each case, the benefits match the outlays in the year 2004 and thereafter both show a negative outlay, which basically reflects interest payments. If these are excluded, the net outlay reaches zero at the end of the study period. In the case of the railroad, initial benefits do not balance outlay, since much of the cost reduction is absorbed by annual payments for the external financing, and to the utility. However, as the electrification of the network proceeds, capital expenditures by the railroads decrease, and 10 and 20 years after startup, payments cease for utility investment and external financing. The result, shown on Figure 2-5, is a rapid and sustained increase in railroad net cash flow.

Alternatives were explored under which progressively more of the project was financed by the external sources and for the case in which the entire investment cost is handled by the railroad. These changes would have no effect on the return on investment of the project but affect radically the 'gearing' of the railroad investment.

Table 2-14 illustrates the varying investment strategies that were examined for their effect on the railroad cash flows. The bar chart of Figure 2-7 indicates the portion of the maximum net outlay assumed by the railroad, external fund source, and utility industry for case numbers 100, 105, 306, and 307.

TABLE 2-14. OUTLAY STRATEGIES CONSIDERED

| | CASE NUMBER | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| INVESTMENT ITEM | 100 | 101* | 102 | 103 | 104 | 105 | 306 | 307 |
| CATENARY | E-100@ | E-100 | E-100 | E-100 | E-100 | E-100 | R-25@ E-75 | R-100 |
| SUBSTATIONS | E-50 U-50@ | E-50 U-50 | E-50 U-50 | E-50 U-50 | E-50 U-50 | R-50 U-50 | R-50 U-50 | R-50 U-50 |
| UTILITY CONNECTIONS | U-100 | U-100 | U-100 | U-100 | U-100 | U-100 | U-100 | U-100 |
| SIGNALS & COMMUNICATIONS | R-25 E-75 | R-25 E-75 | R-75 E-25 | R-75 E-25 | R-100 | R-100 | R-100 | R-100 |
| CIVIL RECONSTRUCTION | R-25 E-75 | R-25 E-75 | R-75 E-25 | R-75 E-25 | R-100 | R-100 | R-100 | R-100 |
| SYSTEMS ENGINEERING | E-100 | E-100 | E-100 | R-75 E-25 | R-100 | R-100 | R-100 | R-100 |
| CONSTRUCTION ENGINEERING | E-100 | E-100 | E-100 | R-75 E-25 | R-100 | R-100 | R-100 | R-100 |
| ELECTRIC LOCOMOTIVES | R-100 | R-100 | R-100 | R-100 | R-100 | R-100 | R-100 | R-100 |

*Assumes a general rate of inflation of 7% annually; all other cases assume 0% inflation.

@R = Internal Railroad Financing
E = External Source of Financing
U = Financed by Electric Utilities

<u>NOTE</u>: Case 306 is base case in this report.

## 2.10 SENSITIVITY TESTS

In any feasibility study of the magnitude of the electrification proposed, there are bound to be major factors where the assumptions made have a significant effect on the results obtained.

The time scale studied - 1980-2036 - itself presented problems in defining a number of basic parameters. It is virtually impossible to forecast accurately economic growth (or recession), or the rate of inflation, or the price and availability of fuel oil, for example, over a 56 year future period.

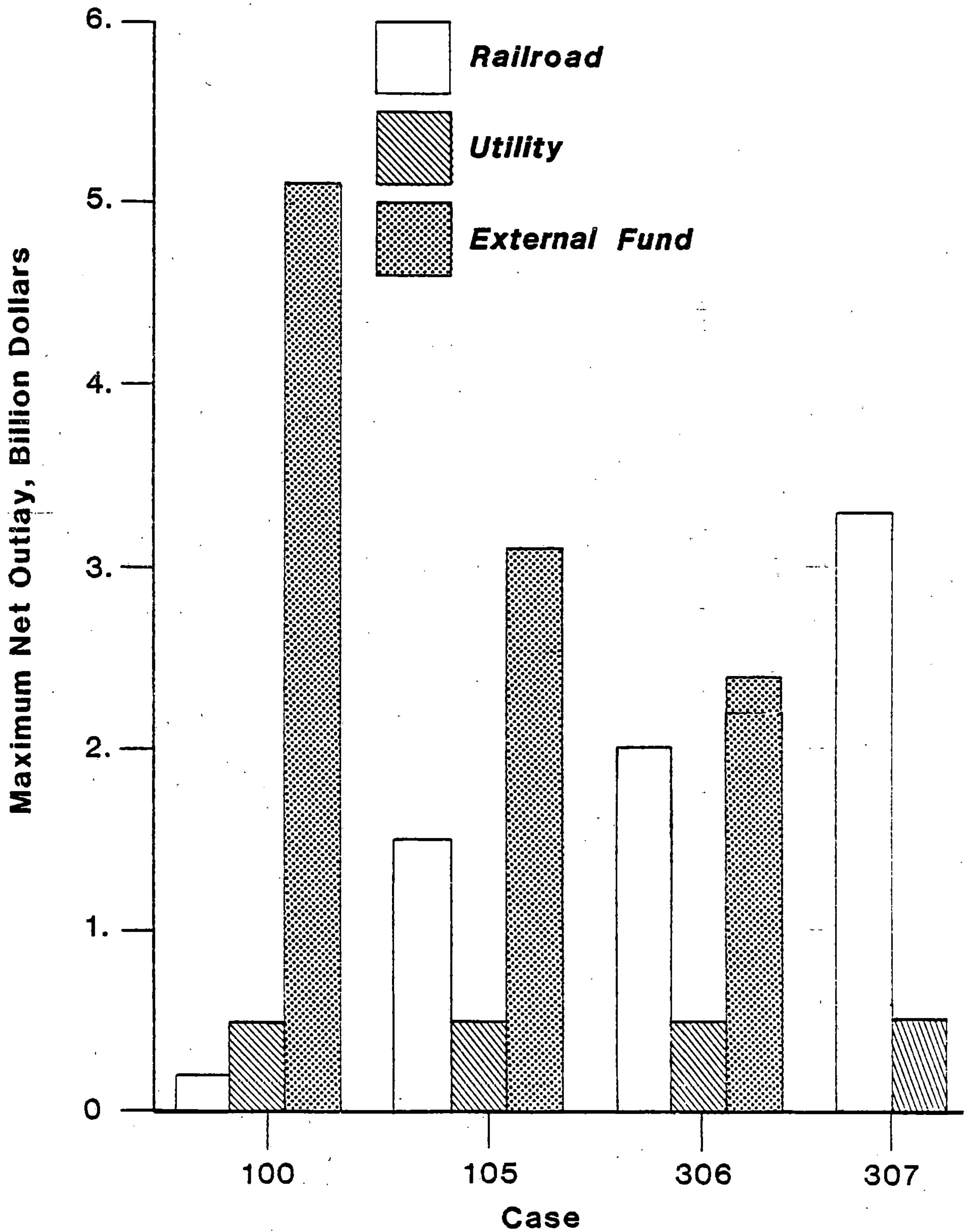





FIGURE 2-7. MAXIMUM NET OUTLAY, BILLION DOLLARS

Many of the costs of electrification were, of necessity, theoretical estimates, based on experience elsewhere, and largely unrelated to U.S. conditions. Major assumptions had to be made regarding the types of electric locomotive to be used, availability, and maintenance cost. Assumptions regarding operating arrangements for electric traction are fundamental to the results obtained.

Figure 2-8 indicates the major areas of uncertainty which were explored.

The first group of variables considered were those concerned with physical performance:

1. Rate of traffic growth;

2. Fuel costs and the difference between the cost of diesel fuel and electricity;

3. Locomotive maintenance costs.*

The next group of variables related to the costs of the electric locomotives themselves:

1. The capital cost of locomotives;

2. Dispatch level (HP per ton);

3. Replacement ratio of electric to diesel.

*The locomotive maintenance costs were affected by the cost per locomotive mile, and the dispatch level.

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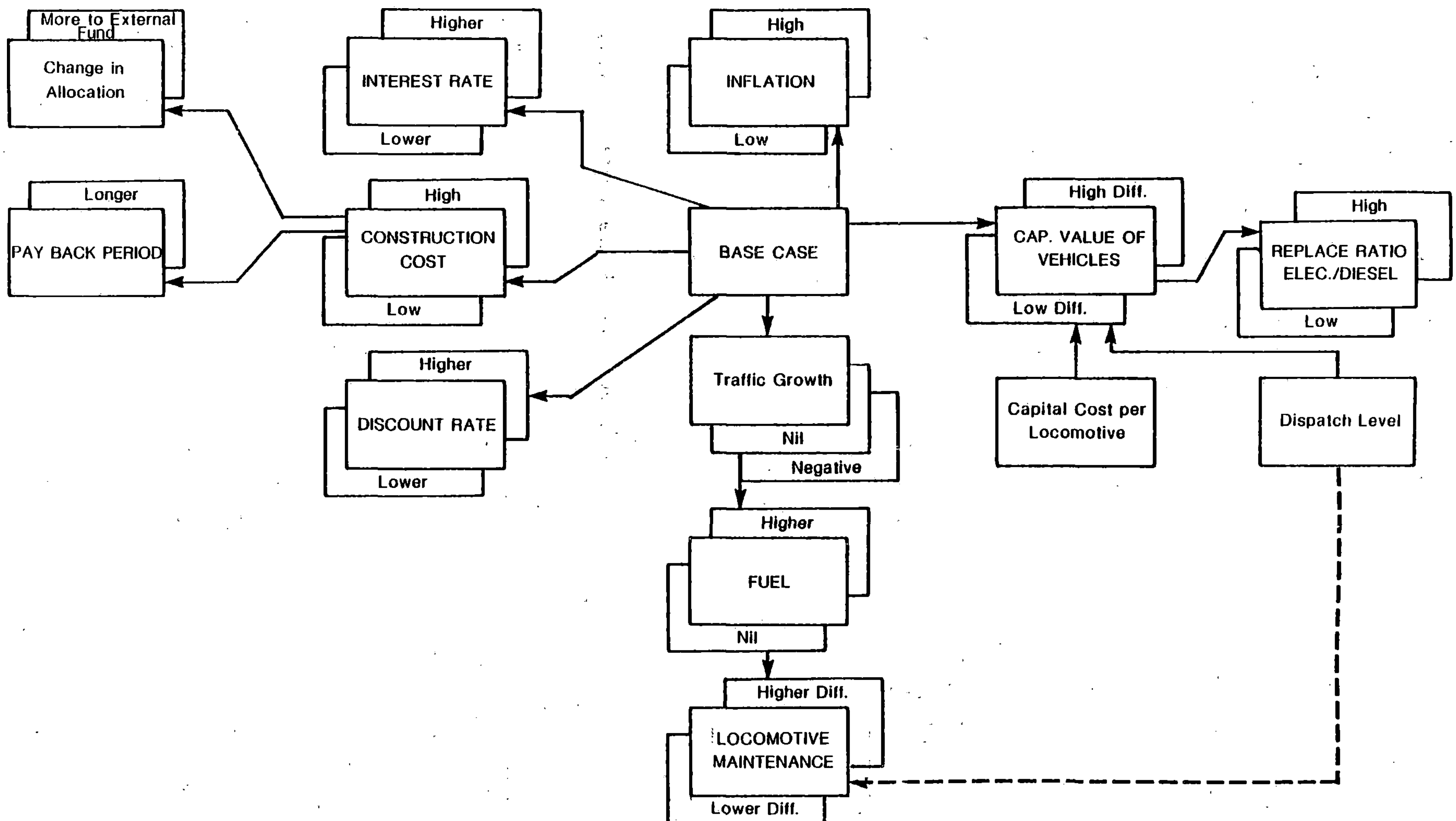


FIGURE 2-8. INPUT VARIABLES INCLUDED IN THE SENSITIVITY STUDY

The third group of variables related to the costs of fixed installations:

1. Cost of construction;

2. Change in pay back period;

3. Change in proportion financed by railroads.

Finally, alternative economic financial assumptions were considered:

1. Discount rate;

2. Interest rate;

3. Inflation rate.

Initially, each variable was considered independently. Then the variables were grouped to establish their significance in total. In a simplified way this established the main areas of risk associated with the calculations, although at this stage no attempt was made to provide a detailed risk analysis.

Figure 2-9 shows the effect of percentage changes of selected variables on the rate of return on investment established in the base case. For example, a 10 percent increase in the capital cost of catenary reduces the rate of return by about one percent; a 10 percent negative variation in traffic growth would reduce the rate of return by a lesser amount, about 0.5 percent.

To establish the relative effect on rate of return, the expected deviation of each variable from the nominal value must be specified. Figure 2-10 is a bar chart depicting the results of sensitivity tests based on subjective opinions of the degree

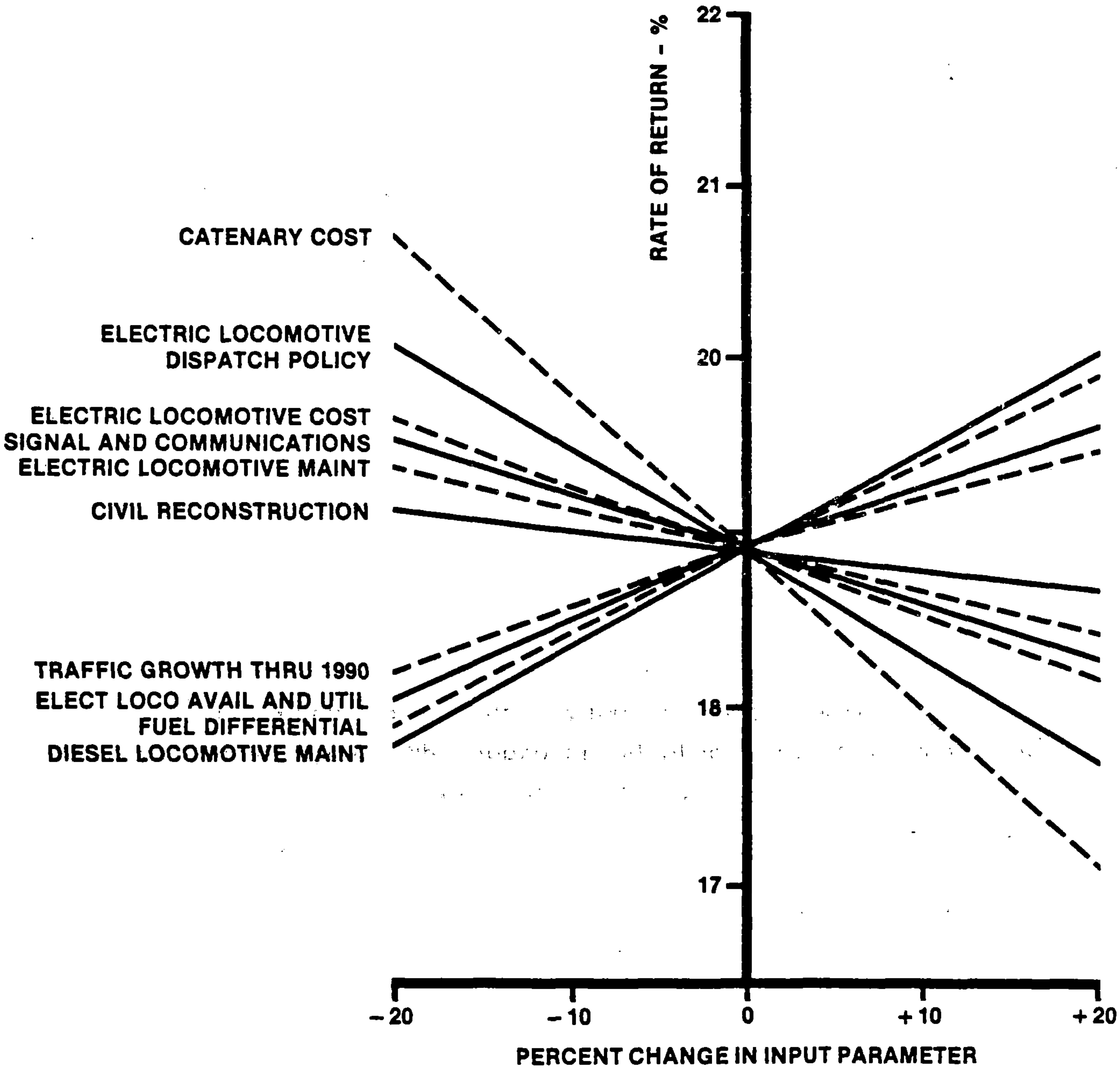


FIGURE 2-9. GENERALIZED SENSITIVITY RESULTS

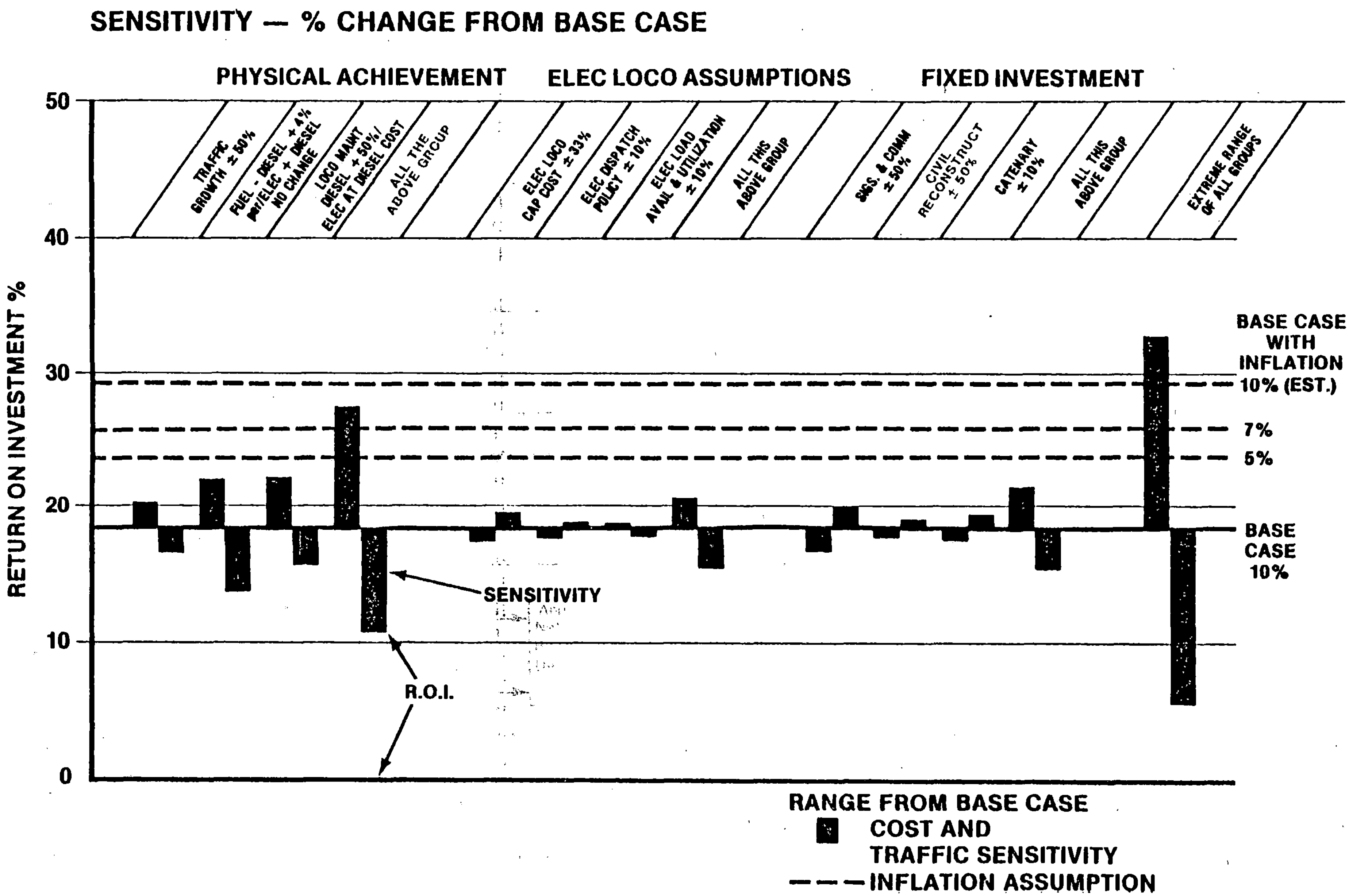


FIGURE 2-10. SENSITIVITY RESULTS FOR A SPECIFIED RANGE OF EACH VARIABLE

of risk associated with each parameter. For each variable, a bar indicates the percentage change from the base case return on investment caused by the chosen variation. The size of each bar indicates the degree of significance of the effect of changing a particular variable by the amounts shown at the top of the chart. The total effect of cumulative variations of the parameters of all variables in each group is also depicted. Finally, the extreme range of all favorable/unfavorable variations is shown. This is a highly unlikely situation and is given only to show the robustness of the results. A positive return on investment exists even under the least favorable combination of assumptions. The effect of inflation at rates from five to 10 percent is shown by the dotted lines identified with the right hand side of the chart.

The following paragraphs discuss the results of the sensitivity test:

Physical Achievement

In this group, the possibility of errors in forecasting future traffic levels, fuel costs, and the difference in locomotive maintenance costs was tested. These variables proved to be the most sensitive and taken together gave a range of plus nine to minus seven percent around the result achieved in the base case. Within the group, alteration of the fuel differential between diesel and electricity to plus four percent a year increased the rate of return by four percent; an assumption of no increase in either diesel fuel or electricity reduced the rate of return by two percent. Equally important in this group was the effect of changes in the assumptions regarding the relative costs of maintenance of diesel and electric locomotives. An assumption that costs of electric locomotive maintenance would be accurate at 85 cents per mile, but that the maintenance costs of a diesel locomotive would be 50 percent higher (Two dollars per mile) increased the rate of return by four percent, while an assumption that the costs of maintenance of both diesel and electric locomotives would be the same (1.33 dollars mile) reduced the rate of return by five percent. The third element in this group had a relatively small impact - a 50 percent plus or minus assumption on the rate of traffic growth made only two percent difference to the rate of return.

Electric Locomotive Assumptions

The assumption that the capital costs of electric locomotives might be one third higher, or lower, altered the rate of return by one percent. Also tested was sensitivity to variation in the assumptions on electric locomotive dispatch levels, and availability. In each case, a 10 percent change plus or minus had a negligible effect on the return on investment. The range of effect for the whole group was from plus two percent to minus two percent on the rate of return; about as important in total as the effect of the least important factor in the previous group.

Fixed Investment Costs

In this group, the catenary costs can be estimated with reasonable accuracy and a variation of plus/minus 10 percent was assumed. This changed the rate of return by less than one percent. The effect of an assumption of plus/minus 50 percent on the costs of bridge and tunnel reconstruction costs (which were theoretical estimates) also had no significant impact on the rate of return. However, variation of the costs of signalling and communications by plus/minus 50 percent did change the rate of return by more than one percent.

Inflation

The effect of inflation was measured at five percent, seven percent and 10 percent a year cumulative over the life of the project. In each case, the return on investment increased by slightly more than the inflation rate.

Summary

The results of the sensitivity analysis are summarized in Table 2-15.

The rate of return is relatively stable even with wide up and down changes in the basic assumptions. The largest deviations up and down from the base case for any one factor are plus four percent and minus five percent, respectively, which is of about the same magnitude as the effect of a five percent inflation rate. Most of the other sensitivities were below two percent plus or minus in their effects. However, the group concerned with physical achievement (traffic growth, fuel cost differential, and difference in locomotive maintenance costs) were seen to be much more important than the other two groups.

TABLE 2-15. SUMMARY OF SENSITIVITY TO CHANGES IN ASSUMPTIONS

| SENSITIVITY GROUP TESTED | PERCENT CHANGE IN RATE OF RETURN | |
|---|---|---|
| | FAVORABLE | UNFAVORABLE |
| Base Case* | 19 | |
| Changes in: | | |
| Physical Achievement | +9 | -7 |
| Electric Locomotive Assumptions | +2 | -2 |
| Fixed Investment Cost Assumptions | +3 | -3 |
| Inflation at: | | |
| 5 Percent/Year Cumulative | +5 | |
| 7 Percent/Year Cumulative | +7 | |
| 10 Percent/Year Cumulative | +11 | |

*In constant dollars.

# 3. MODEL DESCRIPTION

A proposed investment project being considered by a railroad may alter the cost of operation and the quality of service provided which may, in turn, affect freight rates and traffic volume. To understand the manner in which these variables interact to alter earnings requires an analysis at the railroad "system" level with consideration given to rate setting procedures, traffic demand forecasts, operational alternatives, and financing and taxation strategies. Frequently, a simpler concept is employed in which quality of service, freight rates and volume of traffic are assumed to be unaltered by the project being considered. The value of the investment is then measured by the amount of operating cost reduction that can be achieved.

Railroad electrification has been examined at both levels. A study by SRI International[13] examines the effect of several rate setting philosophies. Traffic growth for electrified operation is assumed to be incrementally greater than for diesel operation. This type of analysis provides a useful measure of the economic value of electrification from the railroad point of view. Most electrification analyses, however, assume rates, traffic and quality of service are unaltered by the conversion. From the point of view of the railroad, this approach may overstate or understate the economic value. If a portion of the reduced operating costs is actually passed on to the shipper through reduced rates and service improvements, and that portion exceeds the increment of revenue produced by an increase in traffic (new business), then the simplified model would overestimate the value. Conversely, if the revenue from increased traffic exceeds the operating savings passed on to existing customers, the simplified model underestimates the value.

In attempting to measure the overall effectiveness of electrification as stated in Section 3.1 below, the issue of apportioning cost reductions between shipper and consignee and the issue of acquiring new business at the expense of other railroads or other transportation modes should not be considered. For this application, the simplified model based on the differential costs of operation is the appropriate choice. The Rail Electrification Assessment Model is a differential, discounted cash flow analysis based on identical traffic, freight rates and quality of service for diesel and electric operation.

The financial index used in the model to measure the time value of an investment is the internal rate of return (ROR). This is the most frequently used index in the railroad industry for discretionary investment projects[14] and is stipulated by the Federal Railroad Administration in applications for Title V assistance under the Railroad Revitalization and Regulatory Reform Act of 1976 (4-R Act)[15]. The ROR is computed using conventional procedures of engineering economy to determine the time value of the differential cash flow which results when electrification replaces diesel operation[16].

## 3.1 GENERAL STRUCTURE

The computer model used in this study calculates the costs, savings and rate of return that result from converting to electrified operation, route segments of any railroad or combination of railroads that presently use diesel locomotives, together with relevant statistics of operation. Results are presented for each route segment, for the combined segments of each railroad and for the combined segments of any number of railroads.

The model was developed to use route and operational characteristics which have the most significant effect on the economics of electrification as route segment-specific input variables. The American Railway Engineering Association (AREA) has identified the cost elements which should be considered in making electrification economic studies[17]. The cost elements for this model, which closely resemble the AREA cost elements, are described in Section 4.1.1. The cost elements were discussed with, and agreed to, by the Planning Committee.

The model has the capability to:

1. Accumulate statistical data pertaining to the economics of electrification of a network composed of many route segments;

2. Compare the economics of individual route segments.

The model can evaluate only within the set of most significant parameters included in its formulation. It does, however, provides a uniform and expeditious procedure for establishing the value of electrification on many route segments. Thus, the model provides the capability to evaluate the benefits of electrification in more detail over a wider range of situations and with a higher level of confidence in the results than has previously been possible using "average" or "typical" characteristics.

The model has been formulated to use as input information which has been shown to be significant in previous studies. The procedure used for developing input data from basic operational and route characteristics of a segment is described in Section 4. This procedure was used for developing all of the input data in the FRA network study that was described in Section 2 even though feasibility studies were readily available for some of the route segments from which to obtain model input data. In this way all the results were comparable. The methodology was validated by comparisons with these feasibility results.

Figure 3-1 is a block diagram portrayal of the major elements of the model. The blocks within the double dotted lines identify the model functions performed by the computer. To the left is the systemwide input data and data specific to the route segments (links). The two link specific data files can accept data for any number of route segments to be evaluated. This data is processed sequentially by route segment to produce cost/benefit results for each. The systemwide data contains some information that is invariant across all links and some which varies by geographic region or with type of equipment specified. The values for variable systemwide data to evaluate a particular route segment are established from information contained in the Link Data File.

Many economic models specify as input data the cash flow on a year-by-year basis. This is impractical when examining a network that consists of many segments, each requiring a separate cash flow. The approach adopted here is to have the model compute the cash flow of each route segment using a simpler set of input data that consists of "base year" data, a prescribed conversion schedule and a set of growth and inflation rates applicable over the study period.

The initial step in computing cash flow over the study period is to grow the traffic-dependent data found in the Link Data File. The function of the block in Figure 3-1 entitled "Apply Link and Network Growth Rates" is to compute and retain traffic density. From this result, motive power requirements and energy consumption on an operating route segment for each year of the study period can be calculated. Data for both

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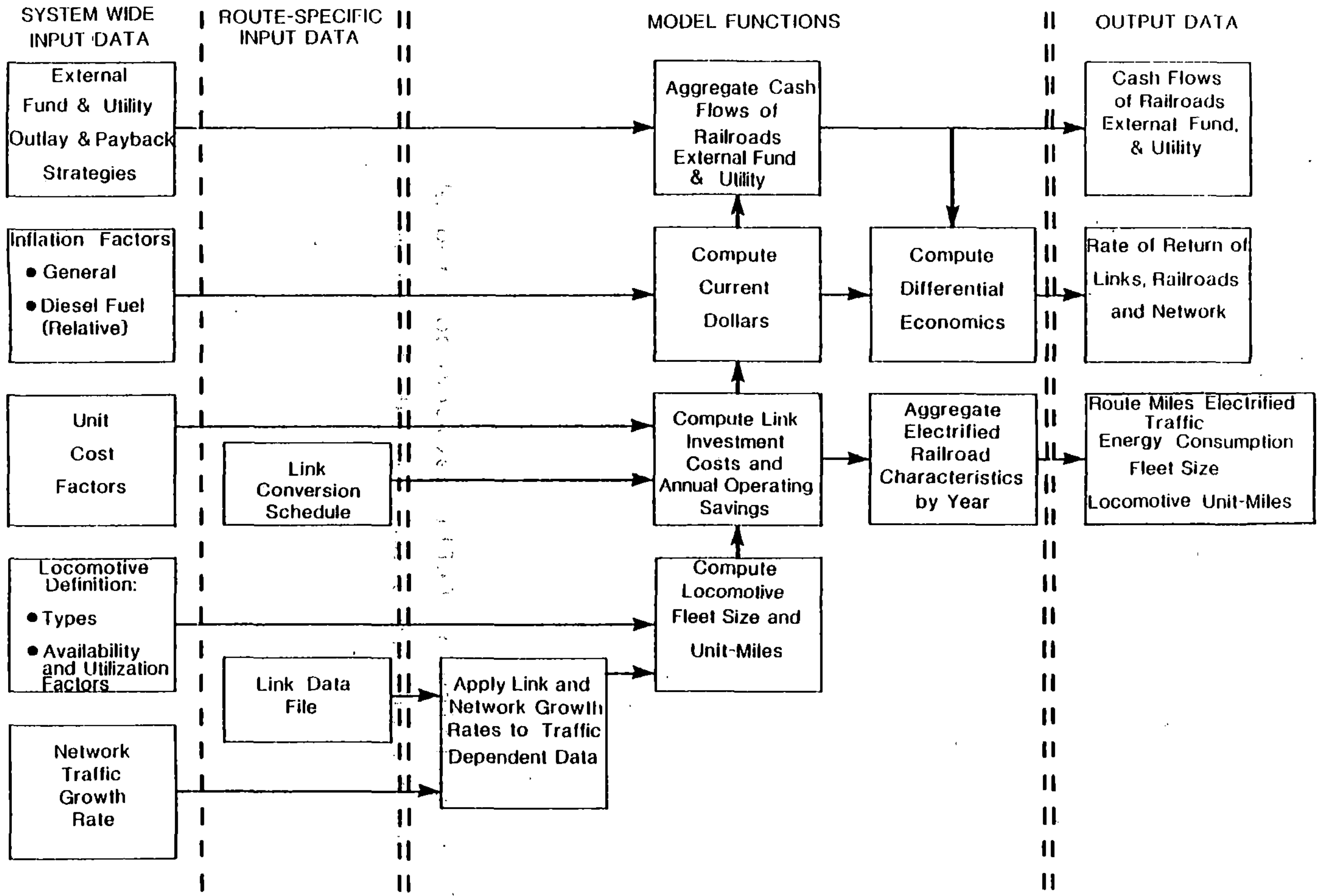



FIGURE 3-1. BLOCK DIAGRAM REPRESENTATION OF THE RAILROAD ELECTRIFICATION ASSESSMENT MODEL

diesel and electric operation is computed with no regard at this point to when electrification occurs. The link conversion schedule subsequently establishes what portion of the study period is pertinent in determining costs for the economic analysis.

To the right in Figure 3-1 is the output data presented for each link and aggregated for each railroad and for all railroads combined. The rate of return for individual links is presented with and without the differential inflation of fuel costs using equity funds, and as an option with the existence of financing support from the external and utility funds.

A qualitative description of the input data blocks of Figure 3-1 follows (Sections 3.2 and 3.3) as an introduction to further discussion of the model methodology (Section 3.4). The output data is described in Section 3.5.

## 3.2 ROUTE-SPECIFIC INPUT DATA

### Link Data File

The link data file contains the information required to convert route and operational characteristics into investment and operating costs. The data is stored sequentially by route segment for all segments that are to be anlayzed. Table 3-1 lists the data contained in the file for each route segment. Traffic density (Item IIa), locomotive horsepower (Item IVa), annual diesel purchase (Item IVf), and energy consumption (Items Va and b) are for a specified year called the traffic base year. All other items are assumed to be independent of traffic level. Diesel runtime and turnaround time (Items IVd and e) are not used by the model for computational purposes and are included only for recording in the output because they are

TABLE 3-1. INFORMATION CONTAINED IN THE LINK DATA FILE FOR EACH ROUTE SEGMENT

| ITEM | DESCRIPTION OF CONTENT |
|---|---|
| I. Route Characteristics | |
| a. Route Definition | Code number, railroad name; end points identified by name; Bureau of Census region. |
| b. Trackage Electrified | Route miles categorized by number of tracks and degree of curvature; siding and yard mileage added. |
| c. Bridges and Tunnels | Number of railroad truss bridges and overhead highway bridges that require increased clearance; total length of tunnels requiring increased clearance. |
| d. Ruling Grade | In each direction. |
| II. Traffic | |
| a. Density | Average traffic density in each direction for four types of service. |
| b. Growth | Annual growth of traffic in each direction for each type of service; year through which the growth is applicable. |
| c. Operating Route Mileage | Distance for which the average traffic density is computed (may differ from total route miles electrified). |
| III. Wayside Electrified Equipment | |
| a. Catenary Service Class | Normal or high speed. |
| b. Substations | Number required for each track category (1, 2, 3 and 4 track). |
| c. Utility Connection | Total miles of transmission line that must be constructed to connect railroad substations on the route segment to existing utility facilities. |

TABLE 3-1. INFORMATION CONTAINED IN THE LINK DATA FILE FOR EACH ROUTE SEGMENT (CONT'D)

| ITEM | DESCRIPTION OF CONTENT |
|---|---|
| IV. Locomotives | |
| a. Prevalent Locomotive Type (and characteristics) | Items a. thru d. are by type of service and for both diesel and electric operation; Items b. through d. are also by direction. |
| b. Dispatch Level | |
| c. Directional horsepower requirement | |
| d. Runtime between operating end points | |
| e. Diesel Turnaround Time | |
| f. Diesel Release Policy | Sell or transfer. |
| V. Energy Consumption | |
| a. Electric Energy | Megawatt-hours consumed annually by direction and service category. |
| b. Diesel Fuel | Millions of gallons consumed annually by direction and service category. |

basic data used in establishing locomotive horsepower requirements.

## Link Conversion Schedule

The time required to design and install the fixed plant equipment required for conversion to electrified operation is specified for each route segment by a set of five dates (year and month) as follows:

1. Start design date;
2. Complete design date;
3. Start construction date;
4. Fifty percent commission date;
5. One-hundred percent commission date.

It is assumed that each route segment is converted in two equal parts, one part being completed and ready for operation at 50 percent commission date. The construction period for the first part is from the start construction date to the 50 percent commission date. The second part becomes operational on the 100 percent commission date and the construction period is equal in length to the first construction period. The entire route can become operational on the same date by making the 50 percent and 100 percent commission dates equal. The schedule of individual route segments in the file can overlap without restriction to represent simultaneous construction that would be required for large scale electrification.

## 3.3 SYSTEMWIDE INPUT DATA

### Investment Finance

It is assumed that initial purchase of capital equipment required for conversion is made in part by the railroad, together with a combination of external finance and funds provided by the electric utility. The loans have specified interest rates and are repaid over specified time periods with annual payments which may be uniform or proportional to the annual energy consumption on the route for which the funds were borrowed. Table 3-2 indicates the outlay and payback parameters which must be specified in terms of percentage

TABLE 3-2. INVESTMENT OUTLAY AND PAYBACK PARAMETERS

ELECTRIFICATION OUTLAY STRATEGY

| | RAILROAD EQUITY FUND (PERCENT) | EXTERNAL FUND (PERCENT) | UTILITY FUND (PERCENT) |
|---|---|---|---|
| Catenary | X | X | X |
| Substations | X | X | X |
| Utility Connection | X | X | X |
| Signal & Communication Compatibility | X | X | X |
| Civil Reconstruction | X | X | X |
| Systems Engineering | X | X | X |
| Construction Supervision | X | X | X |
| Electric Locomotives | X | X | X |

PAYBACK STRATEGY

| | EXTERNAL FUND | UTILITY |
|---|---|---|
| Payback Period (years) | X | X |
| Interest Rate (percent) | X | X |
| Repayment Schedule: | X | X |
| 1. Uniform | | |
| 2. Proportional to Electric Energy Consumption | | |

distribution of funding responsibility between the railroad, external fund and utility fund.

## Unit Cost Factors

The unit cost factors defined in Table 3-3 are used in computing the costs and saving associated with electrification. All costs must be for a year called the currency base year.*

## Systemwide Compounding Factors

Table 3-4 lists four systemwide compounding factors. The two railroad system growth rates are the projected average change in traffic level of all railroads in each year of the specified time period. The factors are applied by default for any year on any link for which route-specific growth rates are not provided. These growth factors are also used for determining the number of diesel locomotives required annually by a railroad in years subsequent to the traffic base year.

The general inflation rate is an annual factor applied to the unit costs of the currency base year in order to establish current dollars. The general inflation can be set to zero to perform constant dollar analyses.

The differential escalation rate of diesel fuel is the amount by which the rate of inflation in diesel fuel cost exceeds the general inflation rate. Electric energy cost is

*The currency base year and traffic base year, to be defined later, are separately specified in order that traffic forecasts and cost estimates can be updated independently.

TABLE 3-3. DESCRIPTION OF UNIT COST FACTORS

| ITEM | DESCRIPTION OF CONTENT |
|---|---|
| I. Construction | |
| a. Catenary ($/Route Mile) | Normal and high speed types costed for 1, 2, 3 and 4 tracks, for three ranges of average curvature and for 25KV and 50KV design voltages. |
| b. Substations ($/Substation) | To serve 1, 2, 3 or 4 tracks. |
| c. Utility Connection ($K/Transmission Line Mile, $K/substation) | |
| II. Reconstruction | |
| a. Bridges ($/Bridge) | Up to 4 categories of bridge type may be costed. |
| b. Tunnels ($/Foot of Tunnel) | Up to 4 categories of tunnel type may be costed. |
| c. Signal and Communication ($/Route Mile) | |
| III. Locomotives | |
| a. Diesel ($/Rail Horsepower) | Up to 8 locomotive types may be costed. |
| b. Electric ($/Rail Horsepower) | Up to 4 locomotive types may be costed. |
| IV. Maintenance | |
| a. Diesel ($/Unit-Mile) | For each locomotive type identified. |
| b. Electric ($/Unit-Mile) | For each locomotive type identified. |
| c. Wayside ($/Track-Mile) | |
| V. Energy | |
| a. Electric Energy (¢/Kilowatt-Hour) | Up to nine regional rates can be established. |
| b. Diesel Fuel ($/Gallon) | |

TABLE 3-4. SYSTEM-WIDE COMPOUNDING FACTORS

| |
|---|
| Railroad System Growth Rate Through Year XXXX (Percent)* |
| Railroad System Growth Rate After Year XXXX (Percent) |
| General Inflation Rate (Percent) |
| Differential Escalation Rate of Diesel Fuel Through Year YYYY (Percent) |

*The links to be electrified are assigned specific growth rates.

assumed to increase at the general inflation rate. This was found to be an over-simplification, but was overcome as discussed in Section 4.1.2. In future work it would be preferable to provide an ability to also alter the real price of electric energy independently. The energy differential can be changed once during the life of the project.

Locomotive Definition

A locomotive type is established for each combination of horsepower rating and axle count that is currently used in diesel operation or will be available for use in electric operation to carry the preponderance of traffic on the links. Designation of locomotives by type has been included in the model to enable the sizing of an electric fleet based on at least equivalent horsepower and tractive effort capability to the present diesel fleet, thereby avoiding the need for predictions from a train performance calculator. A procedure for establishing an equivalent electric fleet is discussed in detail in Section 3.4.2.

## 3.4 MODEL METHODOLOGY

In this Section, three major aspects of model methodology are discussed:

1. Traffic definition;

2. Fleet sizing procedure and locomotive unit-mile computation;

3. Development of the differential cash flow

Other aspects of model methodology and the computational procedures employed are described in Volume II, Section 5.

### 3.4.1 Traffic Definition

In the previous FRA network analyses made through 1980, an average traffic density and a single annual growth factor were applied uniformly to all links. These assumptions did not introduce any large error into the resulting estimates of overall ROR when looking at a full national network, but they did contribute to a significant distortion in the relative economics of one link versus another.

In the present model, the traffic for each route segment is input with sufficient detail and accuracy to achieve the desired discrimination in economic value. There are four aspects to traffic contained in input data as follows:

1. Traffic is specified by direction in order to include the impact of imbalanced traffic on locomotive fleet size and maintenance;

2. Traffic between two points is specified by up to four types of service that have been defined as bulk, normal, expedited and passenger, in order to accommodate major distinctions that may exist in any of the following: locomotive type, dispatch level, run time, energy consumption and maintenance;

3. When there is more than one distinct pair of operating end points for the motive power on a route segment, then the fleet, energy and maintenance requirements are calculated for the traffic moved over each operating sector by the separate fleets. Multiple operating sectors may result from:

    a. Traffic that originates, enters, leaves and/or terminates at intermediate points on a route segment, assuming it is desired to haul this traffic with an electric fleet - otherwise, intermediate traffic is ignored;

    b. Route segments that contain branches;

    c. Helper locomotives added to mainline motive power at major grades for part of the segment.

4. Annual traffic growth on a route segment is specified for each direction, type of service and traffic pattern. This growth rate is applied from the traffic base year to a specified year, following which a systemwide annual growth factor is applied for the remainder of the study period.

Figure 3-2 illustrates typical traffic patterns which may exist on a route segment being considered for electrification. Distances are indicated by two letters with a bar over them. Traffic density for any operating sector is defined as the

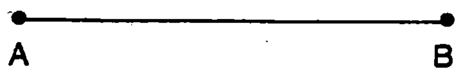
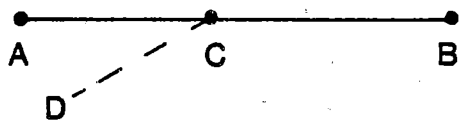
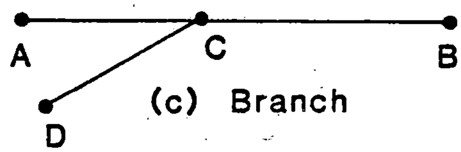
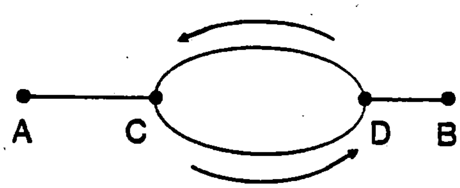
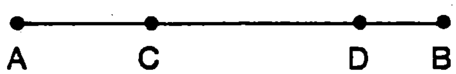
| ELECTRIFIED ROUTE SEGMENT | ROUTE CONFIGURATION | BASIC OPERATING ROUTE SECTORS |
|---|---|---|
| $\overline{AB}$ | <br>(a) Normal | $\overline{AB}$ |
| $\overline{AB}$ | <br>(b) Intermediate Origin | $\overline{AB}$, $\overline{AC}$, $\overline{CB}$ |
| $\overline{AB}$ + $\overline{CD}$ | <br>(c) Branch | $\overline{AB}$, $\overline{BD}$, $\overline{DC}$, $\overline{AC}$, $\overline{CB}$ |
| $\overline{AB}$ + $\overline{CD}$ | <br>(d) Separated Track | $\overline{AB}$ |
| $\overline{AB}$ | <br>(e) Helper on Intermediate Sector | $\overline{AB}$, $\overline{CD}$ |

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FIGURE 3-2. TYPICAL TRAFFIC PATTERNS ON A ROUTE SEGMENT annual traffic volume moved along the sector by locomotives that operate between its end points divided by the length of the operating sector. Sectors are chosen to achieve a reasonably uniform density of traffic, and can be split where necessary to avoid wide variations. Peaking of traffic during part of the year is handled by adjusting the locomotive utilization factor (see Section 4.2.4 and 4.2.5). The level of utilization is assumed to have no effect on energy consumption and locomotive maintenance.

A route with one operating route sector as in Figures 3-2(a) and (d) would require one set of input data as listed in Table 3-1. Multiple traffic patterns as in Figures 3(b), (c), and (e) require that input data proportional to traffic density be included for each operating sector.

### 3.4.2 Fleet Sizing And Locomotive Unit-Miles

#### Fleet Sizing

The link data file contains the horsepower requirement in each direction separately for both diesel and electric operation of each sector. The directional rail horsepower is:

1. the rail horsepower required in a given direction to move the gross tonnage in the base year including cars and locomotives;

2. Adjusted upward by a factor for locomotive utilization;

3. Divided by the number of one-way trip times in one year.

The computer model calculates the fleet size required to balance power requirements in the two directions on each operating sector. The fleet sizes on a link with multiple operating sectors is the sum of the fleet size of the sectors which comprise the link. This computation is repeated for each year of the study period using the directional horsepower appropriately updated to account for traffic growth.

If there is only one category of traffic on a sector (or more than one category all with the same locomotive type) then the fleet size is determined by doubling the larger of the two directional power requirements. If there is more than one category of service and each uses a different predominant locomotive type, power imbalances in one service category can be used to offset imbalance in another category, if they are imbalanced in opposite directions. This reduces the overall fleet requirement (diesel and electric) on the sector.*

Two constraints were imposed to assure that the use of a locomotive in other than its selected service category is operationally viable:

1. A locomotive is only assigned to a return trip in another service category if the runtime is less than that for the category for which it is prevalent;

*It should be noted that an operating procedure must be hypothesized which constrains locomotive movement to the sector in order to establish <u>both</u> the diesel and electric fleet sizes. While this is at variance with current diesel operation in which locomotives run through to other portions of the railroad, so would it be at variance with a fully electrified railroad in which electric locomotives would "run through." Constraining both diesel and electric locomotive movement on each sector eliminates any distortion in the results due to the order of electrification. Increase in fleet size of the railroad resulting from this constraint is ignored.

2. A locomotive is only assigned to a return trip in another category if the dispatch level (RHP/GT) exceeds that of the category for which it is prevalent.

If these constraints cannot be met, an excess locomotive is "deadheaded" to the other end of the sector. The first constraint assures a locomotive is always available for use in its assigned category. The second assures adequate tractive effort capability of the locomotive when used in other categories. To satisfy these constraints in the model, the service categories were arranged in what is generally the order of increasing dispatch level and speed as follows:

1. Bulk;
2. Normal;
3. Expedited;
4. Passenger.

The algorithm permits the locomotive for any service category to be substituted only into a higher service category. Any imbalance in power requirement that remains after this interchange of locomotives between service categories is eliminated by deadheading the excess power.

Helper locomotives on each grade are treated as a separate fleet analogous to other traffic sectors on a route segment.

## Locomotive Unit-Miles

The mileage accumulated annually by each locomotive type is used to compute locomotive maintenance cost. This computation follows the fleet sizing computation in order that the mileage accumulated by locomotives which are deadheaded may also be included. The equations for the unit-mile computation are given in Volume II, Section 5.

### 3.4.3 Development Of The Differential Cash Flow

There are four basic assumptions made in constructing the differential cash flow that is used to compute the rate of return:

1. The cash flow is expressed in current dollars (based on inflation factors that are specified as input data);*

2. The cost of electrification is considered in total, regardless of the sources of the funds, thereby producing an equity rate of return. An alternative calculation assumes that portions of the initial investment are financed by external sources or by the electric utility thereby shifting these costs into an annual loan repayment over a specified period at a specifed interest rate. This produces a leveraged rate of return;

3. All captial equipment is straight line depreciated over prescribed economic lifetimes, is replaced as necessary, and a residual value is calculated at the end of the study period;

4. No taxes and tax credits are included.

Costs are quantified where they differ for diesel and electric operation. Those cost elements that have been included in the model are delineated in Table 2-11. Cost elements are separated into two basic categories: (1) initial capital equipment costs that occur prior to commissioning, and

*When the general inflation rate is set to zero, the cash flow is constant dollars.

(2) annual operating costs that occur subsequent to commissioning, and capital equipment expenditures subsequent to commissioning including locomotive purchases for growth and replacement and fixed plant purchases for replacement. Development of the cash flow for each of these categories is described in the following sections.

Allocation of Initial Capital Costs Over the Construction Period

A discounted cash flow analysis of electrification is highly sensitive to the timing of capital expenditure prior to commissioning. To some extent the timing of expenditures can be controlled to suit the cash flow requirements of the railroad. The obvious incentive is to complete construction as quickly as possible once the commitment to electrification has been made. To assure comparability in analyzing multiple route segments, a standardized procedure was devised to allocate the initial capital cost over the design and construction periods defined in Section 3.2.

The cost elements allocated are those listed under investments in Table 2-11.* The manner in which they are allocated over the design and construction period is illustrated in Figure 3-3. The design engineering cost is uniformly distributed over the period from start design to complete design. The construction engineering cost is uniformly distributed over the period from start construction to 100 percent commissioning. Fixed plant equipment includes catenary, substations, utility connections, signal and communication compatibility modifications and civil reconstruction. One-half of the total of the fixed plant cost

*Calculation of the value of each cost element is a computer function described in Volume II, Section 5.6.

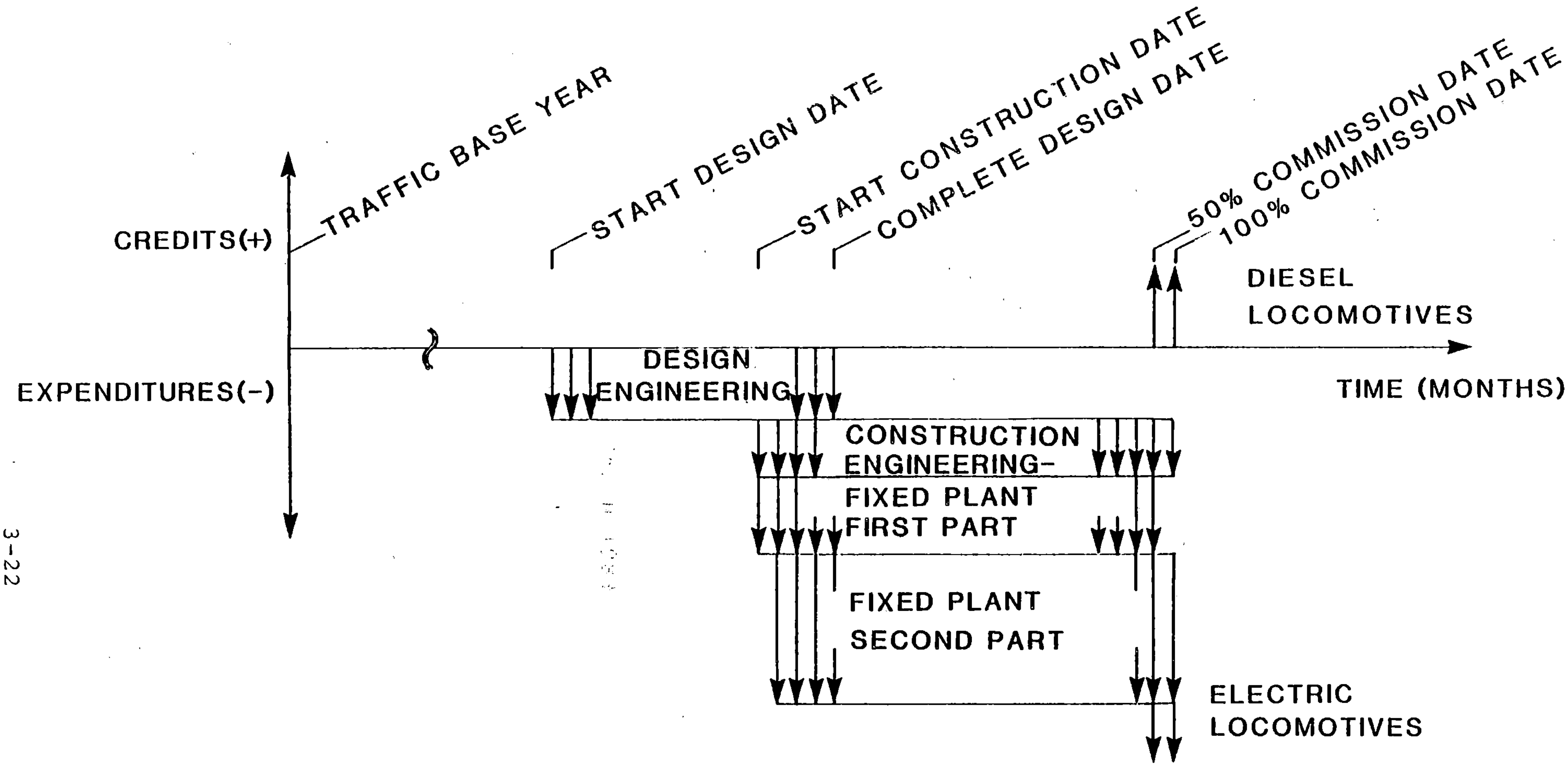


FIGURE 3-3. ALLOCATIONS OF INITIAL CAPITAL EXPENDITURES OVER THE CONSTRUCTION PERIOD

is uniformly distributed over the period from start construction to the 50 percent commission date; the other half is uniformly distributed over a period of equal length that ends on the 100 percent commission date. Electric locomotives are purchased on the 50 percent commission date to operate one-half of the route. On the 100 percent commission date, the additional locomotives required to operate the entire route are purchased. One-half of the credit for diesel locomotives released by electrification is taken on the 50 percent commission date and one-half on the 100 percent commission date. If credit is taken by avoiding replacement diesel purchases for the remainder of the railroad, new locomotive cost is used. If credit is taken by selling the released locomotives, the depreciated locomotive value is used.*

The initial capital costs are, in general, allocated over periods to the nearest month. Annual cash flow is used to compute the rate-of-return. Thus, after costs have been allocated as described above, the annual cash flow is calculated by summing all expenditures within each calendar year.

The model has the capability to emulate a railroad decision on whether to sell released diesel locomotives or avoid new purchases (see Section 2.7 for discussion of the decision). The model is formulated so that: (1) any percentage of the released diesels on any route segment may be sold and transferred, (2) diesel life can be separately specified for each route segment, and (3) credit in any year for avoided diesel purchases never exceeds the average annual purchase of the railroad with any excess credited in the next year.

*Average age is assumed to be one-half of the economic life, to be consistent with the diesel replacement schedule adopted (see discussion of equipment replacement in this section).

## Operational Costs and Equipment Replacement Costs

The cost elements which occur subsequent to the initial capital investment are the operating costs and captial replacement costs. Figure 3-4 illustrates how the cash flow results from summing the operating cost elements. (Locomotive replacement, a capital cost, also appears in the figure and will be discussed later.) Negative cashflow is expense to the railroad and positive cash flow is expense avoided by the railroad. The general inflation rate and the traffic growth rate are zero in the illustration while diesel fuel cost is shown to escalate each year up to a specified year. If the traffic growth rate were non-zero, locomotive maintenance, electric energy and diesel fuel costs would also show a compounding effect. If the general inflation rate were non-zero, all five of the operating costs would show a compounding effect.

Costs are computed on an annual basis for each full year subsequent to the 100 percent commission date. Costs are prorated during the startup period where the 50 percent and 100 percent commissioning dates are different or there is partial year operation.

Figures 3-3 and 3-4, considered together, depict the cash flow for computing the equity rate of return. The cash flow for computing the leveraged rate of return would contain only the reduced capital expenditure by the railroad; the remaining capital expenditure is replaced by loan payments to the external and utility funds, included as an annual expense. The length of the loans are specified. The payment schedule may be uniform, like the common home mortgage or proportional to the electric energy consumption. The proportional repayment schedule is adjusted so that the loan is repaid in the specified time if the projected traffic level is realized. This is a low risk loan option for the railroad because

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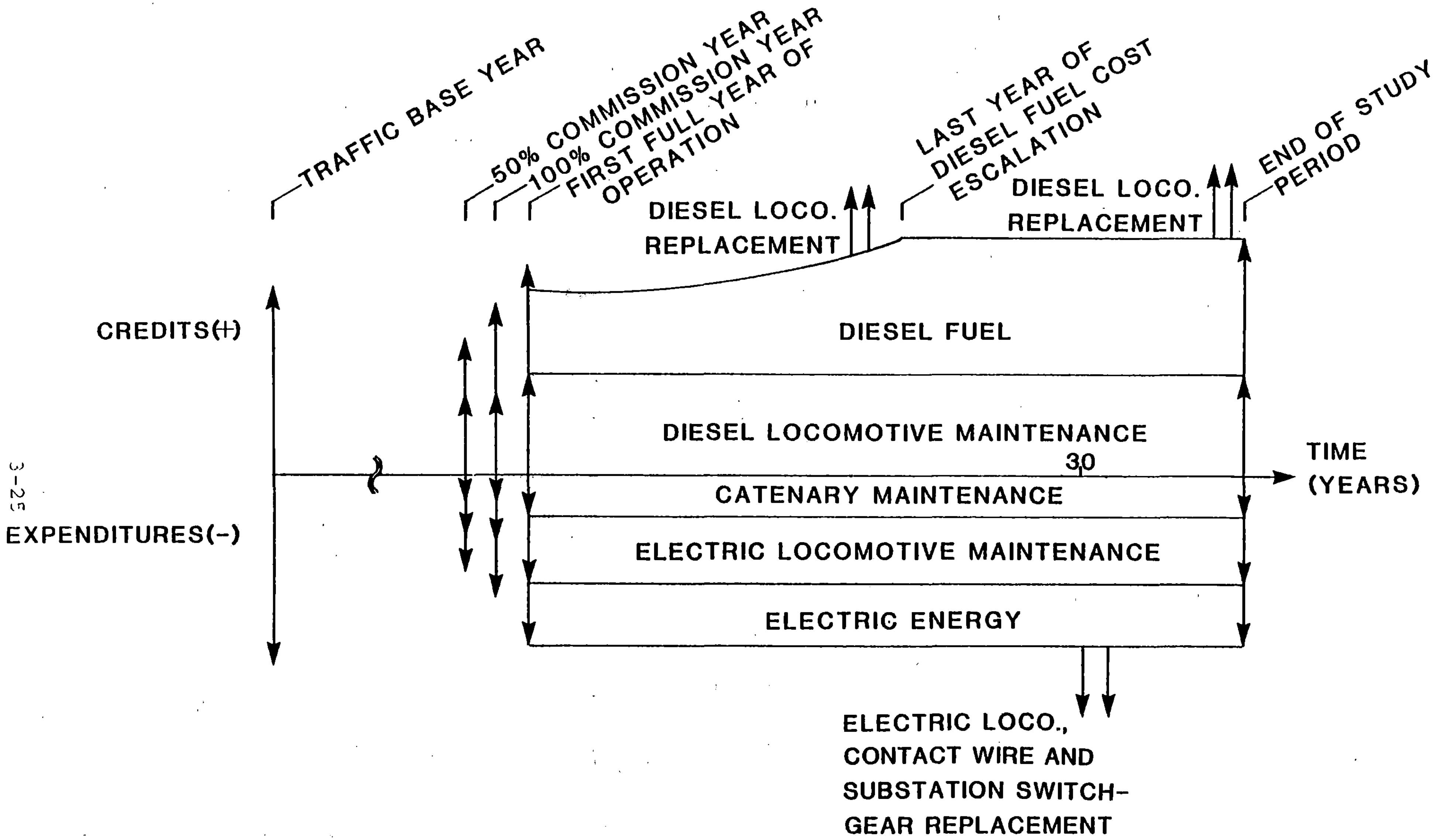



a - Transer of Diesel Locomotives Released by Electrification

FIGURE 3-4. CASH FLOW RESULTING FROM OPERATIONAL AND EQUIPMENT REPLACEMENT COSTS (DIESEL LOCOMOTIVES TRANSFERRED) payments are reduced and the repayment period extended when the traffic level is not realized. Payment for both loans begins in the first full year of operation with interest being charged from the date funds are disbursed.

Locomotives and fixed plant require replacement at the end of their economic life. Table 3-5 identifies the equipment for which a replacement schedule has been implemented in the model. Locomotives are scrapped and replaced at the end of their economic life and are not rebuilt (i.e., they have no residual value). Catenary contact wire and substation switchgear are replaced after thirty years at a cost estimated to be 20 percent and 30 percent, respectively, of the initial investment. Economic life of the remainder of the catenary and substation equipment is set at sixty years, generally well beyond the study period used to evaluate electrification. Modifications made to the signal and communication system for compatibility and to the overhead structures for clearance have a predictable economic life. However, no reinvestment is charged to electrification based on the assumption that there is no cost differential in renewing diesel compatable equipment and electrification compatable equipment.

In Figure 3-4, the expenditures thirty years subsequent to commissioning is the total cost of replacing the initial electric locomotive fleet, the contact wire and the substations switchgear. The two diesel locomotive replacement credits are for purchases subsequent to commissioning that can be avoided because that much locomotive cost was initially avoided.* The diesel credit depicted in Figure 3-4 is for the diesel release option in which new purchases are avoided.

*If the initial locomotive expenditure and/or credit was spread over more than one calendar year, that would be replicated for replacement.

TABLE 3-5. EQUIPMENT LIFE AND REINVESTMENT FACTORS

| CAPITAL COST ELEMENT | | LIFE (YEARS) | PERCENT REINVESTMENT |
|---|---|---|---|
| Electric Locomotive | | 30 | 100 |
| Diesel Locomotive | | 18* | 100 |
| Catenary: | Wire | 30 | 20 |
| | Poles and Hardware | 60 | 80 |
| Substations: | Switchgear | 30 | 30 |
| | Other | 60 | 70 |
| Signal and Communications | | 60 | 0 |
| Civil Reconstruction | | 60 | 0 |

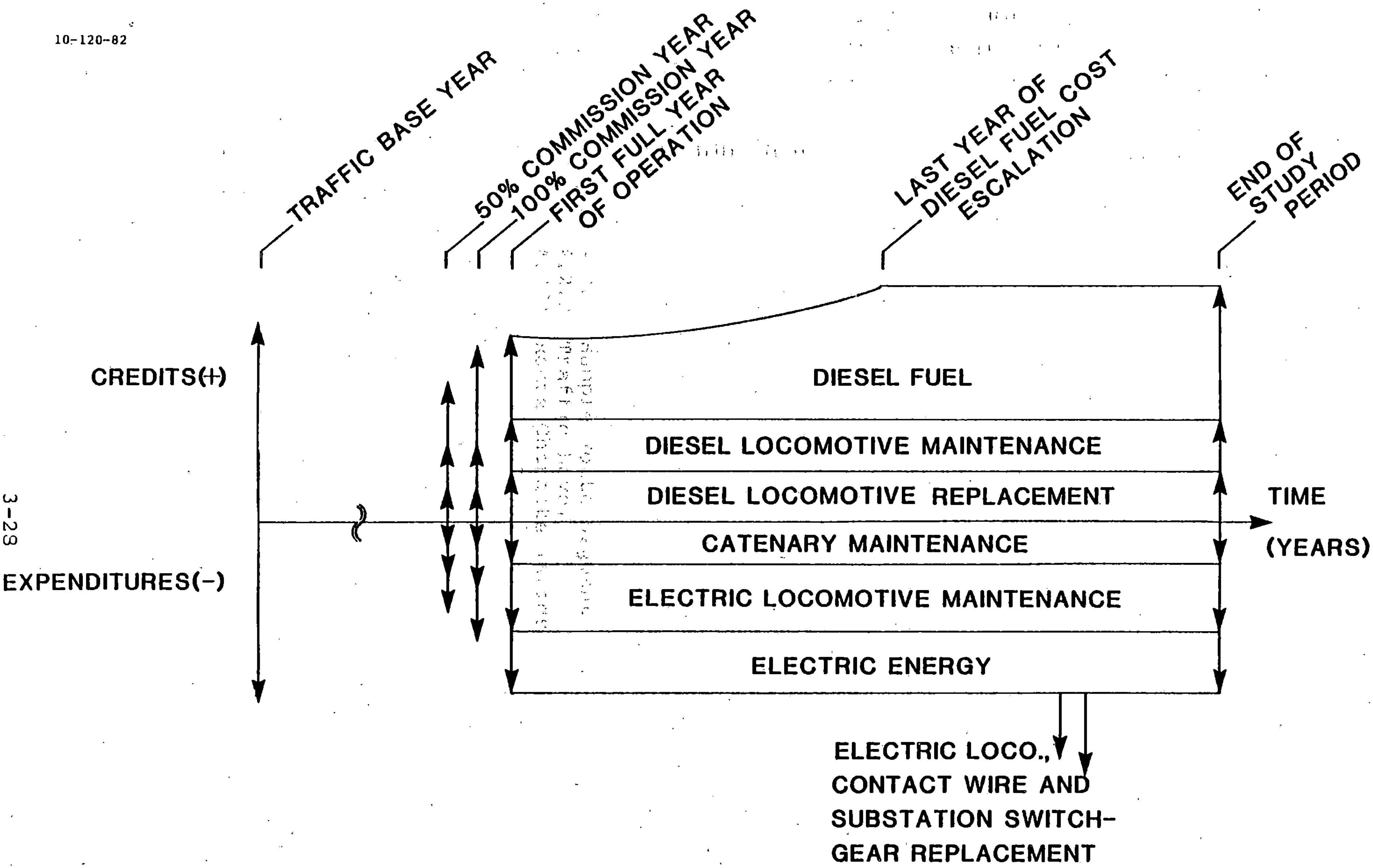
*Input variable which can be specified separately for each route segment.

For a small railroad that sold the released diesels, the credit would be entirely for the avoidance of new locomotive purchases equal to 1/18 of the fleet required for the route segment.* The cash flow for this is illustrated in Figure 3-5.

## 3.5 MODEL OUTPUT DATA

When multiple links are run for multiple railroads, the output data as summarized in Table 3-6 is produced. The equity rate of return for individual links is always computed with and without the differential inflation of fuel cost. As an option,

*Based on the assumption that the current fleet is uniformly distributed in age over the economic life. The corresponding credit for selling the existing fleet is one-half of a new fleet value because the average age of the fleet is nine years.




b – Sale of Diesel Locomotives Released by Electrification

FIGURE 3-5. CASH FLOW RESULTING FROM OPERATIONAL AND EQUIPMENT REPLACEMENT COSTS (DIESEL LOCOMOTIVES SOLD)

TABLE 3-6. SUMMARY OF MODEL OUTPUT DATA

- System-Wide Input Data
  - Outlay and payback by external and utility funds
  - Traffic growth rates
  - Inflation factors
  - Unit cost factors in currency base year
- Link Specific Input Data
  - Route characteristics
  - Operational characteristics in traffic base year
  - Electrification conversion schedule
- Link Specific Economics
  - Initial investment costs
  - Costs and credits in first full year of operation
  - Link rate of return
- Railroad Summary
  - Cumulative route-miles and traffic by year
  - Costs and credits by year for all links (cash flow)
  - Railroad rate of return
- Network Summary
  - Cumulative route-miles and traffic by year
  - Cash flow of external and utility funds and aggregated railroads
  - Network rate of return
  - Graphical plots of rate of return

the leveraged rate of return is also computed for each link. Only equity rates of return are computed at the railroad and the network total levels. The only other option is to include or delete the graphic plots of network data. The rest of the output is always computed.

It is possible to produce certain data that are not explicitly included in Table 3-6 by selective use of input data. For example, the cash flow of an individual link is obtained by running the model with only that link present in the link data files. The railroad and network cash flows then become the cash flows of the link. Similarly, using only data for links of a single railroad, the network summary by year provides external and utility fund balances of the railroad, which are not included in the railroad cash flow.

A sample of output data is presented in Volume II.

# 4. PREPARATION OF INPUT DATA FOR NETWORK ANALYSIS

Data sources and computational procedures used to obtain input data to the Railroad Electrification Assessment Model for the FRA network study are described in this section. They are not part of the computer model and can be replaced by alternatives, as appropriate, in other model applications. For example, if a feasibility study has been performed on a route, most of the input data would be available so that preliminary computations are minimal.

The network procedures have been included to provide more detail on the network study and to give a more precise definition to model input data. Preparation of the systemwide data is given in Section 4.1 followed by the route-specific data in Section 4.2. One of the network segments is introduced to illustrate the procedure used. Input data for this sample segment are then used in Volume II to illustrate model computations.

## 4.1 SYSTEMWIDE INPUT DATA

### 4.1.1 Unit Cost Factors

A summary of the unit cost factors as they appear in the computer output is shown in Table 4-1. All of the costs are in 1980 dollars. The basis for the development of each cost item is described below.

#### Diesel Fuel Cost

A uniform cost of one dollar per gallon was set for all railroad links based on a survey made in December 1980 of railroads that participated on the Planning Committee.

TABLE 4-1. UNIT COST FACTORS (AS LISTED ON PAGE 2 OF COMPUTER OUTPUT)

| | | | | | | |
|---|---|---|---|---|---|---|
| Energy: | | | | | | |
| Diesel Fuel ($/gal) | 1.00 | | | | | |
| Electric Rate by Census Region | | 1: 5.26 | 2: 4.50 | 3: 4.09 | 4: 4.09 | 5: 3.56 |
| (cents/kwh)* | | 6: 3.49 | 7: 2.87 | 8: 2.78 | 9: 2.54 | |
| Locomotive Rail Horsepower | | | | | | |
| By Diesel Locomotive Type ($/RHP)* | | 1: 371.00 | 2: 429.00 | 3: 259.00 | 4: 299.00 | |
| | | 5: 272.00 | 6: 233.00 | 7: 273.00 | 8: 0.00 | |
| By Electric Locomotive Type ($/RHP)* | | 1: 360.00 | 2: 300.00 | 3: 233.00 | 4: 0.00 | |
| Service, Inspection & Maintenance | | | | | | |
| By Diesel Locomotive Type | | 1: 1.33 | 2: 1.33 | 3: 1.33 | 4: 1.33 | |
| ($/unit-mile)* | | 5: 1.33 | 6: 1.33 | 7: 1.33 | 8: 1.33 | |
| By Electric Locomotive Type | | 1: 0.85 | 2: 0.85 | 3: 0.85 | 4: 0.85 | |
| Wayside Maintenance ($/track-mile) | 2500.00 | | | | | |

| | | NUMBER OF TRACKS | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| Construction: | | | | | |
| Catenary ($/route-mile) | | | | | |
| Highspeed Service: | | | | | |
| Tangent, Light Curvature | | 210000.00 | 389000.00 | 513000.00 | 643000.00 |
| Medium Curvature | | 230000.00 | 408000.00 | 550000.00 | 654000.00 |
| Heavy Curvature | | 281000.00 | 472000.00 | 571000.00 | 739000.00 |
| Lowspeed Service: | | | | | |
| Tangent, Light Curvature | | 139000.00 | 265000.00 | 444000.00 | 450000.00 |
| Medium Curvature | | 162000.00 | 308000.00 | 493000.00 | 500000.00 |
| Heavy Curvature | | 194000.00 | 370000.00 | 616000.00 | 625000.00 |
| Siding and Yards ($/track-mile) | 203000.00 | | | | |
| Substations ($1000'S/Station) | | | | | |
| 25 KV (Regions 1 & 2) | | 2410.00 | 2670.00 | 2930.00 | 3200.00 |
| 50 KV (Regions 3-9) | | 3380.00 | 3710.00 | 4030.00 | 4360.00 |
| Utility Connection | | | | | |
| To Each Station ($1000'S/Mile) | 200.00 | | | | |
| At Each Station ($1000'S/Station) | 75.00 | | | | |
| Reconstruction: | | | | | |
| Bridges ($/Bridge) | | 50000.00 | 0.00 | 0.00 | 0.00 |
| Tunnels ($/Foot of Tunnel) | | 1400.00 | 2480.00 | 0.00 | 0.00 |
| Signalling and Communications ($/Route-Mile) | 100000.00 | | | | |
| Engineering Fees: | | | | | |
| Design Engineering (%) | 10.00 | | | | |
| Construction Engineering (%) | 1.5 | | | | |

*See user documentation for definitions of census regions and complete characteristics of the locomotive types.

## Electric Energy Rate

The 1980 electric energy rate for each of the nine Bureau of Census regions was based on 1978 rates compiled by the Edison Electric Institute[11], the latest data available at the time the estimates were being made. The consumer price index was used to escalate from 1978 to 1980. The rates vary between 2.54 cents per kilowatt-hour in the Pacific Region to 5.26 cents per kilowatt-hour in the New England Region. Industrial rates were used as a proxy for traction rates since the latter do not exist for most regions of the country. Average industrial demand charges are included in this energy rate.

## Diesel Locomotive Costs

The costs of diesel locomotive types purchased in 1980 were established as the average of costs recorded in the R-1 accounts to the Interstate Commerce Commission for that year by all of the class I railroads.* The costs are therefore interpreted to be for the typical options and accessories. The cost of locomotive types with no record of purchase in 1980 were estimated based on variances of cost with power or traction capability in other years, appropriately scaled. The locomotive costs in Table 4-1 are for the locomotive types defined in Table 2-5.

## Electric Locomotive Costs

It was necessary to estimate the cost of the electric locomotive types because none of the three types used in the

*Diesel locomotive types in use on the network are identified in Table 2-5.

study are currently in production in the U.S. The type 3 locomotive, which is a 6,000 rail horsepower, six-axle unit,* was estimated to cost 1.4M dollars or $233 per rail horsepower when produced in quantities as given in Table 2-7. The costs for the types 1 and 2 were estimated by scaling the type 3 cost based on cost variations between diesel types with similar variations in power and traction ratings. The type 2 locomotive, a 4,000 horsepower, six-axle unit was estimated to cost 1.2M dollars and a type 1, 2,500 horsepower, four-axle unit was estimated to cost 0.9M dollars.

## Diesel Locomotive Service, Inspection and Maintenance Cost

A uniform cost of 1.33 dollars per unit-mile was used for all locomotive types. This average is unchanged from that used in the 1980 update of the 4-R study[4]. The average for all locomotives was determined by scaling the maintenance cost of the Conrail feasibility study[18] using a factor developed from relevant expenditures reported in the R-1 annual reports to the Interstate Commerce Commission (ICC) by all of the Class I railroads. (See Appendix E).

## Electric Locomotive Service, Inspection and Maintenance

A uniform cost was established for all electric locomotive types by applying a factor of 0.64 to the diesel locomotive cost per unit-mile. This factor was recommended by the Technical and Operations Committee as a result of a meeting held in March 1981 in which briefings were provided by operators of electrified railroads as well as locomotive builders. The recommended factor results in electric

*A more complete definition of electric locomotive types used for the network study appears in Table 2-6.

locomotive service, inspection and maintenance costs that are about 20 percent higher than the cost factors reported in most electrification feasibility studies[18], [19]. The Canadian network feasibility study[20] used a maintenance cost ratio of 75 percent on a locomotive unit basis, which is a factor on a unit-mile basis of 0.5-0.6 when the higher annual mileage of the electric is considered.

Wayside Maintenance

An annual cost of 2500 dollars per track mile per year was used for all railroad links for the maintenance of catenary, structures, substations, and sectionalizing stations. This cost is essentially unchanged from the 1980 update which used $4400 per route mile per year and is conservative compared to most feasibility studies. The Conrail study, for example, has set the cost at just over $1000 per track mile[18].

Catenary Cost

The cost of catenary, including installation, was established in a format which acknowledges three major cost impacts, namely: speed of train operation, number of parallel tracks being electrified and the degree of track curvature. The catenary costs for high speed based on service are Gibbs & Hill estimates prepared for TSC under contract by Booz, Allen and Hamilton[21]. The catenary costs for low speed service are based on estimates prepared for TSC under contract by Electrack, Inc.[22] where the following assumptions are made: (1) the factors used in the Electrack estimates for plains, rural and hilly terrain are equated to the curvature factors of the model; light, medium and heavy, respectively, and (2) the medium wind and ice loading condition of the Electrack estimates is used. The cost of catenary for sidings and yards was established by increasing the cost of single track, low speed catenary of medium curvature by 25 percent to account for difficulties encountered in locations with switching complexities and restriction on catenary pole location.

Substation Costs

A 25KV substation with two 15MVA transformers, and which serves 3 tracks, is estimated to cost $2.93M in reference[18]. The cost components of this estimate are:*

| | |
|---|---|
| Basic substation | |
| (Two - 15MVA transformers, incoming line, breakers, relays, site preparation.) | $2.62M |
| Catenary sectionalizing stations | .28M |
| Real estate | .03M |
| Total | $2.93M |

The costs for 25KV substations that serve two and three tracks and for 50KV substations that serve two and three tracks are estimated in reference[22], with the 25KV, 3-track substation being approximately 25 percent less in cost than the above estimate. The two and three track costs used in this study (Table 4-1) were developed by increasing each of the estimates of reference[22] by one-third to coincide with the higher estimate of reference [18]. However, the substations were spaced to the longer distances recommended in[22], thereby implying the costs are for substations of a larger rating. The 25KV substations are rated at 45MVA and the 50KV substations are rated at 90MVA (See Section 4.2.3 for a discussion of substation size and spacing). One and four track costs were scaled linearly from the two and three track estimates.

*Data taken from reference[18], Tables 2.2-1, and 2.2-2.

## Utility Connection Costs

Utility connection costs were established for two factors: extension of transmission line and connection and metering equipment at each railroad substation. Cost estimates for these factors are Gibbs & Hill estimates that appear in Reference[21]; these are $200,000 per mile of transmission line installed and $75,000 per substation connection.

## Civil Reconstruction Cost

An average bridge modification cost of 50,000 dollars was assumed to cover the cost of clearance modifications to an overhead highway bridge or a through railroad truss bridge. This estimate is consistent with an estimate used recently in a feasibility study for a western railroad and is somewhat less than the estimate in the Conrail feasibility study[18] where much of the route has 3 or more tracks. Estimates of tunnel modification costs to increase clearance by 2 feet for one and two tracks that appear in Reference[23] were escalated using the consumer price index to $1400 and $2480 per foot.

These are averages of the bridge and tunnel costs of 25KV and 50KV catenary. Costs frequently may vary significantly between 25KV and 50KV since the lesser clearance of the lower voltage level can sometimes be achieved by lowering the track, thereby avoiding the necessity of tunnel scarfing or daylighting and bridge raising work. For example, recently prepared estimates for single-track tunnel on a western railroad were $670 and $2,560 per foot for 25KV and 50KV respectively. Modification to the model should be considered to account for this if detailed clearance cost estimates are desired.

## Signal and Communication System Modification Cost

The average cost of achieving electrical compatability between the traction power supply and the signal and communication (S&C)

systems vary from a low of $45,000 per route mile for one western railroad that has been studied to over $200,000 for Conrail east of Harrisburg. The wide variation in type of signal and communication systems in place and the varying philosophies applied in assessing costs to compatability versus improvement make it inappropriate to assign an average value to this cost.

Notwithstanding, an average cost of $100,000 per route-mile was used in this study for all railroads with typical dc signalling and trackside communication lines. The costs for Union Pacific electrification were altered to $115,000 per route-mile to cover the additional modifications resulting from cab signalling modifications. The costs for the MKT route were altered to $60,000 per route-mile because part of the route is not signalled and would therefore require no modification. S&C improvements are not included in this study.

Engineering Fees

The design fee covers feasibility study and preliminary and detail design of an architectural and engineering firm and is set at 10 percent, somewhat above the baseline fee of 6 percent that is charged for projects where standards and recommended practices are well established. The construction engineering fee of 1 1/2 percent is for supervisory oversight during construction. (The costs of the above fixed plant equipment are turnkey costs, i.e., they contain any design costs the supplier must incur in building and installing his equipment.)

### 4.1.2 Fuel Cost Projections

The computer model calculates the effect of changes in the relative unit costs of diesel oil fuel and electric power by holding the electric power costs constant, and increasing the cost of diesel fuel oil to the required degree. For the base case of the previous FRA studies a three percent differential was used.

Recent fuel cost forecasts by power companies, oil companies, and independent forecasters that have been assembled by the Southern Railway are shown in Figure 4-1. These and data that have been used for a study on the Burlington Northern Railroad suggest that the differential may be less than three percent. Using these forecasts as a basis, calculations were made of the forecast change in fuel prices over the 20-year period 1980-2000:

| | Changes in Fuel Prices per Gallon-equiv. | | |
|---|---|---|---|
| | Oil | Electricity | Difference |
| Number of Forecasts | 5 | 4 | |
| Avg. Price in 1980 | 100 cents | 42 cents | 58 cents |
| Forecast Price in 2000 | 180 cents | 63 cents | 117 cents |

To account for the increase in both diesel fuel and electricity costs the following methodology was used. The electricity price was held constant, and the difference shown above was added to give an equivalent oil fuel price with the same absolute differential per gallon as that forecast. Thus:

| | |
|---|---|
| Constant Electricity Price (gal-equiv) | 42 cents/gal |
| Increased Differential for Year 2000 | 117 cents/gal |
| New Equivalent Oil Price | 159 cents/gal |

Equivalent oil price in 2000 is 59 cents higher than oil price in 1980 (159 cents - 100 cents) and this is equal to a cumulative annual rate of increase of 2.3 percent. This percentage, when applied to the oil price while holding the electric power unit cost constant, produces the difference in energy cost in the year 2000 which resulted from the average of the original forecasts. Note that the individual costs of electricity and diesel fuel in the model are therefore somewhat less than forecast.

Beyond the year 2000, the prices of both fuels were held constant, although there are arguments in widening the differential thereafter.

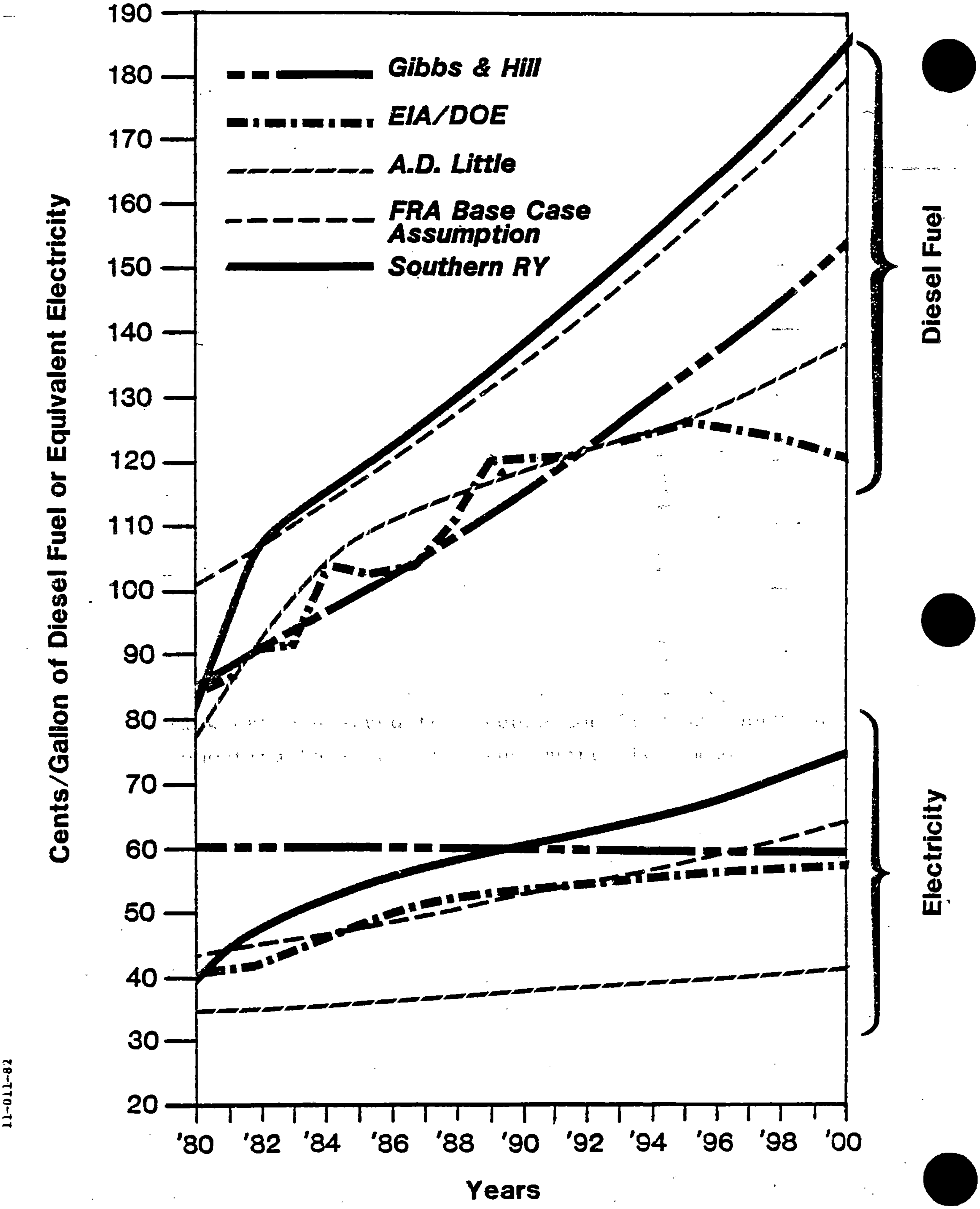



FIGURE 4-1. ENERGY COST PROJECTIONS

## 4.2 ROUTE-SPECIFIC INPUT DATA

Development of the Link Data File (See Table 3-1 and Volume II, Section II for definition) from source data is, in essence, configuring or designing the diesel and electric rail systems that are to be compared and computing the energy consumption of each in the base traffic year. Some of the link data can be transcribed directly from the engineering design records and operating statistics that are kept for a link. Other input data does not exist in the form required and must be developed from the source data. The design computations required for developing the route-specific input data were reduced to a set of worksheet procedures that are described in this section.*

Source data for the hypothetical network was obtained from:

1. Published data readily available including railroad timetables, AAR and ICC records, and FRA studies;

2. Railroad supplied data furnished by those railroads participating in the study;

Table 4-2 identifies the characteristics obtained from published data and the specific source for each. Figure 4-2 is a sample of the Railroad Questionnaire form used to obtain data from the railroads. The data required from the railroads that

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*The design computations are not part of the computer model since that would prevent the use of the design data obtained from other feasibility studies. While a separate program could have been developed, computations for the hypothetical network were performed manually because the procedures were in their infancy and subject to frequent change. The multitude of special considerations that must be weighed in making these computations would make the value of a general purpose design program questionable.

TABLE 4-2. ROUTE CHARACTERISTICS OBTAINED FROM PUBLISHED SOURCES

| CHARACTERISTICS | SOURCE: 10,000 ROUTE-MILE CORE | SOURCE: REMAINDER OF 29,000 ROUTE-MILE NETWORK |
|---|---|---|
| ● Route and track mileage | | |
| – By number of tracks | Railroad timetables | Railroad timetables |
| – By average curvature category | FRA Data Base* | Estimated |
| ● Number of bridges | FRA Data Base* | FRA Data Base* |
| ● Average grade category | FRA Data Base* | Estimated |
| ● New transmission line | A.D. Little [24] | A.D. Little [24] |
| ● Substation spacing | Electrack [22] | Electrack [22] |

*Assimilated by the Policy Office during studies under the 4-R Act.

is not generally available on a route-specific basis was estimated by railroad personnel familiar with operations. Instructions for completion of the questionnaire are indicated in Appendix F. For consistency of traffic projections on a national basis, items 1 and 2 of the questionnaire were completed by the FRA (description follows). The participating railroads were asked to comment on the reasonableness of this traffic data and supply items 3 through 10.

### 4.2.1 Sample Route Segment

To illustrate the preparation of entries to the Link Data File a representative route segment from the network is used. It is identified in this report as a segment of the Urail

RAILROAD QUESTIONNAIRE - TRAFFIC AND OPERATIONAL DATA

Railroad: URAIL & Company

Route Sector: UTown yard Forward (FWD) ----- To: UCity, USA Reverse (REV) -----

| QUESTIONNAIRE ITEM | DIRECTION | COMMODITY GROUP 1 COAL | 2 GRAIN | 3 CHEMICALS | 4 IRON ORE | 5 SAND, STONE, GRAVEL | 6 NONMETALLIC MIN. | 7 FOREST PRODUCTS | 8 CEMENT, CLAY & GLASS | 9 FOOD | 10 GRAIN MILL PROD. | 11 PULP, PAPER | 12 PRIMARY METALS | 13 TRANS. EQUIPMENT | 14 LUMBER, WOOD | 15 FREIGHT FWDR., & LCL | 16 ALL OTHER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. FRA projected annual growth in revenue tonnage to 1990. | FWD | -9.3 | 4.8 | 2.8 | 0 | 1.7 | 2.4 | 0 | -0.8 | -0.2 | 1.4 | 2.3 | 1.6 | 2.9 | -0.5 | 3.0 | 3.0 |
| | REV | 0 | 0 | 1.4 | 0 | 5.8 | 2.2 | -2.1 | -0.3 | -1.0 | -0.3 | 3.0 | 1.2 | 1.7 | -2.1 | 2.3 | 2.3 |
| 2. Percent of actual 1980 revenue tonnage. | FWD | 0.4 | 15.9 | 2.3 | 0.1 | 0.1 | 0.3 | 1.0 | 1.7 | 1.2 | 1.1 | 1.5 | 1.9 | 0.6 | 0.9 | 7.1 | 3.7 |
| | REV | 0 | 3.8 | 0.5 | 0.9 | 0.1 | 1.4 | 0.3 | 0.6 | 4.9 | 0 | 5.7 | 4.5 | 1.1 | 32.7 | 2.7 | 1.0 |
| 3. Check those commodity groups where a measurable percentage moves in expedited service. | | | | | | | | | | X | | | | X | X | X | X |

| | | EXPEDITED | NORMAL | BULK | PASSENGER |
|---|---|---|---|---|---|
| 4. Diesel dispatch level in horsepower per ton. | FWD | 3.1 | 1.8 | - | - |
| | REV | 3.0 | 1.9 (+ 1.2)* | - | - |
| 5. Prevelent type of diesel locomotive used. | | SD-40-2 | SD-40-2 (SD-40-2) | - | - |
| 6. Typical running time. | FWD | 13 hr., 10 min. | 21 hr., 45 min. | - | - |
| | REV | 13 hr., 25 min. | 16 hr., 15 min. | - | - |

| | FORWARD | REVERSE |
|---|---|---|
| 7. Ruling Grade | 1.0 | 1.0 (1.8)** |
| 8. 1980 Actual Gross Ton Miles (average). Does/does not include locomotives. | 16.6 | 15.8 |
| 9. Approximate percentage of total tonnage moving in expedited service. | 40% | 50% |
| 10. Percentage of total tonnage expected to move with electric locomotives. | 100% | 100% |

*Helper at Big Mountain Pass where one-way operating mileage is 18.2 miles.
**Reverse ruling grade outside helper district is 1.0; inside, 1.8.

FIGURE 4-2. COMPLETED RAILROAD QUESTIONNAIRE FOR THE SAMPLE SEGMENT

Railroad Company operating between Utown Yard and Ucity, USA. The entries on the Railroad Questionnnaire in Figure 4-2 are for the sample segment. This segment is seen to carry a significant amount of grain from Utown to Ucity, the forward direction, and an even greater amount of lumber in the reverse direction. Food, transportation, equipment, lumber, freight forwarder and other commodity classifications are indicated to be moved in expedited service. Helper locomotives are required for normal service in the reverse direction. The route characteristics obtained from published data are summarized in Table 4-3.

### 4.2.2 Traffic Level

The average 1980 traffic density on each route segment, in each direction, was provided by the railroad (see Figure 4-2, Questionnaire item number 8) with an indication of whether motive power tonnage was included. The traffic density required for differential analysis of electrification is that which would be moved by electric locomotives after

**TABLE 4-3. ROUTE CHARACTERISTICS FOR THE SAMPLE SEGMENT**

| | |
|---|---|
| Route Miles: | |
| 1 Track | 406.1 |
| 2 Track | 97.6 |
| Sidings and Yards | 202.4 |
| Number of Overhead Highway Bridges | 59 |
| New Transmission Line Required (Miles) | 45 |
| Substation Spacing (Miles) | 75 |

conversion.* An estimate of that level was obtained as the product of Questionnaire items number 8 and number 10.

The electrification model has been purposely configured to accept traffic density and the associated annual growth factors for up to four distinct categories of train service.** Thus, it is necessary to apportion the traffic accordingly. Apportionment factors were developed, based on waybill statistics of commodity mix hauled on each sector and based on railroad designation of which commodities are moved with each type of train service (Questionniare item number 3).

The associated annual growth factors for each service category are the weighted averages of the growth factors of each commodity. The procedure for developing the traffic data required for input to REAM is depicted in Figure 4-3. The two blocks to the left indicate the procedure for obtaining the commodity mix and the percent increase in traffic by commodity on each route segment. The block to the right depicts the conversion of density and growth by commodity on a revenue tonnage basis to density and growth by service category on a gross tonnage basis. The procedures depicted in each block are described in more detail in the following subsection.

Traffic Growth

It was the recommendation of the Planning Committee that growth rates be obtained from the projections for the growth of

---

*Traffic that would continue to be hauled by diesel locomotives would typically be that entering at intermediate points and continuing for only a short distance on the electrified sector before exiting or terminating.

**The purpose of the service categories is to highlight equipment and operational variations on a route, in particular, the type of locomotive required (see Section 3.4.2).

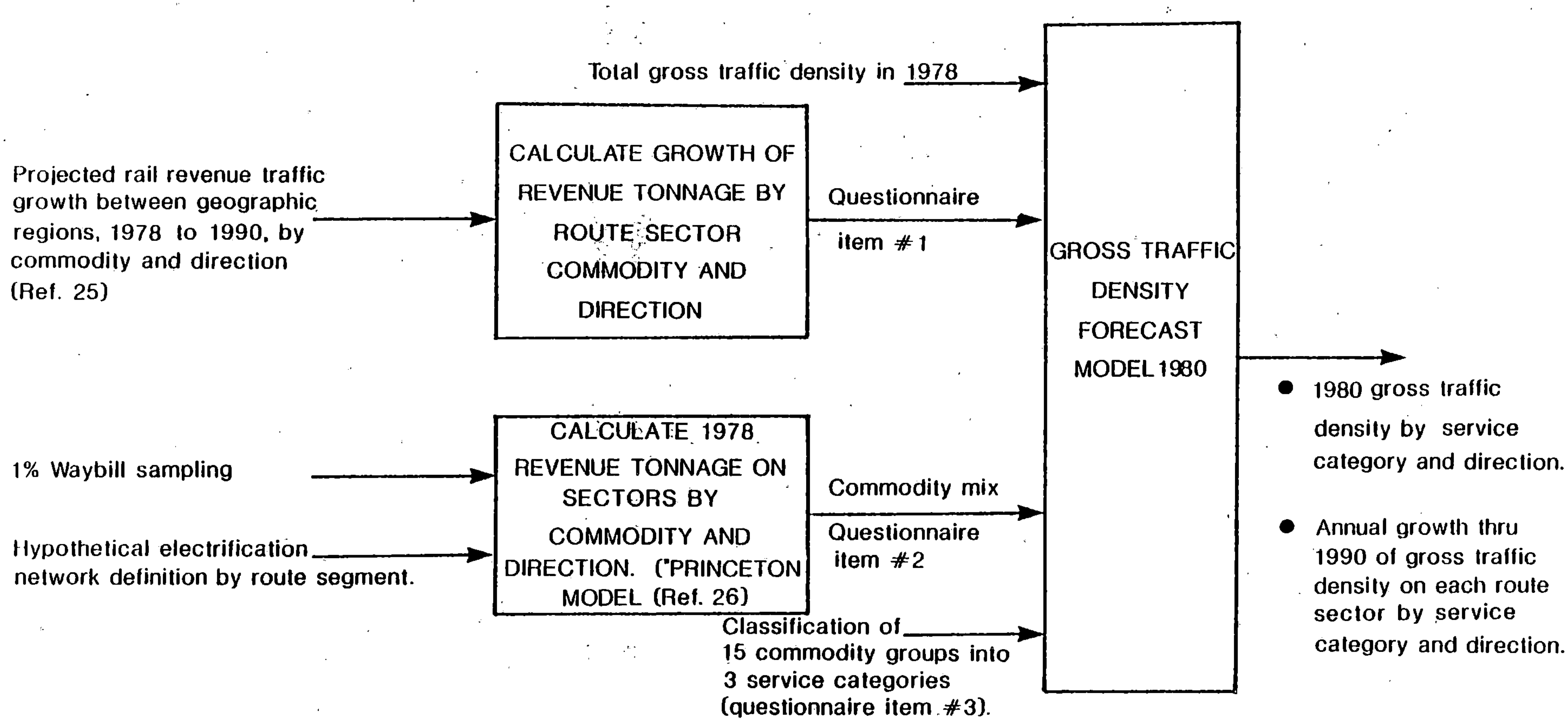


FIGURE 4-3. BLOCK DIAGRAM OF PROCEDURE FOR DEVELOPING ROUTE SPECIFIC TRAFFIC FORECASTS BY SERVICE CATEGORY

fifteen commodity groups through the year 1990 as published by FRA's Office of Policy in the report, Railroad Freight Traffic Flows 1990[25]. Use of these projections provides: (1) uniform underlying assumptions regarding such factors as the general condition of the economy and treatment of traffic subject to merger, and (2) the requisite breakdown by commodity groups from a publicly available source (railroad growth projections are generally treated as proprietary data). In applying these results to the electrification analysis the following difficulties were encountered:

1. Growth was projected only through 1990 while the electrification analysis ran through 2036;

2. The country was divided into 129 traffic regions, each having a principal city or railroad junction designated as the node for that region. The 129 nodes were then connected by a series of links corresponding to one or more railroad mainlines. And while some traffic links corresponded to more than one electrification link, some long electrification links corresponded to more than one traffic link;

It was generally agreed that any projections beyond 1990 would be meaningless. Thus, the model was constructed to accomodate a two stage projection; link specific to 1990 and a system wide growth beyond 1990.* No growth beyond 1990 was assumed to be consistent with the objective of remaining basically conservative in placing value on electrification.

*In actual application, the use of discounted cash flow in calculation of return on investment made growth beyond 1990 of little consequence.

In some cases, conversion of generalized flow over traffic links to flow over electrification links was straight forward. For example, traffic link 193 in Figure 4-4 solely represents the Union Pacific's line between Salt Lake City and Las Vegas, which is designated as electrification link UP202189 (see Appendix C for listing of electricification links).

When more than one traffic link was required to represent an electrification link, the growth rate was taken to be the average for the traffic links . Such is the case for the Burlington Northern electrification link from Chicago to Minneapolis, BN010, which corresponds to traffic links 54 and 243. The third column of Appendix C identifies the traffic links corresponding to each electrification link. The correlation factor in the last column indicates the degree of correspondence.

Traffic link 56 between Chicago and Davenport represents five roughly parallel mainlines, three of which are included in the electrification study. Hence, any commodity hauled by each of the three carriers has the same growth rate - i.e., each carrier maintains its current share (portion) of each commodity for the entire electrification study period. Since the mix of traffic is different on each of the parallel lines, the overall growth rate for each service category is different. This subject is addressed in the next subsection.

Table 4-4 is the predicated twelve year change in traffic by commodity on the traffic link that corresponds to the sample route segment. Such data was obtained for each electrified sector from the source file used in developing the 1990 projections of Reference[25] and averaged, if necessary, as described in the previous paragraph.

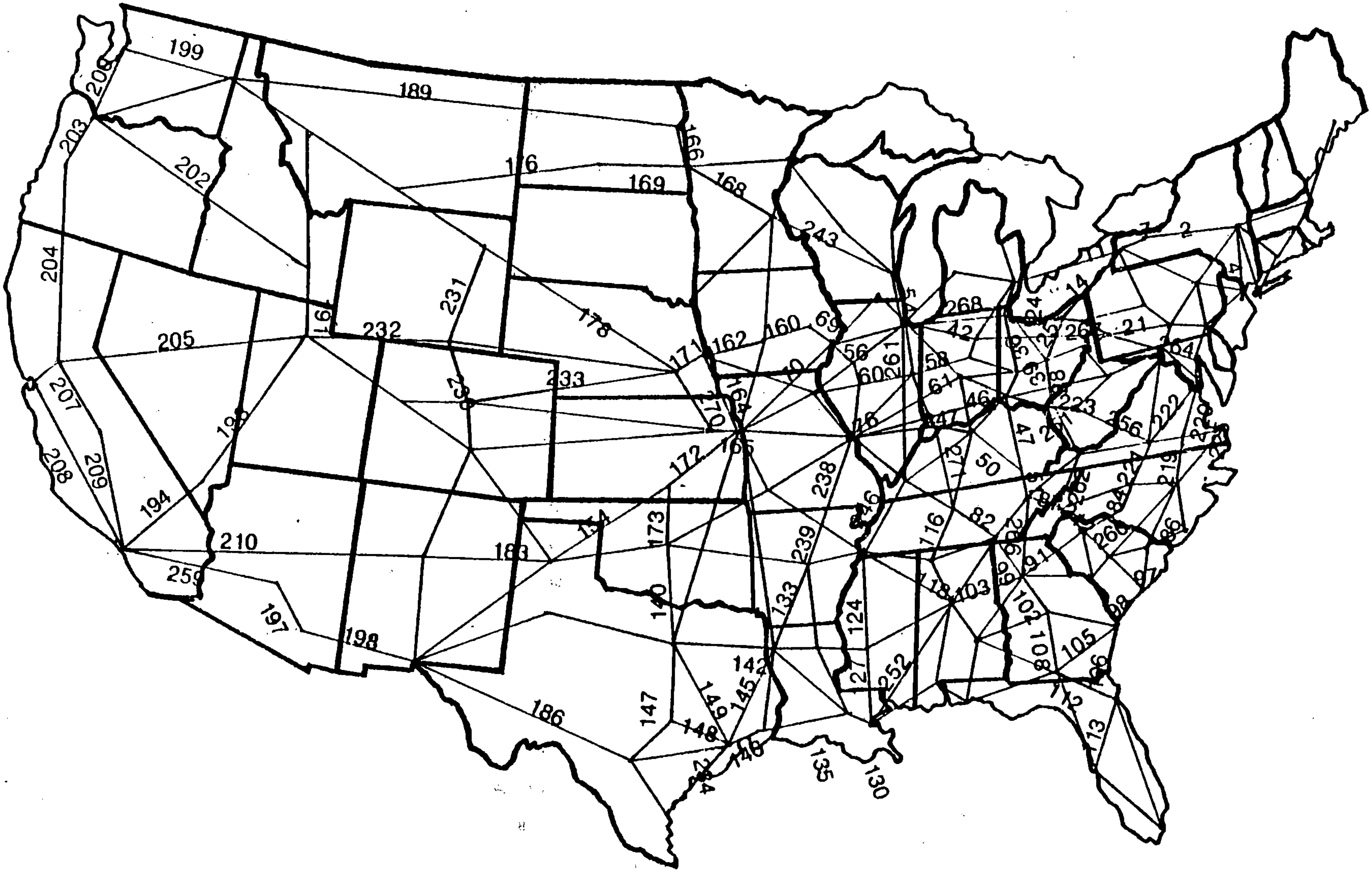


FIGURE 4-4. TRAFFIC LINKS BETWEEN 129 FRA TRAFFIC REGIONS (REF. 25)

TABLE 4-4. PREDICTED PERCENT GROWTH IN TRAFFIC FROM 1978 TO 1990 FOR THE TRAFFIC LINK CORRESPONDING TO THE SAMPLE SEGMENT

| DIRECTION | COMMODITY GROUP | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 COAL | 2 GRAIN | 3 CHEM-ICALS | 4 IRON ORE | 5 SAND, STONE, GRAVEL | 6 NONMET-ALLIC MIN. | 7 FOREST PRO-DUCTS | 8 CEMENT, CLAY & GLASS | 9 FOOD | 10 GRAIN MILL PROD. | 11 PULP & PAPER | 12 PRIM-ARY METALS | 13 TRANS. EQUIP-MENT | 14 LUMBER & WOOD | 15 ALL OTHER |
| FWD | -69.0 | 75.3 | 39.0 | 0 | 22.2 | 32.2 | 0 | -8.9 | - 1.8 | 17.4 | 30.8 | 21.5 | 40.2 | - 6.3 | 43.0 |
| REV | 0 | 0 | 18.3 | 0 | 95.5 | 30.4 | -22.5 | -3.6 | -10.9 | - 3.3 | 43.1 | 15.8 | 22.6 | -22.6 | 31.7 |

Source: FRA Data Base used to produce Reference 25.

## Commodity Mix

A one percent waybill sample maintained by the Association of American Railroads was used to establish the commodity mix on each route sector. The one percent waybill sample indicates junctions through which a commodity passes. This data is entered into a computer algorithm, called the "Princeton Model"[26] which assigns probable routing based on such factors as distance and historical trends. Several steps were required to produce the desired commodity mix:

1. The waybill statistics are quoted in carloads. Car flow was converted to revenue-ton flow on each link by computing tons/car from the Quarterly Commodity Statistics (QCS) of the Interstate Commerce Commission for each railroad and commodity group and applying this value to the car flows;

2. The way bill statistics are typically reported for 37 commodities as shown in Table 4-5. For compatibility with the format of the growth data, the commodities were combined into the 15 groups, as defined by Table 4-6, with the "other" category absorbing the waybill groups and portions of groups that could not be identified with any of the other 14. Included in "All Other" were STCC groups

TABLE 4-5. COMMODITY GROUPS FOR WHICH WAYBILL STATISTICS ARE ACCUMULATED

| MAJOR INDUSTRY GROUP NUMBERS | |
|---|---|
| GROUP | DESCRIPTION |
| 01 | Farm products |
| 08 | Forest products |
| 09 | Fresh fish or other marine products |
| 10 | Metallic ores |
| 11 | Coal |
| 13 | Crude petroleum, natural gas or gasoline |
| 14 | Nonmetallic minerals; except fuels |
| 19 | Ordnance or accessories |
| 20 | Food or kindred products |
| 21 | Tobacco products; except insecticides - see Major Industry Group 28 |
| 22 | Textile mill products |
| 23 | Apparel, or other finished textile products or knit apparel |
| 24 | Lumber or wood products; except furniture - see major Industry Group 25 |
| 25 | Furniture or fixtures |
| 26 | Pulp, paper, or allied products |
| 27 | Printed matter |
| 28 | Chemicals or allied products |
| 29 | Petroleum or coal products |
| 30 | Rubber or miscellaneous plastics products |
| 31 | Leather or leather products |
| 32 | Clay, concrete, glass or stone products |

TABLE 4-5. COMMODITY GROUPS FOR WHICH WAYBILL STATISTICS ARE ACCUMULATED (CONT'D)

| MAJOR INDUSTRY GROUP NUMBERS | |
|---|---|
| GROUP | DESCRIPTION |
| 33 | Primary metal products; inc. galvanized; except coating or other allied processing - see Major Industry Group 34 |
| 34 | Fabricated metal products; except: Ordnance - see Major Industry Group 19 ; Machinery - Groups 35, 36; Transportation equipment - Group 37 |
| 35 | Machinery; except electrical - see Major Industry Group 36 |
| 36 | Electrical machinery or equipment, or supplies |
| 37 | Transportation equipment |
| 38 | Instruments, photographic goods or optical goods, watches or clocks |
| 39 | Miscellaneous products or manufacturing |
| 40 | Waste or scrap materials not identified by industry producing |
| 41 | Miscellaneous freight shipments |
| 42 | Containers, carriers or devices, shipping, returned empty |
| 43 | Mail and express traffic |
| 44 | Freight forwarder traffic |
| 45 | Shipper association or similar traffic |
| 46 | Miscellaneous mixed shipments; except forwarder - see Major Industry Group 44 and 45 - Freight forwarder and Shipper associations |
| 47 | Small packaged freight shipments |
| 49 | Hazardous materials |

TABLE 4-6. DEFINITION OF COMMODITY GROUPINGS

| ITEM | GROUPING | COMMODITIES INCLUDED | STCC (CODE) |
|---|---|---|---|
| 1 | Coal | Bituminous | 1121 |
| | | Lignite | 1122 |
| | | Anthracite | 111 |
| 2 | Grain | Wheat | 01137 |
| | | Corn | 01132 |
| | | Sorghum | 01136 |
| | | Barley | 01131 |
| | | Soybeans | 0114 |
| | | Oats, rice, and other grains | - |
| 3 | Chemicals | Industrial chemicals | 281 |
| | | Agricultural chemicals | 287 |
| | | Plastic materials and synthetic resins | 282 |
| | | Common salt | 28991 |
| | | Other chemicals and products | - |
| 4 | Iron Ore | Crude ore | 10111, 10112 |
| | | Concentrates and agglomerates | 10113 |
| 5 | Stone, Sand, and Gravel | Crushed stone | 142 |
| | | Aggregate sand | 14411 |
| | | Aggregate gravel | 14412 |
| | | Industrial sand | 14413 |
| 6 | Nonmetallic Minerals | Phosphate rock | 14714 |
| | | Rock salt | 14715 |
| | | Sulphur | 14716 |
| | | Clay, ceramic, or refractory minerals | 145 |
| | | Gypsum and anhydrite | 14911 |
| | | Asphalt and bitumens | 14913 |
| | | Other nonmetallic minerals | - |
| 7 | Forest Products | Pulpwood logs | 24114 |
| | | Wood chips | 24115 |
| | | Saw logs | 24111 |
| 8 | Cement, Clay and Glass | Hydraulic cement | 324 |
| | | Structural clay products | 325 |
| | | Concrete, gypsum and plaster products | 327 |
| | | Processed clay and kaolin | 3295 |
| | | Other cement, clay and glass products | - |

TABLE 4-6. DEFINITION OF COMMODITY GROUPINGS (CONT'D)

| ITEM | GROUPING | COMMODITIES INCLUDED | STCC (CODE) |
|---|---|---|---|
| 9 | Food Products | Beverages | 208 |
| | | Sugar | 206 |
| | | Canned and preserved fruits and vegetables | 203 |
| | | Meat and dairy products | 201, 202 |
| | | Soybean oil | 20921 |
| | | Cottonseed oil and byproducts | 2093 |
| | | Other food products | - |
| 10 | Grain Mill Products | Flour | 2041, 22045 |
| | | Prepared feeds | 20421 |
| | | Soybean meal and flour | 20923 |
| | | Corn starch and syrup | 2046 |
| | | Cereal preparations | 2043 |
| | | Milled rice | 2044 |
| 11 | Pulp and Paper | Pulp and pulpmill products | 261 |
| | | Paper | 262 |
| | | Paperboard, pulpboard and fiberboard | 263 |
| | | Corregated paper products | 264 |
| | | Building paper and board | 266 |
| | | Containers and boxes | 265 |
| 12 | Primary Metal Products | Steel works and rolling mill products | 331 |
| | | Iron or steel castings | 332 |
| | | Nonferrous metal primary smelter products | 333 |
| | | Nonferrous metal basic shapes | 335 |
| | | Other primary metal products | - |
| 13 | Transportation Equipment | Motor vehicles | 3711 |
| | | Motor vehicle parts and accessories | 3714 |
| | | Railroad equipment | 374 |
| | | Other transportation equipment | - |
| 14 | Lumber and Wood Products | Lumber and dimension stock | 242 |
| | | Millwork, veneer and plywood | 243 |
| | | Particle board | 24996 |
| | | Other wood products | - |
| 15 | All Other Products | | |

41, 42, 44, 45, 46, and 47. Freight Forwarder and LCL (less than carload) traffic were subsequently separated into a sixteenth commodity for the electrification study;

3. Traffic flow results from the Princeton Model were readily available for the calendar year 1976. Since the growth data of the FRA study (Reference[25]) was for the period 1978 to 1990, it was necessary to use other growth data to estimate the traffic flows for some reference year within the study period. Factors based on 1976 and 1979 statistics by direction and commodity from the QCS of the ICC were used to update the 1976 traffic flows to 1979.

Table 4-7 shows the flow of 3 of the 16 commodities on the sample route segment as predicted by the Princeton model. The flows have been adjusted as described above. The sample route segment consists of 24 traffic links. To obtain the average revenue tonnage of each commodity, the density of each link must be weighted by its length. The commodity mix is then computed as the fraction of the total revenue tonnage (both directions) that each commodity represents. The resulting commodity mix on the sample route segment is shown in Figure 4-2, questionnaire item 2.

Railroad Questionnaire Response

The commodity mix and the commodity growth rates were sent to each of the railroads involved for their comment. They were given the option of changing any of the elements they wished, both in the growth projections and the traffic splits. The responses ranged from no comment through minor modifications, to complete substitutions of railroad-generated data. For example the procedures, as outlined, did not pick up increases in coal traffic subsequent to 1979. This was a major change

TABLE 4-7. 1979 FLOW OF THREE SELECTED COMMODITIES ON THE SAMPLE ROUTE SEGMENT

| TRAFFIC LINK | FRA LINE IDENTIFICATION CODE* | MILLION REVENUE TONS | | | | | |
|---|---|---|---|---|---|---|---|
| | | GRAIN | | IRON | | COAL | |
| | | FWD | REV | FWD | REV | FWD | REV |
| 00847 | UR184 | .40 | 0.89 | .00 | .00 | .00 | .04 |
| 00848 | UR184 | .40 | 1.11 | .00 | .00 | .00 | .04 |
| 00707 | UR184 | .40 | 1.11 | .00 | .00 | .00 | .04 |
| 00706 | UR184 | .40 | 1.19 | .00 | .00 | .00 | .04 |
| 00728 | UR377 | .32 | 1.32 | .00 | .00 | .00 | .04 |
| 00729 | UR377 | .32 | 1.32 | .00 | .00 | .00 | .04 |
| 00741 | UR565 | .31 | 1.32 | .00 | .00 | .00 | .04 |
| 00742 | UR565 | .28 | 1.40 | .00 | .00 | .00 | .03 |
| 00744 | UR565 | .28 | 1.40 | .00 | .00 | .00 | .03 |
| 00743 | UR565 | .28 | 1.40 | .12 | .00 | .00 | .03 |
| 00745 | UR378 | .28 | 1.41 | .12 | .00 | .00 | .03 |
| 00746 | UR378 | .28 | 1.41 | .12 | .00 | .00 | .03 |
| 00753 | UR566 | .28 | 1.41 | .12 | .00 | .00 | .03 |
| 00754 | UR566 | .28 | 1.41 | .12 | .00 | .00 | .03 |
| 00725 | UR566 | .28 | 1.41 | .12 | .00 | .00 | .03 |
| 00724 | UR566 | .28 | 1.41 | .12 | .00 | .00 | .03 |
| 01015 | UR691 | .28 | 1.41 | .12 | .00 | .00 | .03 |
| 01016 | UR691 | .28 | 1.41 | .12 | .00 | .00 | .03 |
| 01007 | UR433 | .48 | 1.96 | .16 | .00 | .00 | .03 |
| 01008 | UR433 | .48 | 1.96 | .16 | .00 | .00 | .03 |
| 01005 | UR433 | .48 | 1.96 | .16 | .00 | .00 | .03 |
| 01006 | UR433 | .48 | 1.96 | .16 | .00 | .00 | .03 |
| 00952 | UR103 | .48 | 1.96 | .16 | .00 | .00 | .03 |
| 00953 | UR103 | .48 | 1.96 | .16 | .00 | .00 | .03 |

*The Line Identification Code is the designation given to track segments in the 4-R Act Study of the FRA (Reference 27).

input by the railroads. The increased growth in coal traffic is noted in Table 2-4, where the bulk traffic growth (which is predominantly coal) is substantially larger than the growth of other service categories. In all cases where a railroad supplied growth or mix data, that data was used even though it was recognized that some loss of comparability would result.

Examination of the returned questionnaires indicate that, for question 3 commodities, (9) food, (13) transportation equipment, and (15) freight forwarder and LCL traffic moved for the most part in expedited services. This allocation was pursued throughout, with the one exception of one railroad where data from question 9 was used. Some commodities were considered to move in bulk service, but this occurred only where the distinction was made by the railroad concerned.

## Growth Traffic Forecast by Service Category

An algorithm was formulted to calculate for each route sector:

1. Traffic density split (gross tons per year including locomotive consist weight) by service category for base year;

2. Annual growth in traffic in each service category defined;

3. Designation of service category in which each commodity is moved;

4. Total traffic density by direction in the base year;

5. Designation of the year for which the commodity mix applies (it need not be the base year for which the growth traffic split is sought).

The algorithm also requires specification of constants that convert revenue tonnage to gross tonnage:

$a_i$ = ratio of the average lightweight of cars used to haul commodity i to the average weight of commodity i carried in a single car.

$b_i$ = ratio of empty to loaded car-miles in hauling commodity i.

c = ratio of locomotive weight to trailing train weight.

For the network study, $a_i$, $b_i$, and c were formulated using industry wide data as shown in Table 4-8. Note, $a_i$ was approximated by taking the ratio of the lightweight of the most populous car of the preferred car type for hauling commodity i to the average revenue tons hauled in that car type, ignoring commodity*.

The computer results for the sample sector are summarized in Table 4-9. The results become input data to the REAM. The equations that define the algorithm are given in Appendix G along with a description of the computer program which was used for generating the results for the network study. Figure G-1

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*The values for $a_i$ could be more accurately established by decomposing tabulated data of Reference[28] for loaded and unloaded weights of all car types carrying all commodity groups. Likewise the constant c could be made service category specific from statistics of the questionnaire response on dispatch level and prevalent locomotive type. However, the purpose is only to establish the split in the stated total traffic level. Thus, the additional accuracy is not warranted.

## TABLE 4-8. CONSTANTS IN THE TRAFFIC FORECAST MODEL

| CAR TYPE | CLASSIFICATION OF COMMODITY GROUPS BY PREFERRED CAR TYPE[1] | A- AVERAGE REVENUE TONS PER CARLOAD[2] | B- REPRESENTATIVE CAR - LIGHT-WEIGHT TONS[3] | a= RATIO: B/A | b= RATIO: EMPTY TO LOADED CAR MILES[4] | c= RATIO: LOCOMOTIVE WEIGHT/TRAILING TRAIN WEIGHT[5] |
|---|---|---|---|---|---|---|
| Box | Cement, glass and clay; grain mill products; pulp and paper; other | 35 | 31 | 0.89 | 0.69 | 0.08 |
| Hopper (Open) | Coal, iron ore, sand, stone, gravel nonmetallic minerals, forest products | 75 | 27 | 0.36 | 0.91 | 0.08 |
| Hopper (Closed) | Grain | 75 | 31 | 0.41 | 0.91 | 0.08 |
| Tank | Chemicals | 64 | 30 | 0.47 | 1.06 | 0.08 |
| Gondola | Cement, clay, glass, primary metals | 70 | 28 | 0.40 | 0.86 | 0.08 |
| Refrigerator | Food | 32 | 40 | 1.25 | 0.77 | 0.08 |
| Autorack | Transportation equipment | 60 | 58 | 0.97 | 0.94 | 0.08 |
| Flat | Lumber and wood | 30 | 41 | 1.37 | 0.88 | 0.08 |
| Passenger Car | Passengers | - | - | - | - | - |

[1] Reference 29.

[2] FRA Waybill Sampling Data, 1974.

[3] Reference 28.

[4] ICC Bureau of Accounts, 1972 Statement No. 152-72.

[5] Based on a typical dispatch level of 1.25 HP/ton and a typical locomotive weight of 0.06 ton/HP.

c = (.06 ton/HP) x (1.25 HP/ton) = .08.

TABLE 4-9. GROSS TRAFFIC FORECAST FOR THE SAMPLE SECTOR

| SERVICE CATEGORY | 1980 TRAFFIC DENSITY MGT/YEAR | | ANNUAL GROWTH RATE PERCENT THROUGH 1990 | |
|---|---|---|---|---|
| | FWD | REV | FWD | REV |
| Bulk | - | - | - | - |
| Normal | 9.8 | 7.9 | 1.2 | -0.3 |
| Expedited | 6.8 | 7.9 | 1.9 | 1.0 |
| Passenger | - | - | - | - |
| TOTAL | 16.6 | 15.8 | | |

is the computer results for the sample sector, annotated to indicate the input data used and output results. Note the annual growth rates in Table 4-9 have been transcribed from Figure C-1. However, the traffic split in Table 4-9 was based on questionnaire item 9, rather than that predicted by the traffic model for the default definition of normal and expedited service.

### 4.2.3 Route Characteristics

The route characteristsics define the physical makeup of each route segment. The specific items of interest are: the track itself, including sidings and yards; bridges and tunnels; the electrification system; and grade crossing signals.

Track Characteristics

Each route segment is defined by its unique Link File Identification, which consists of the two-letter railroad identifier, the Link Identification Code (LIC)[27] for the starting link, the LIC for the ending link, and the Census Region[30] to the ending link. Using this route and LIC data, track charts and railroad time tables are then used to obtain the number of route miles with one, two, three, and four or more tracks. However, these routes miles must also be broken out by class of curvature.

The class of curvature is defined as:

Tangent - Tangent to 1°;
Medium - Greater than 1° but less than 3°;
Heavy - Equal to or greater than 3°.

For this study, the breakout of track by curvature was done two ways; by use of the FRA Data Base for the 10,000-mile core and by estimation for the remainder.

Using the FRA Data Base, the milage of each link which fell into each class of curvature was obtained by assigning the length of each element to the appropriate curvature class, and then adding to obtain the total per class for each link. See Worksheet No. 1, Figure 4-5. The links were then added to yield the total miles per curve class for the entire route segment. The example shows the data for the first LIC (of a total of 9 LICs) for the selected route segment. Note that in this example all track falls into the tangent class. Since the Data Base information then available did not include track data, the percentage of Tangent, Medium, and Heavy curvature

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Sheet 1 of 1 sheets

Railroad: URail & Company

From - To: UTown Yard to UCity

| FRA LIC | ELEM. NO. | ROUTE MILES | RM BY NO. OF TRACKS | | | | GRADE PERCENT | RM x GRADE | CURVE DEGREE | RM BY CURVE CLASS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | | | | TAN. | MED. | HVY. |
| UR 999 | 1 | 2.60 | | | | | .07 | 0.182 | .80 | 2.6 | | |
| | 2 | 1.30 | | | | | .44 | 0.572 | .46 | 1.3 | | |
| | 3 | 2.60 | | | | | .20 | 0.52 | .76 | 2.6 | | |
| | 4 | 6.10 | | | | | .77 | 4.697 | .36 | 6.1 | | |
| | 5 | 1.10 | | | | | .72 | 0.792 | 0 | 1.1 | | |
| | 6 | 3.00 | | | | | .49 | 1.47 | 0 | 3.0 | | |
| | 7 | 7.00 | | | | | .75 | 5.25 | .42 | 7.0 | | |
| | 8 | 3.10 | | | | | .29 | 0.899 | .20 | 3.1 | | |
| | 9 | 1.90 | | | | | .42 | 0.798 | .22 | 1.9 | | |
| | 10 | 3.30 | | | | | .76 | 2.508 | .04 | 3.3 | | |
| | 11 | 2.00 | | | | | .27 | 0.54 | .02 | 2.0 | | |
| | 12 | 3.00 | | | | | .63 | 1.89 | .78 | 3.0 | | |
| | 13 | 17.90 | | | | | .32 | 5.728 | .24 | 17.9 | | |
| | 14 | 1.10 | | | | | .60 | 0.66 | .54 | 1.1 | | |
| | 15 | 16.90 | | | | | .47 | 7.943 | .10 | 16.9 | | |
| | 16 | 0.80 | | | | | .24 | 0.192 | 0 | 0.8 | | |
| | 17 | 2.00 | | | | | .68 | 1.36 | .60 | 2.0 | | |
| | 18 | 5.50 | | | | | .73 | 4.015 | .40 | 5.5 | | |
| | 19 | 1.10 | | | | | .64 | 0.704 | 0 | 1.1 | | |
| | 20 | 0.60 | | | | | .41 | 0.246 | 0 | 0.6 | | |
| | 21 | 1.40 | | | | | .57 | 0.798 | .36 | 1.4 | | |
| | 22 | 3.20 | | | | | .65 | 2.08 | .42 | 3.2 | | |
| | 23 | 0.70 | | | | | .46 | 0.322 | 0 | 0.7 | | |
| | 24 | 1.40 | | | | | .51 | 0.714 | 0 | 1.4 | | |
| | 25 | 1.30 | | | | | .29 | 0.377 | 0 | 1.3 | | |
| | 26 | 1.40 | | | | | .58 | 0.812 | .08 | 1.4 | | |
| | 27 | 0.50 | | | | | .45 | 0.225 | .90 | 0.5 | | |
| | 28 | 11.70 | | | | | .46 | 5.382 | .02 | 11.7 | | |
| | 29 | 0.50 | | | | | .30 | 0.15 | 0 | 0.5 | | |
| TOTAL | | 105.0 | | | | | | 51.826 | | 105.0 | 0 | 0 |

Curve Classes:

Tan.: $0 \le C \le 1°$
Med.: $1° < C < 3°$
Hvy.: $C \ge 3°$

$$\text{Avg Gd} = \frac{\sum \text{RM x Grade}}{\sum \text{RM}}$$

$$\text{Avg Gd} = \frac{51.826}{105} = 0.494$$

FIGURE 4-5. WORKSHEET NO. 1 - RIGHT-OF-WAY DESCRIPTION

FRA LIC - Obtain from route segment list, or Ref. 14.

Element Number - Enter sequentially for each LIC.

Route-Miles - Enter route miles for each element. Obtain from FRA Data Base.

Route-Miles by Number of Tracks - Obtain from Data Base (not always available) and enter under appropriate number of tracks.

Grade - Obtain from Data Base and enter; maintain sign.

Route-Miles x Grade - Multiply Route Miles by Grades, enter absolute value.

Curve - Obtain from Data Base.

Route-Miles by Curve - Enter Route Miles under appropriate curve class.

Total - Add indicated columns. Add RM by Number of Tracks by each curve class to produce a four a three matrix.

$$\text{Calculate Avg. Grade} = \frac{\text{RM x Grade for entire route segment}}{\text{Route-Miles for entire route segment}}$$

FIGURE 4-6. INSTRUCTIONS, WORKSHEET NO. 1

was calculated, and these percentages were than applied proportionally to the previously prepared route miles of one, two, three, and four tracks. The resulting three by four matrix was entered into Records, 17, 18, and 19 of the Link Data File. (See Section 4.2.7 and Figure 4-21 to follow.)

Estimation was used for the remainder of the network. The use of the Data Base described above was very tedious and time-consuming. The data gave the results that 89+ percent of the 10,0000 mile core was tangent, 10+ percent was medium curvature, and 0.5+ percent was heavy curvature. Using the catenary cost data indicated in Figure 4-1, the costs were compared for 80 percent tangent/20 percent medium, 90 percent tangent/10 percent medium, and 99 percent tangent/one percent medium curvature. Using the 90 percent/10 percent cost as the reference, the 80 percent/20 percent cost was 1.2 percent greater and the 99 percent/one percent cost was 1.1 percent less. Since the catenary cost appeared to be reasonably insensitive to 10 percent shift between curvature categories, most of the route segments for the remainder of the network were estimated to have 90 percent tangent and 10 percent medium curvature trackage. However, for a few route segments which were known to lie in rugged terrain, the estimate was changed to 85 percent tangent and 15 percent medium curvature track.

Operating Route Miles

As discussed in Section 3.2, the traffic and/or the locomotives may not travel the same distance as given by the sum of the Miles of Main Line Track Wired. In this case, the operating Route Miles is given by the railroad as part of the traffic and operating information added to the Railroad Questionare. In the selected example, a helper locomotive is required for normal service in the reverse direction, and the length of the helper operation is given separately on the questionnaire.

The Operating Route Miles is entered into Record 12 on the Link Data Form.

## Sidings and Yards

Sidings and yard data consists of all miles of catenary construction not included in the main line track data, and is the track miles of sidings, interlockings, cross-overs, etc., obtained from track charts summed with the estimated miles of yard wired. Yards of small, medium, and large size were wired for 10, 20, and 30 miles respectively.

The total mileage is entered into Record 16 of the LDF.

## Grade Characteristics

Average grade characteristics can be obtained from track charts or by estimation. The processes are similar to those used to obtain cuvature data, and use the same Worksheet No. 1, Figure 4-5.

For this study, the average grade was obtained from track charts for the 10,000-mile core. The mileage and grade were obtained and entered on the worksheet for each route element, and their product was calculated for the formula given in the instructions. In the example, data are entered for the first nine LICs for the selected route segment, and the average grade is caluculated. Note that average grade is calculated for the entire route segment, and not for a single LIC as shown in the example.

The average grade was estimated for each route segment of the remainder of the network as the track chart procedure was very time consuming. Three categories of grade were defined:

Light - Grade 0 percent to 0.33 percent;

Medium - Grade 0.34 percent to 0.67 percent;

Heavy - Grade greater than 0.68 percent.

A feel for the magnitude of the average grade was developed during the prepartion of the data for the 10,000-mile core. The average grades for the remainder of the network were estimated as Light, Medium, or Heavy by comparing the terrain to similar terrain in the 10,000-mile core.

The average grade is not entered onto the Link Data File, but is used on Worksheet No. 9, Figure 4-18, to calculate Electric Energy Consumption.

Grade characteristics for the Ruling Grade can be obtained from the FRA Data Base, track charts, or other railroad data.

For this study, the Ruling Grade values were supplied by the railroads on the Railroad Questionnaire, Item 7.

The forward and reverse Ruling Grades are entered onto the LDF in Records 13 and 14 respectively, and are used to determine elecric locomotive dispatch policy on Worksheet No. 4, Figure 4-12.

The special case involving helpers must be noted. When a helper is used, the ruling grade within the helper district is entered into the Link Data File for the helper calculations, and the ruling grade outside the helper district is entered onto the LDF for the complete route segment calculations.

## Bridge and Tunnel Count

The critical data is the number of bridges and length of tunnels (total) requiring increased clearance. This type of data is not readily accessible for a large network. Hence, the following procedure was adopted:

The count of the number of bridges and tunnels can be obtained from the FRA Data Base.

The raw count of the number of bridges was adjusted to reflect the percentage of total bridges which would probably require reconstruction based on the findings of the Conrail electrification study[18]. In Census Regions 1 and 2, 25KV catenary voltages were used; here the raw bridge count was multiplied by 0.25, since it is estimated that 25 percent of the bridges will require reconsruction to accomomdiate the catenary. In all other Census Regions, 50KV catenary voltages were used; the raw bridge count was multiplied by 0.65, since it is estimated that 65 percent of the bridges will require reconstruction to accomodate the larger clearances required by the higher voltage.

The adjusted bridge count is entered into Record 22 on the LDF.

The only reliable sources of information on tunnel modification are tunnel engineering and design drawings. The tunnel data for this study are incomplete. Where tunnel data are given, they were provided by the railroad.*

*The tunnel count can usually be obtained from the FRA Data Base which lists the number of tunnels, but does not include the length, the number of tracks, or the overhead clearance. It would be inappropriate to establish a factor which estimates the fraction of tunnels requiring modification as with bridges since the number of tunnels examined was small.

Tunnel data are entered into Record 21 of the LDF.

## Substation Requirements

The number of electric traction power substations is established by the catenary voltage selected and by the practice of the railroad as regards to the terrain and power grid accessibility. The catenary voltage of 25KV was chosen for Census Regions 1 and 2 (New England plus New York, New Jersey and Pennsylvania); physical clearance problems caused by the higher degree of urbanization and the large amount of old right-of-way construction this area were reduced by selecting 25KV. For all other areas, 50KV was selected.

In practice, the decision between 25KV and 50KV is link specific. The reduction in civil reconstruction costs for 25KV may exceed the increase in substation and utility connection costs, and hence 25KV may be more cost-effective.*

From the data given in Reference 22, the average substation spacing for 25KV and 50KV for each of the eight listed railroads were calculated. These spacings were used to compute the number of substations, by number of tracks, for each route segment of the eight listed railroads. See Worksheet No. 2, Figure 4-7. The weighted average spacings for the eight railroads were also calculated, and were used to compute the number of substation for the other railroads. The spread of the substation spacing is given below:

---

*Such is the case, for example, on the Family Line route from Elkhorn City, KY to Erwin, NC, where nearly seven miles of tunnel makes civil reconstruction the largest single investment at 50KV.

Revision Date: 9/22/82

Railroad: URail & Company  From - To: UTown Yard to UCity

Voltage Used = $\frac{50}{\text{25kv or 50kv}}$:  Substation Spacing = $\frac{75}{\text{Miles}}$

| | WIRED ROUTE-MILES | BY TRACK-MILES 1 TRACK | 2 TRACKS | 3 TRACKS | 4 TRACKS |
|---|---|---|---|---|---|
| Miles | 504 (Total) | 406 | 98 | 0 | 0 |
| Substations | 7 (Total) | 5 | 2 | 0 | 0 |

FIGURE 4-7. WORKSHEET NO. 2 - CALCULATION OF NUMBER OF SUBSTATION

Voltage Used - Enter 25KV for Regions 1 and 2, 50KV for all other Regions.

Substation Spacing - Obtain from Reference 22, or use 30 miles for 25KV and 75 miles for 50KV systems.

Wired Route-Miles - Obtain from LDF Records 17, 18 and 19. Add 1, 2, 3 and 4 track entries and enter total.

Calculate results as follows:

1. Divide Total Miles by Substation Spacing. Round off fraction according to Rounding Rule, and enter result into Total Substations;
2. Divide 4-track mileage by the substation spacing, round off results, and enter under 4-track Substations;
3. Repeat for 3-track and 2-track;
4. Add substations for 4, 3 and 2 tracks. Subtract sum from Total Substations and enter result under 1-track Substations.

| | |
|---|---|
| Rounding Rule | If fraction of a substation is equal to, or greater than, 0.3, round up to the next largest whole number. |
| Note 1 | If 4-track mileage is too small to indicate one substation, add it to 3-track mileage. If this sum is still too small to indicate one substation, add it to the 2-track mileage. |
| Note 2 | The intent of the Rounding Rule and Note 1 is to bias the number of substations toward the larger number of tracks and hence toward the larger and more costly substations. This is done to provide a contingency margin needed because of uncertainties in track arrangements, substation feed locations, current loads, etc. |
| Example | Divide total route-miles by substation spacing, 504/75 = 6.72. By rounding rule, round up to 7 and enter. Divide 2-track route miles by spacing 98/75 = 1.307. Round up to 2 and enter. Subtract 2-track stations from total stations, 7-2 = 5, and enter under 1-track heading. |

FIGURE 4-8. INSTRUCTIONS, WORKSHEET NO. 2

| | 25KV | 50KV |
|---|---|---|
| Minimum Spacing | 18 miles | 59 miles |
| Maximum Spacing | 35 miles | 93 miles |
| Average Spacing | 30 miles | 75 miles |

Substation data are entered into Record 20 of the LDF.

## Utility Connection Mileage

The miles of utility connection is the sum of the lengths of new transmission lines which connect the substations to the primary power grid. For many of the route segments, the miles can be obtained from Table A-2[24]; it was used for this study whenever the table included the route segment. If the total route mileage exceeded the route segment mileage, the length of the total utility connection was pro-rated by the ratio of the route segment mileage to the total route mileage.

If the route segment was not available in Reference 24, the utility connection miles was calculated by multiplying the route segment total of Main Line Track Wired by 0.09 for 50KV feeders and by 0.18 for 25KV feeders (based on the average miles of utility connection per route mile of electrification for all routes).

Utility connection data are entered into Record 23 of the LDF.

## Train-Activated Grade Crossings

The number of crossings is obtained from the FRA Data Base by adding the number for every LIC in the route segment, and is entered into Record 24 of the LDF. The model does not use this data in the configuration documented by this report. It should also be noted that no route-specific input data is prepared for other electric compatibility modifications required to the signal and communication system. The model as configured assumes the cost of all such modifications is proportional to the route miles wired for electrification.

### 4.2.4 Directional Diesel Power Requirements

The diesel dispatch level as reported on the Railroad Questionnaire is based on the nameplate power rating of the diesel engine/generator. The nameplate or most frequently quoted diesel rating is the horsepower available for traction and does not include losses in the generator or alternator/rectifier and traction motors as indicated in Figure 4-9. It is necessary to use the rating at the rail for compatibility with the nameplate horsepower rating of an electric locomotive, which is specified at the rail. The efficiency factor was assumed to be 0.85. Worksheet No. 3 (Figure 4-10) defines the procedure used in the network analysis for conversion to rated power at the rail. Note that for the sample segment, the diesel helper dispatch level is separately converted.

The directional diesel power requirement is calculated using the dispatch level at the rail, runtime and other data as indicated by the instructions on Worksheet No. 4 (Figure 4-11). The dispatch level and run time are critical data that are typically established by a train performance calculator when performing a feasibility study. The use of questionnaire data obviates the use of a TPC and includes the "factor of safety" that a railroad applies to contend with unpredictable events such as locomotive failure and weather-dependent variations in traction.

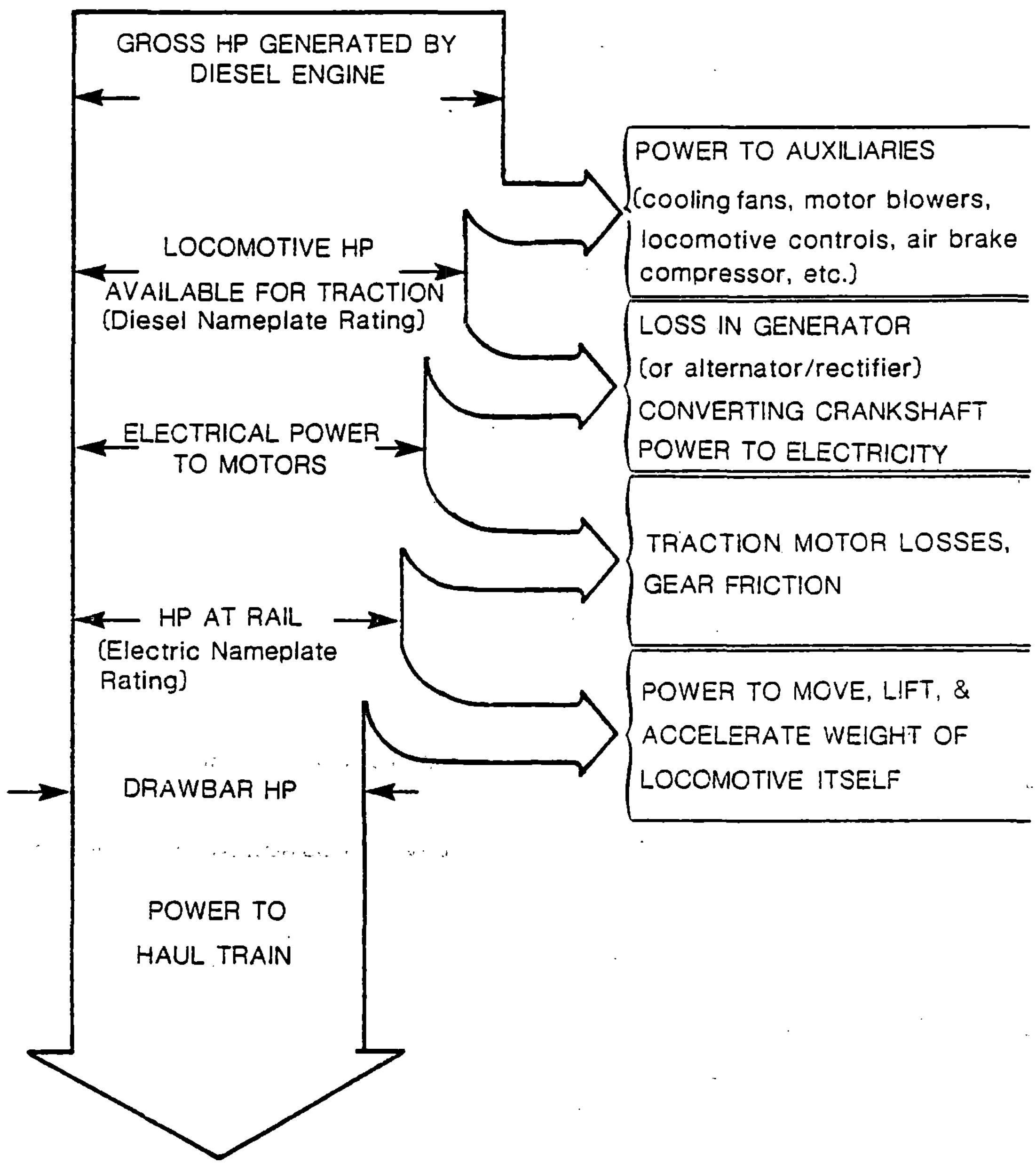



FIGURE 4-9. COMPARISON OF LOCOMOTIVE HORSEPOWER RATINGS

Revision Date: 9/22/81

Railroad: URail & Company    From - To: UTown Yard to UCity, USA

NV

| TOS | Dir: | 1<br>Dispatch Level, Rated HP/GT | x | 2<br>Effic. Factor | = | 3<br>Dispatch Level, Rail HP/GT |
|---|---|---|---|---|---|---|
| BULK | Fwd | | x | | = | |
| | Rev | | x | | = | |
| NORM | Fwd | 1.8 | x | 0.85 | = | 1.53 |
| | Rev | 1.9(+1.2)* | x | 0.85 | = | 1.62(+1.02)* |
| EXPD | Fwd | 3.1 | x | 0.85 | = | 2.64 |
| | Rev | 3.0 | x | 0.85 | = | 2.55 |
| PASS | Fwd | | x | | = | |
| | Rev | | x | | = | |

INSTRUCTIONS

1. Dispatch Level (Rated HP/GT). Obtain from the Railroad Questionnaire for each type of service present on the route sector.

2. Conversion Factor. Efficiency factor to account for power losses between diesel engine and wheels. Use the same factor for all diesel locomotives on all route segments.

3. Dispatch Level (Rail HP/GT). The result is rail horsepower per trailing gross ton delivered to the rail by the Diesel locomotive. Enter forward dispatch levels in record 33 of the Link Data File form; enter reverse dispatch levels in record 34 of the Link Data File form.

*Helper Locos at Big Mountain Pass.

FIGURE 4-10. WORKSHEET NO. 3 - DIESEL LOCOMOTIVE DISPATCH POLICY

Revision Date: ________

Railroad: URail & Company　　　　From - To: UTown Yard to UCity, USA

| TOS | Dir: | Traffic Density GT/YR | x | Dispatch Level Rail HP/GT | x | Sched. Time Hrs. | + | Tranand Time Hrs. | x | Year / 8760 hrs. | ÷ | Utiliz. Factor | = | Directional Rail HP Required |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK | Fwd | ______ | x | ______ | x | (______ | + | ______) | x | 1/8760 | ÷ | ______ | = | ______ |
| | Rev | ______ | x | ______ | x | (______ | + | ______) | x | 1/8760 | ÷ | ______ | = | ______ |
| NORM | Fwd | $9.79 \times 10^6$ | x | 1.53 | x | (21.75 | + | 1.5) | x | 1/8760 | ÷ | 0.72 | = | 55198 |
| Helper | | $7.93 \times 10^6$ | x | 1.02 | x | 1.36 | + | 0 | x | 1 | ÷ | 0.72 | = | 1760 |
| | Rev | $7.93 \times 10^6$ | x | 1.62 | x | (16.25 | + | 1.5) | x | 1/8760 | ÷ | 0.72 | = | 36142 |
| EXPD | Fwd | $6.81 \times 10^6$ | x | 2.64 | x | (13.17 | + | 1.5) | x | 1/8760 | ÷ | 0.72 | = | 41803 |
| | Rev | $7.87 \times 10^6$ | x | 2.55 | x | (13.42 | + | 1.5) | x | 1/8760 | ÷ | 0.72 | = | 47458 |
| PASS | Fwd | ______ | x | ______ | x | (______ | + | ______) | x | 1/8760 | ÷ | ______ | = | ______ |
| | Rev | ______ | x | ______ | x | (______ | + | ______) | x | 1/8760 | ÷ | ______ | = | ______ |

INSTRUCTIONS

1. Traffic Density (Gross Tons Per Year). Obtain from the Traffic Forecast Summary Sheet, the base year traffic densities, or from items 8 and 9 of the Railroad Qustionnaire by Type of Service in each Direction.
2. Dispatch Level (Rail HP/GT). Obtain from Worksheet No. 3, Column 3, by TOS and Direction.

FIGURE 4-11. WORKSHEET NO. 4 - DIESEL LOCOMOTIVE DIRECTIONAL POWER REQUIREMENT

INSTRUCTIONS (CONT'D)

3. Schedule Time (Hours).

- For mainline locomotives, copy from Railroad Questionnaire by TOS and Direction.
- For helper locomotives assisting in one direction; multiply length of the grade, obtained from Railroad Questionnaire x 0.075.
- For helper locomotives assisting in both directions: multiply the length of the grade, as obtained from the Railroad Questionnaire by 0.10.

4. Turnaround Time (Hours).

- For mainline locomotives obtain operating route-miles from W.S. No. 1 and compute:

  Turnaround Time = .003 x (operating route-miles) (Based on the assumption that a diesel locomotive travels 1,000 miles between stops of 3-hour duration for inspection, refueling and sanding).

- For helper locomotives enter turnaround time = 0.

5. Utilization (Factor). This factor accounts for the fraction of a year that the locomotive is on the road or at an end point for inspection, refueling and sanding. Non-utilized times include maintenance and repair time, time in storage because of seasonal lulls in traffic, and waiting time for schedule considerations. Use the same factor for all diesel locomotives on all route sectors.

6. Directional Rail Horsepower Required. The result is the rail horsepower required to move the annual gross tonnage in one direction where the return trip time of the locomotives is ignored. Enter the forward and reverse results in records 31 and 32 of the LDF form, respectively.

FIGURE 4-11. WORKSHEET NO. 4 - DIESEL LOCOMOTIVE DIRECTIONAL POWER REQUIREMENT (CONT'D)

The diesel utilization factor, as defined in item 5 of Worksheet No. 4, was assumed to be 0.72 for each railroad in the network study with concurrence of the Planning Committee.

Schedule time and turnaround time are calculated differently for helper locomotives. Speed up a grade is assumed to be 10 mph. If the return trip is downhill (helpers not working) the speed is assumed to be 20 mph. The average one-way trip time in hours required to establish the directional helper power requirements is as follows:

<u>Help in one direction</u>:

$$1/2 \times \left( \frac{\text{One-way mileage of helper}}{(10)} + \frac{\text{One-way mileage of helper}}{(20)} \right)$$

$$= 0.75 \times \text{one-way mileage}$$

<u>Help in both directions</u>:

$$\frac{\text{One-way mileage of helper}}{(10)} = 0.10 \times \text{one-way mileage}$$

No turnaround time is entered for helper locomotive since, in most cases, they have a lower utilization rate than mainline locomotives due to infrequency of trains requiring assistance. They can therefore be serviced while waiting.

### 4.2.5 Directional Electric Locomotive Power Requirement

#### Selection of Electric Locomotive Type and Dispatch Level

It can be inferred that the dispatch level stated on the Railroad Questionnaire for diesel service provides adequate tractive effort, as well as horsepower, to meet the demands imposed by service and terrain on the sector. It is assumed that maximum tractive effort is required on the ruling grade of the sector. This tractive effort is readily calculated and can be converted to an equivalent "traction" dispatch level requirement (power per trailing gross ton) for the prevalent diesel locomotive type.* For sectors with large ruling grades and slow moving trains the dispatch policy as stated on the questionnaire is likely to be established by traction. When ruling grades are small and train speed is higher, power requirements are likely to establish the dispatch level. The prevalent locomotive would be fully utilized if both tractive and power requirements resulted in the same dispatch level.

In selecting an electric locomotive type and a corresponding dispatch level for a sector, it is presumed to be a desirable situation when tractive and power dispatch capabilities are fully utilized. The prevalent electric locomotive is selected to have a ratio of power to tractive effort capability similar to the prevalent diesel if calculations show the diesel to be "fully utilized." For those situations in which tractive dispatch requirement is calculated to be significantly lower than the level stated on the questionnaire (which is then taken to be the power dispatch

*The Davis equation is used, with aerodynamic resistance omitted since the train is assumed to be climbing the grade at 10 mph; tractive effort per trailing gross ton equals 4 + 20 X Ruling Grade in percent (Ref. 5).

requirement), an electric replacement is selected which has a higher ratio of power to tractive effort capability, thereby replacing an underutilized diesel with a more fully utilized electric.

Worksheet No. 4 (Figure 4-12) describes the procedure for selecting electric locomotive type and dispatch level. The procedure is repeated for each type of service that exists on the sector and results in a independent determination of locomotive type for each. For the network study, more than one prevalent locomotive type was identified for eight of the 127 sectors. Review of the Railroad Questionnaires indicate that most railroads select the same type of diesel locomotive for all service categories on a sector. Deviation from current practice in selecting electric locomotive type was implemented to take advantage of the higher horsepower to tractive effort rating of electric locomotives in expedited service.

Only three electric locomotive types were considered in this study. There were seven diesel types indicated as prevalent on the questionnaires completed for the 96 link network. Thus, there are fewer combinations of power and tractive effort ratings from which to choose in attempting to find an electric locomotive type that is fully utilized. The selection procedure adopted is to replace a diesel with an electric which has precisely the tractive capability required for the ruling grade and a minimum of horsepower in excess of the diesel dispatch. While it would be equally acceptable from a performance point of view to select an electric with precisely equivalent power capability and a minimum of tractive effort capability in excess of the diesel, this approach is less cost-effective with the present electric locomotive cost structure. There are two exceptions to the selection philosophy:

Revision Date: ________

Railroad: URail & Company

From - To: UTown Yard to UCity, USA

Type of Service: Normal

1. DOMINANT DIRECTION from Worksheet No. 4 (direction requiring greatest Diesel Horsepower): FWD x REV ___.

2. Prevalent Diesel Loco Type # 4 Diesel Rail HP/lb $TE_A$ 2250/66,200 = 0.39.

3. Diesel Rail HP Dispatch Levels: Forward 1.53 Reverse 1.62.

*4. For the dominant direction, calculate the Davis Equation Dispatch Level (DEDL):

DEDL = (4 + 20[Ruling Grade] x Prev. Diesel Rail HP/lb $TE_A$) = (4 + 20(1.)) x .039 = .936.

*5. Calculate possible dispatch levels, by direction:

**FORWARD DIRECTION**

4 + 20(Ruling Grade) = 4 + 20(1.0) = 24

| Elec. Loc. | lb $TE_A$ per GT | x | Elec. Rail HP/lb $TE_A$ | = | Elec. Rail $HP_A$/GT |
|---|---|---|---|---|---|
| 1 | 24 | x | 0.038 | = | .912 |
| 2 | 24 | x | 0.041 | = | .984 |
| 3 | 24 | x | 0.062 | = | 1.488 |

**REVERSE DIRECTION**

4 + 20(Ruling Grade) = 4 + 20(1.0) = 24

| Elec. Loc. | lb $TE_A$ per GT | x | Elec. Rail HP/lb $TE_A$ | = | Elec. Rail HP /GT |
|---|---|---|---|---|---|
| 1 | ________ | x | 0.038 | = | ________ |
| 2 | ________ | x | 0.041 | = | ________ |
| 3 | ________ | x | 0.062 | = | ________ |

*6a. Select Locomotive Type and Dispatch Level: Type Locomotive 3.

Fwd Elec. Loco. Disp. Level 1.53 Rev Elec. Loco. Disp. Level 1.62.

6b. Select Electric Locomotive Type and Dispatch Level: Type Locomotive ______.

Dispatch Level = (Diesel Dispatch Level) x (Electric RHP/lb. of T.E.) - (Diesel RHP/lb. of T.E.).

Fwd Dispatch Level = (___) x (___)/(___) = _____

Rev Dispatch Level = (___) x (___)/(___) = _____

FIGURE 4-12. WORKSHEET NO. 5 - ELECTRIC LOCOMOTIVE SELECTION AND DISPATCH LEVEL

INSTRUCTIONS

1. Dominant Direction: Obtain from W.S. No. 4 the direction requiring the greatest horsepower for the designated type of service.

2. Prevalent Diesel Locomotive Type/Ratio Diesel Power to Traction: Obtain the prevalent diesel locomotive type from the Railroad Questionnaire for the designated type of service. Obtain the ratio of diesel rail horsepower to tractive effort ratings from the Table of Diesel Locomotive Design Characteristics, Table 2-5.

3. Diesel Dispatch Levels: Obtain from W.S. No. 2 the rail horsepower dispatch level of the road locomotive in each direction for the designated type of service.

*4. Tractive Dispatch Requirement for the Dominant Direction:

- Obtain the ruling grade (outside the helper district if there is a helper) from the Railroad Questionnaire.
- Copy the prevalent diesel locomotive power to tractive effort ratio from Item 2 above.
- Calculate the traction dispatch requirement using the Davis equation indicated.
- Decision Rule: If the traction dispatch requirement is less than the dominant dispatch level recorded in Item 3, complete Items 5 and 6a below; if the traction dispatch requirement is greater, complete Item 6b.

*5. Possible Electric Dispatch Levels in Dominant Direction:

- For the dominant direction, copy the ruling grade from Item 4 into the Davis equation and calculate the tractive effort requirement.
- Convert the tractive effort requirement into a tractive dispatch level (rail horsepower per gross ton) for each candidate electric locomotive by use of the indicated equation.

6. Selection of Electric Locomotive Type and Dispatch Level:

*a. - Select the electric locomotive type for which the traction dispatch requirement just exceeds the diesel dispatch level (Item 3). Record the locomotive type selected and the corresponding dominant tractive dispatch level.

- Calculate the dispatch level in the other (non-dominant) direction for the selected electric locomotive type (perform the calculation in the unused column of Item 5 of the Worksheet) and record the result in the appropriate direction in Item 6.

*Use only Item 6B when calculating helper dispatch level.

FIGURE 4-12. WORKSHEET NO. 5 - ELECTRIC LOCOMOTIVE SELECTION AND DISPATCH LEVEL (CONT'D)

INSTRUCTIONS (CONT'D)

6. Selection of Electric Locomotive Type and Dispatch Level: (Cont'd)

NOTE: If none of the electric dispatch levels in the dominant direction exceed the diesel dispatch level, select electric locomotive Type 3 and use the diesel dispatch levels, Item 3, for the electric dispatch levels.

*b. Road Locomotives:

- Copy the diesel dispatch level from Item 2.
- Select the electric locomotive type that corresponds to the prevalent diesel locomotive type (Item 2), using the following table and record:

| Electric Type | Diesel Type |
|---|---|
| 1 | 1, 2, 7 |
| 2 | 4 |
| 3 | 3, 5, 6 |

- Copy the power to tractive ratio from Item 5 for the electric type selected.
- Copy the diesel power to tractive effort ratio from Item 1.
- Calculate the electric dispatch level in each direction using the equation indicated.

Helper Locomotives:

- Obtain the diesel helper dispatch level from the Railroad Questionnaire.
- Use the electric locomotive type selected for the road locomotive (Item 6 of the corresponding worksheet No. 5).
- Copy the power to tractive effort ratio from Item 5 for the electric type.
- Obtain the diesel power to tractive effort ratio from the Table of Diesel Locomotive Design Characteristics, Table 2-5.
- Calculate the electric dispatch level using the equation indicated.

FIGURE 4-12. WORKSHEET NO. 5 - ELECTRIC LOCOMOTIVE SELECTION AND DISPATCH LEVEL (CONT'D)

1. When the diesel dispatch level is greater than the tractive dispatch requirement of any candidate electric type, the electric with the largest power to tractive effort rating is selected and is dispatched at the diesel dispatch level. It is power limited on the sector;

2. When the traction dispatch level of the diesel is calculated to be greater than the stated dispatch level from the questionnaire, the calculation is discarded as being invalid (for such reasons as "doubling" up in the hill) and the electric type is selected with a power to tractive effort rating just greater than the diesel and is dispatched with the same tractive capability.

The selection of electric locomotive type and dispatch level for the sample sector is shown in Figures 4-12, 4-13, and 4-14. Three worksheets are required for the sample sector because there are two types of service, one of which requires determination of dispatch level of a helper locomotive in addition to the road locomotive.

Helper Locomotive Dispatch Level

If a helper is used on a sector for one or more types of service, it is presumed to be the same type as that of the road locomotive it assists. Electric helpers are dispatched with same tractive effort capability as the diesel now in service.*

*Some reduction in size of the electric helper fleet could be achieved if the tractive capability of the electric road locomotives exceeds that of the diesels they replace. This was not considered since the electric helpers most probably would be required to assist dieselized trains that would continue to operate on the sector.

Revision Date: ______

Railroad: URail & Company

From - To: UTown Yard to UCity, USA

Type of Service: Expedited

1. DOMINANT DIRECTION from Worksheet No. 4 (direction requiring greatest Diesel Horsepower): FWD ___ REV _x_.

2. Prevalent Diesel Loco Type # __4__ Diesel Rail HP/lb $TE_A$ __.039__.

3. Diesel Rail HP Dispatch Levels: Forward 2.64 Reverse 2.55.

*4. For the dominant direction, calculate the Davis Equation Dispatch Level (DEDL):

DEDL = (4 + 20(Ruling Grade] x Prev. Diesel Rail HP/lb $TE_A$) = (4 + 20(1.)) x .039 = .936.

*5. Calculate possible dispatch levels, by direction:

**FORWARD DIRECTION**

4 + 20(Ruling Grade) = 4 + 20(___) = ___

| Elec. Loc. | lb $TE_A$ per GT | x | Elec. Rail HP/lb $TE_A$ | = | Elec. Rail $HP_A$/GT |
|---|---|---|---|---|---|
| 1 | ______ | x | 0.038 | = | ______ |
| 2 | ______ | x | 0.041 | = | ______ |
| 3 | ______ | x | 0.062 | = | ______ |

**REVERSE DIRECTION**

4 + 20(Ruling Grade) = 4 + 20(1.0) = 24

| Elec. Loc. | lb $TE_A$ per GT | x | Elec. Rail HP/lb $TE_A$ | = | Elec. Rail HP /GT |
|---|---|---|---|---|---|
| 1 | 24 | x | 0.038 | = | .912 |
| 2 | 24 | x | 0.041 | = | .984 |
| 3 | 24 | x | 0.062 | = | 1.488 |

*6a. Select Locomotive Type and Dispatch Level: Type Locomotive __3__.

Fwd Elec. Loco. Disp. Level __2.64__ Rev Elec. Loco. Disp. Level __2.55__.

6b. Select Electric Locomotive Type and Dispatch Level: Type Locomotive ______.

Dispatch Level = (Diesel Dispatch Level) x (Electric RHP/lb. of T.E.) - (Diesel RHP/lb. of T.E.).

Fwd Dispatch Level = (___) x (___)/(___) Rev Dispatch Level = (___) x (___)/(___)

= ______ = ______

FIGURE 4-13. WORKSHEET NO. 5 - ELECTRIC LOCOMOTIVE SELECTION AND DISPATCH LEVEL

Revision Date: ________

Railroad: URail & Company

From - To: UTown Yard to UCity, USA

Type of Service: Helper

1. DOMINANT DIRECTION from Worksheet No. 4 (direction requiring greatest Diesel Horsepower): FWD ___ REV _x_.

2. Prevalent Diesel Loco Type # __4__ Diesel Rail HP/lb $TE_A$ __0.39__.

3. Diesel Rail HP Dispatch Levels: Forward _____ Reverse 1.02.

*4. For the dominant direction, calculate the Davis Equation Dispatch Level (DEDL):

DEDL = (4 + 20[Ruling Grade] x Prev. Diesel Rail HP/lb $TE_A$) = (4 + 20(1.)) x ____ = ____.

*5. Calculate possible dispatch levels, by direction:

**FORWARD DIRECTION**

4 + 20(Ruling Grade) = 4 + 20(___) = ___

| Elec. Loc. | lb $TE_A$ per GT | x | Elec. Rail HP/lb $TE_A$ | = | Elec. Rail $HP_A$/GT |
|---|---|---|---|---|---|
| 1 | ________ | x | 0.038 | = | ________ |
| 2 | ________ | x | 0.041 | = | ________ |
| 3 | ________ | x | 0.062 | = | ________ |

**REVERSE DIRECTION**

4 + 20(Ruling Grade) = 4 + 20(1.0) = 24

| Elec. Loc. | lb $TE_A$ per GT | x | Elec. Rail HP/lb $TE_A$ | = | Elec. Rail HP /GT |
|---|---|---|---|---|---|
| 1 | ________ | x | 0.038 | = | ________ |
| 2 | ________ | x | 0.041 | = | ________ |
| 3 | ________ | x | 0.062 | = | ________ |

*6a. Select Locomotive Type and Dispatch Level: Type Locomotive __3__.

Fwd Elec. Loco. Disp. Level ________ Rev Elec. Loco. Disp. Level ________.

6b. Select Electric Locomotive Type and Dispatch Level: Type Locomotive __3__.

Dispatch Level = (Diesel Dispatch Level) x (Electric RHP/lb. of T.E.) - (Diesel RHP/lb. of T.E.).

Fwd Dispatch Level = (___) x (___)/(___) = _____

Rev Dispatch Level = (1.02) x (.062)/(.039) = 1.62

FIGURE 4-14. WORKSHEET NO. 5 - ELECTRIC LOCOMOTIVE SELECTION AND DISPATCH LEVEL

Figure 4-14 illustrates the helper dispatch calculation for reverse, normal traffic on the sample sector.

Directional Power Requirement

The electric power requirement is calculated on Worksheet No. 6 (Figure 4-15) using a procedure similar to that used for calculating diesel power requirement but with the following differences:

1. Dispatch level is obtained from Worksheet No. 5 (Figures 4-12, 13 and 14), item 6a or 6b;

2. Utilization is assumed to be .75, reflecting the need for less repair and routine maintenance;

3. Turnaround time is assumed to be 50 percent less than for diesel locomotives because no time is required for refueling and because less frequent inspection is required.

### 4.2.6 Energy Requirement

The energy required to move the traffic over the operating distance consists of two parts, the direct traction energy and the lift energy. The direct traction energy is that energy required to overcome the losses due to friction and aerodynamic drag and that required to provide the acceleration demands. The Energy Consumption Factor (ECF) used for computing direct traction energy is also a function of the average terrain resistance (i.e., a composite of average grade and grade equivalent curvature) between the starting and ending locations. It is assumed that there is no elevation change between end points; the ECP does make appropriate compensation for hills and valleys within the average grade calculation.

Railroad: URail & Company    From - To: UTown Yard to UCity, USA

| TOS | Dir: | Traffic Density MGT/YR | x | Dispatch Level Rail HP/GT | x | Sched. Time Hrs. | + | Tranand Time Hrs. | x | Year / 8760 hrs. | ÷ | Utiliz. Factor | = | Directional Rail HP Required |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK | Fwd | ______ | x | ______ | x | (____ | + | ____) | x | 1/8760 | ÷ | ____ | = | ______ |
| | Rev | ______ | x | ______ | x | (____ | + | ____) | x | 1/8760 | ÷ | ____ | = | ______ |
| NORM | Fwd | $9.79 \times 10^6$ | x | 1.53 | x | (21.75 | + | .75) | x | 1/8760 | ÷ | .752 | = | 51160 |
| Helper | | $7.93 \times 10^6$ | x | 1.62 | x | 1.365 | + | 0 | x | 1/8760 | ÷ | .752 | = | 2660 |
| | Rev | $7.93 \times 10^6$ | x | 1.62 | x | (16.25 | + | .75) | x | 1/8760 | ÷ | .752 | = | 33141 |
| EXPD | Fwd | $6.81 \times 10^6$ | x | 2.64 | x | (13.17 | + | .75) | x | 1/8760 | ÷ | .752 | = | 37977 |
| | Rev | $7.87 \times 10^6$ | x | 2.55 | x | (13.42 | + | .75) | x | 1/8760 | ÷ | .752 | = | 43153 |
| PASS | Fwd | ______ | x | ______ | x | (____ | + | ____) | x | 1/8760 | ÷ | ____ | = | ______ |
| | Rev | ______ | x | ______ | x | (____ | + | ____) | x | 1/8760 | ÷ | ____ | = | ______ |

INSTRUCTIONS

1. Traffic Density (Gross Tons Per Year). Obtain from the Traffic Forecast Summary Sheet, or W.S. No. 4 the base year traffic densities, by Type of Service in each Direction.

2. Dispatch Level (Rail HP/GT). Obtain from Worksheet No. 5, Item 6a or 6b, by TOS and Direction.

Continued

FIGURE 4-15. WORKSHEET NO. 6 - ELECTRIC LOCOMOTIVE DIRECTIONAL POWER REQUIREMENT

INSTRUCTIONS (CONT'D)

3. Schedule Time (Hours).

   - For mainline locomotives, copy from Railroad Questionnaire by TOS and Direction.
   - For helper locomotives assisting in one direction; multiply length of the grade, obtained from Railroad Questionnaire x 0.075.
   - For helper locomotives assisting in both directions: multiply the length of the grade, as obtained from the Railroad Questionnaire by 0.10.

4. Turnaround Time (Hours).

   - For mainline locomotives obtain operating route-miles from W.S. No. 1 and compute:

     Turnaround Time = .0015 x (operating route miles) (Based on the assumption that an electric locomotive travels 1,000 miles between stops of 1.5-hour duration for inspection and sanding.) Or use half the diesel turnaround time from W.S. No. 4.

   - For helper locomotives enter turnaround time = 0.

5. Utilization (Factor). This factor accounts for the fraction of a year that the locomotive is on the road or at an end point for inspection and sanding. Non-utilized times include maintenance and repair time, time in storage because of seasonal lulls in traffic, and waiting time for schedule considerations. Use the same factor for all electric locomotives on all route sectors.

6. Directional Rail Horsepower Required. The result is the rail horsepower required to move the annual gross tonnage in one direction where the return trip time of the locomotives is ignored. Enter the forward and reverse results in records 31 and 32 of the LDF form, respectively.

FIGURE 4-15. WORKSHEET NO. 6 - ELECTRIC LOCOMOTIVE DIRECTIONAL POWER REQUIREMENT (CONT'D)

Lift energy is the incremental energy expended or recovered due to the difference in elevation between the origin and destination.

Lift Energy Calculation

Lift energy was calculated first for convenience, using Worksheet No. 7 (Figure 4-16). If the starting location was higher than the ending location, lift energy was recoverd and carried a negative sign because the train was travelling downhill. Lift energy was not calculated for helper locomotive operations; the energy expended in climbing the hill (positive sign) is accounted for under the direction traction energy calculation.

One caution is necessary in calculating lift energy. If the average downhill grade exceeds approximately 1/3 percent, braking is required to limit train speed[29]. Thus the recoverable potential energy is limited unless the braking is accomplished by regenerative braking.*

The test is straightfoward.

$$\frac{\frac{\text{Differential Elevation in Feet}}{5280}}{\text{Route Miles of Downgrade}} \times 100 = \text{Equivalent Angle in percent}$$

Setting the Equivalent Angle = 0.33 percent, and solving: Limiting Differential Elevation (feet) = 17.42 X Route-Miles of Downgrade.

*While the electric locomotive can be readily equipped to provide regenerative braking, only friction and dynamic braking were assumed in this study.

Revision Date: ________

Railroad: URail & Company From - To: UTown Yard to UCity, USA

Elevation of Ending Location: 1880 ft.

Minus Elevation of Starting Location: -2491 ft.

Forward Algebraic Differential Elevation: -611 ft.

| TOS | Dir: | 1 Convert Factor | x | 2 Traffic Density MGT/YR | x | 3 Diff. Elevn Ft. | + | 4 Lift Energy MWH | ÷ | 5 Eff. Factor | | 6 Net Lift Energy MWH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK | Fwd | $.753 \times 10^{-6}$ | x | | x | | = | | ÷ | 0.8 | = | |
| | Rev | $.753 \times 10^{-6}$ | x | | x | | = | | ÷ | 0.8 | = | |
| NORM | Fwd | $.753 \times 10^{-6}$ | x | $9.79 \times 10^{6}$ | x | -611 | = | -4504 | ÷ | 0.8 | = | -5630 |
| | Rev | $.753 \times 10^{-6}$ | x | $7.93 \times 10^{6}$ | x | +611 | = | +3649 | ÷ | 0.8 | = | +4561 |
| EXPD | Fwd | $.753 \times 10^{-6}$ | x | $6.81 \times 10^{6}$ | x | -611 | = | -3133 | ÷ | 0.8 | = | -3916 |
| | Rev | $.753 \times 10^{-6}$ | x | $7.87 \times 10^{6}$ | x | +611 | = | +3621 | ÷ | 0.8 | = | +4526 |
| PASS | Fwd | $.753 \times 10^{-6}$ | x | | x | | = | | ÷ | 0.8 | = | |
| | Rev | $.753 \times 10^{-6}$ | x | | x | | = | | ÷ | 0.8 | = | |

INSTRUCTIONS

1. Conversion Factor. This factor converts ton-feet of potential energy into the electrical equivalent in megawatt-hours. Factor = $0.753 \times 10^{-6}$.

2. Traffic Density (Gross Tons per Year). Obtain from the Traffic Forecast Summary Sheet, or W.S. No. 6, by type of service in each direction.

FIGURE 4-16. WORKSHEET NO. 7 - LIFT ENERGY CALCULATION

INSTRUCTIONS (CONT'D)

3. Differential Elevation (Feet). Obtain location elevations from atlases, road maps, etc. Calculate Differential Elevation at top of sheet, being careful to maintain the algebraic sign. Enter with calculated sign for forward direction calculations. Change sign and enter for reverse direction calculations. Maintain the correct sign at all times.

4. Lift Energy (MWH). This is the change in energy caused by moving the traffic through the change in elevation. The energy is negative (recovered) if the traffic moves downhill, and is positive (consumed) if the traffic moves uphill. Maintain the sign.

5. Efficiency Factor. This factor accounts for conversion losses between the substation metering point and the traction motor output, estimated to be 20 percent.

6. Net Lift Energy. Lift energy adjusted for efficiency. Enter in Column 6, Worksheet No. 9 (Figure 4-18).

FIGURE 4-16. WORKSHEET NO. 7 - LIFT ENERGY CALCULATION (CONT'D)

If the differential elevation exceeds the limiting value, the limiting value is used to calculate (negative) lift energy recovered by traveling downhill. However, the actual differential elevation is used to calculate (positive) energy expended climbing the hill.

The braking test was applied in this study using route miles from origin to destination since the miles of downgrade was not readily available. Thus, only short routes with large differential elevations were limited in the amount of lift energy credit. On some of the longest route segments, especially those in mountainous terrain, this procedure may underestimate both the electric energy and diesel fuel consumption.

The factor for converting potential energy into its electrical equivalent indicated on Worksheet No. 7 is obtained as follows:

1 horsepower = 746 watts = 55 ft lbs/sec, or
550 lb-ft = 746 watt-seconds

Since the potential energy is in <u>ton</u>-feet, and electrical energy is in megawatt-hours, the units are converted as follows:

$$550 \text{ lb} \times \frac{\text{ton}}{2000 \text{ lb}} \times \text{ft} = 746 \text{ watts} \times \text{sec} \times \frac{\text{hr}}{3600 \text{ sec}} \times 10^{-6}$$

$$1 \text{ ton-ft} = \frac{746 \times 2000}{550 \times 3600} \times 10^{-6} \text{megawatt-hrs}$$

$$1 \text{ ton-ft} = .753 \times 10^{-6} \text{ megawatt-hrs}$$

## Direct Traction Energy Calculation

Traction energy was calculated using Worksheet No. 8 (Figure 4-17) and No. 9 (Figure 4-18) and the associated Energy Conversion Calculator graph of Figure 4-19[21]. The calculator presents an Energy Consumption Factor (ECF) in watt-hours per ton-mile as a function of average train speed and average grade. Average train speed was obtained on Worksheet No. 8 by dividing the route miles from Worksheet No. 1 by the running time obtained from the questionnaire, item 6. If the average grade was categorized, the center of the indicated range was used; otherwise, the calculated average grade was used. The ECF is read on the left scale at the intersection of the average speed (bottom scale) and the average grade (right scale).

For helper locomotive operations, the traction energy was calculated in the same manner, except that the ruling grade was used instead of the average grade, and the helper district operating route-miles (from the Questionnaire) was used instead of the total operating route-miles. The average speed in the helper district was assumed to be 10 MPH for normal service and 20 MPH for expedited servce.

## Total Electric Energy Consumption

Total electric energy consumption is the sum of traction energy and lift energy, expressed on Worksheet No. 9 in megawatt-hours.

It must be noted that electric energy consumption by TOS and direction cannot be negative. That is, even on short, steep route segments, there will always be some energy consumption. The energy generated by the train coasting downhill cannot now be returned to the power grid, and the locomotive will use some energy to run auxilliary systems.

Revision Date: ________

Railroad: URail & Company From - To: UTown Yard to UCity, USA

| NV | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| TOS | DIR | SCHED TIME | ROUTE MI/SCHED T | = SPD | AVG. GRADE | ECF |
| BULK | F | | / | = | | |
| | R | | / | = | | |
| NORM | F | 21.75 | 503.7 / 21.75 | = 23 | M | 19.5 |
| | R | 16.25 | 503.7 / 16.25 | = 31 | M | 21 |
| EXPD | F | 13.17 | 503.7 / 13.17 | = 38 | M | 22.5 |
| | R | 13.42 | 503.7 / 13.42 | = 38 | M | 22.5 |
| PASS | F | | / | = | | |
| | R | | / | = | | |
| NORM HELP | R | | 18.2 / | = 10 | 1.8 | 44.5 |

FIGURE 4-17. WORKSHEET NO. 8 - ELECTRIC ENERGY CONSUMPTION FACTOR

Railroad: URail & Company    From - To: UTown Yard to UCity, USA

NV

| TOS | Dir: | 1 Traffic Density MGT/YR | x | 2 Route Miles | x | 3 Energy Consumption Factor | x | 4 Eff. Factor | = | 5 Traction Energy MWH | x | 6 Lift Energy MWH | = | 7 Total Energy MWH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BULK | Fwd | | x | | x | $10^{-6}$ | x | 1.25 | x | | x | | = | |
| | Rev | | x | | x | $10^{-6}$ | x | 1.25 | x | | x | | = | |
| NORM | Fwd | $9.79 \times 10^{-6}$ | x | 503.7 | x | $19.5 \times 10^{-6}$ | x | 1.25 | x | 120,199 | x | -5630 | = | 114,569 |
| | Rev | $7.93 \times 10^{-6}$ | x | 503.7 | x | $21 \times 10^{-6}$ | x | 1.25 | x | 104,851 | x | +4561 | = | 109,412 |
| | Helper Rev | $7.93 \times 10^{-6}$ | x | 18.2 | x | $44.5 \times 10^{-6}$ | x | 1.25 | x | 8,028 | x | 0 | = | 8,028 |
| EXPD | Fwd | $6.81 \times 10^{-6}$ | x | 503.7 | x | $22.5 \times 10^{-6}$ | x | 1.25 | x | 96,474 | x | -3916 | = | 92,558 |
| | Rev | $7.87 \times 10^{-6}$ | x | 503.7 | x | $22.5 \times 10^{-6}$ | x | 1.25 | x | 111,491 | x | +4526 | = | 116,017 |
| PASS | Fwd | | x | | x | $\times 10^{-6}$ | x | 1.25 | x | | x | | = | |
| | Rev | $^{-6}$ | x | | x | $\times 10^{-6}$ | x | 1.25 | x | | x | | = | |
| | | | | | | | | TOTAL | | | | | | |

INSTRUCTIONS

1. Traffic Density (MGT/YR). Obtain from lift energy calculation, W.S. No. 7, by TOS and direction.

2. Route Miles (Miles). Obtain from LDF, Record 12, or from W.S. No. 7.

3. Energy Consumption Factor. Obtain from Chart as follows.

4. Schedule Time (Hrs). Obtain from LDF, Record 7, by TOS and direction.

5. Average Speed (MPH). Divide Route Miles by Schedule Time, by TOS and direction.

FIGURE 4-18. WORKSHEET NO. 9 - ELECTRIC ENERGY CALCULATION

INSTRUCTIONS (CONT'D)

6. Average Grade (%). Obtain from Worksheet No. 1.

7. Energy Consumption Factor (WH/TM). Calculate on Worksheet No. 8. Use energy consumption calculator for each TOS, and direction:

   a. Locate average speed on lower x-axis.

   b. From the average speed, move upward until the applicable value of average grade is reached, reading the curves from the calibration values at the right. Use grade in % if available, otherwise use the middle value for the grade class.

   c. From the intersection of average speed and grade curves, move horizontally to the left and read the Energy Consumption Factor. Enter in W.S. No. 8 and Column 3. (Note: $10^{-6}$ factor converts watt-hours to megawatt-hours (MWH).

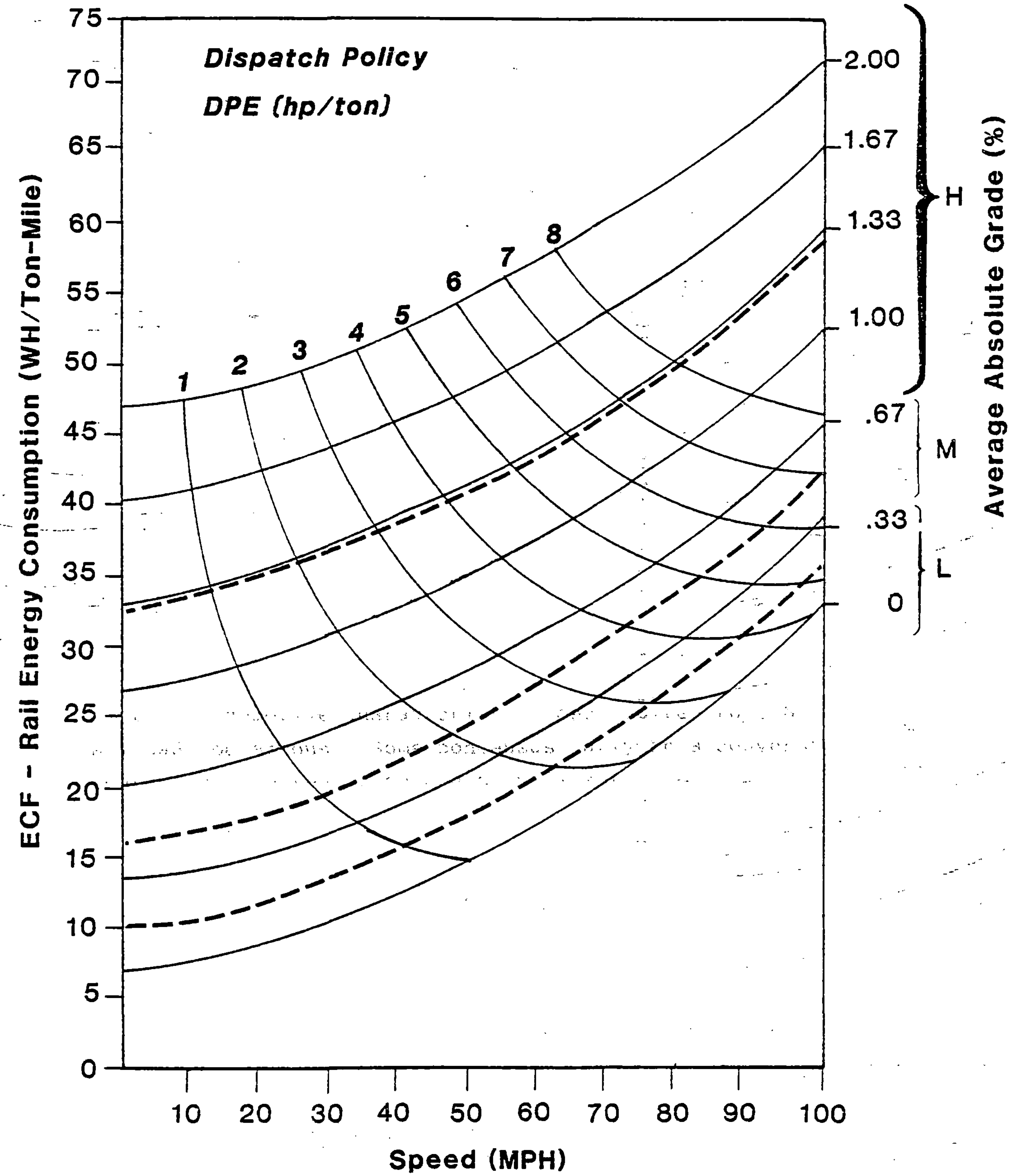
8. Efficiency Factor. This factor accounts for conversion losses, estimated to be 20 percent.

9. Fractin Energy (MWH). This value is the traction energy required.

10. Lift Energy (MWH). Obtain from Worksheet No. 7, Column 6, by TOS and direction.

11. Total Energy (MWH). This result is the total electric energy required. It is the traction energy adjusted for energy added or subtracted because of the difference in elevation between origin and destination.

FIGURE 4-18. WORKSHEET NO. 9 - ELECTRIC ENERGY CALCULATION (CONT'D)




11-009-82

FIGURE 4-19. ENERGY CONSUMPTION CALCULATOR

Enter data into Records 36 and 37 of the LDF.

Diesel Fuel Saved

The diesel fuel saved by use of electric traction energy is calculated on Worksheet No. 10 as the BTU equivalent of Number 2 diesel fuel to the megawatt hours of electric energy. The fuel conversion factor for the network study was 14 KWH required at the metering point of an electric locomotive for each gallon of diesel fuel consumed by a diesel locomotive.*

Enter into Records 38 and 39 of the LDF.

### 4.2.7 Completed Link Data Form for Sample Segment

The data prepared as described above in Section 4.2 are entered on a Link Data File Form as an intermediate step in entering the input data into the computer. Two forms, as shown in Figures 4-21 and 4-22 are necessary for the sample section because there is a helper locomotive. The procedure for completing such forms is described in Volume II.

*Data supplied by Southern Railway that was used in their electrification studies.

Railroad: URail & Company From - To: UTown Yard to UCity, USA

NV

| | | 1 | | 2 | | 3 |
|---|---|---|---|---|---|---|
| TOS | Dir: | Electric Energy MWH | x | Fuel Conversion Factor | = | Diesel Fuel Consumption Mil Gallons |
| BULK | Fwd | | x | $7.14 \times 10^{-5}$ | = | |
| | Rev | | x | $7.14 \times 10^{-5}$ | = | |
| NORM | Fwd | 114,569 | x | $7.14 \times 10^{-5}$ | = | 8.180 |
| | Rev | 109,412 | x | $7.14 \times 10^{-5}$ | = | 7.812 |
| | Helper Rev | 8,028 | x | $7.14 \times 10^{-5}$ | = | 0.573 |
| EXPD | Fwd | 92,558 | x | $7.14 \times 10^{-5}$ | = | 6.609 |
| | Rev | 116,017 | x | $7.14 \times 10^{-5}$ | = | 8.284 |
| PASS | Fwd | | x | $7.14 \times 10^{-5}$ | = | |
| | Rev | | x | $7.14 \times 10^{-5}$ | = | |
| | | | | TOTAL | | Mil Gal |

INSTRUCTIONS

1. Electric Energy (MWH). Obtain from Worksheet No. 9, Column 7, by TOS and direction.
2. Fuel Conversion Factor (Million Gallons/MWH). Conversion factor.
3. Diesel Fuel Consumption (Million Gallons). Result is diesel fuel equivalent to the electrical energy calculated on Worksheet No. 9.

FIGURE 4-20. WORKSHEET NO. 10 - DIESEL FUEL SAVED

Railroad Name: URAIL    Seq. Number: 1    Link File: UR9997778

From-To: UTOWN YARD USA to UCITY USA    Revision NR/Date: Orig. 9/22/82

| DESCRIPTION | | REV | DATA BY TYPE OF SERVICE OR NUMBER OF TRACKS*: BULK OR 1 TRACK | NORMAL OR 2 TRACKS | EXPEDITED OR 3 TRACKS | PASSENGER OR 4 TRACKS |
|---|---|---|---|---|---|---|
| 1. Link File Identification | | | UR9997778 | URAIL: UTO | WN YARD USA | TO UCITY |
| 2. | | | USA | | | |
| 3. Traffic Density, MGT/Yr (TOS) | Fwd | | 0 | 9.79 | 6.81 | 0 |
| 4. | Rev | | 0 | 7.93 | 7.87 | 0 |
| 5. Traffic Growth, % (TOS) | Fwd | | 0 | 1.23 | 1.93 | 0 |
| 6. | Rev | | 0 | -0.33 | 0.95 | 0 |
| 7. Schedule Time, Hrs (TOS) | Fwd | | 0 | 21.75 | 13.75 | 0 |
| 8. | Rev | | 0 | 16.25 | 13.42 | 0 |
| 9. Diesel Turnaround Time, Hrs (TOS) | | | 0 | 1.5 | 1.5 | 0 |
| 10. Catenary Service Class, Pass or Frt | | | 2 | ---------- | ---------- | ---------- |
| 11. Diesel Loco Life, Yrs | | | 18 | ---------- | ---------- | ---------- |
| 12. Operating Route Miles, Mi | | | 503.7 | ---------- | ---------- | ---------- |
| 13. Ruling Grade, % | Fwd | | 1.0 | ---------- | ---------- | ---------- |
| 14. | Rev | | 1.8 | ---------- | ---------- | ---------- |
| 15. Last Year of Traffic Growth Projection, Yr | | | 1990 | ---------- | ---------- | ---------- |
| 16. Sidings & Yards Track, Mi | | | 202.4 | ---------- | ---------- | ---------- |
| 17. Main Line Track Wired, Route Miles (NOT) | Tangent | | 365.49 | 87.84 | 0 | 0 |
| 18. | Med Crv | | 40.61 | 9.76 | 0 | 0 |
| 19. | Hvy Crv | | 0 | 0 | 0 | 0 |
| 20. Substations, Number (NOT) | | | 5 | 2 | 0 | 0 |

*Designation of a four-block record as having dependence on type of service or number of tracks is indicated in this record description by (TOS) and (NOT) respectively. Other records are dependent on neither.

FIGURE 4-21a. LINK DATA FORM, SHEET NO. 1

Railroad Name: URAIL    Seq. Number: 1    Link File: UR9997778

From-To: UTOWN YARD USA to UCITY USA    Revision NR/Date: Orig. 9/22/82

| | DESCRIPTION | REV | DATA BY TYPE OF SERVICE OR NUMBER OF TRACKS: BULK OR 1 TRACK | NORMAL OR 2 TRACKS | EXPEDITED OR 3 TRACKS | PASSENGER OR 4 TRACKS |
|---|---|---|---|---|---|---|
| 21. | Tunnel Reconstruction, Ft (NOT) | | 10500 | 0 | 0 | 0 |
| 22. | Bridge Reconstruction Number (NOT) | | 59 | | | |
| 23. | Utility Connection, Mi | | 45 | ---------- | ---------- | ---------- |
| 24. | Train-Activated Grade Xng Signals, Number | | 29 | ---------- | ---------- | ---------- |
| 25. | Diesel Locos: Rail HP Pur/Fract Sold | | 407000 | 0.00 | ---------- | ---------- |
| 26. | Electric Loco Pwr, Hp (TOS) | Fwd | 0 | 51143 | 37977 | 0 |
| 27. | | Rev | 0 | 33141 | 43153 | 0 |
| 28. | Electric Loco Dispatch Level, Rail HP/GT (TOS) | Fwd | 0 | 1.53 | 2.64 | 0 |
| 29. | | Rev | 0 | 1.62 | 2.55 | 0 |
| 30. | Electric Loco Type, (TOS) | | 0 | 3 | 3 | 0 |
| 31. | Diesel Loco Pwr, HP (TOS) | Fwd | 0 | 55198 | 41803 | 0 |
| 32. | | Rev | 0 | 36142 | 47458 | 0 |
| 33. | Diesel Loco Dispatch Level Rail HP/GT (TOS) | Fwd | 0 | 1.53 | 2.64 | 0 |
| 34. | | Rev | 0 | 1.62 | 2.55 | 0 |
| 35. | Diesel Loco Type, (TOS) | | 0 | 4 | 4 | 0 |
| 36. | Electric Energy Used, MWH/Yr (TOS) | Fwd | 0 | 114569 | 92558 | 0 |
| 37. | | Rev | 0 | 109412 | 116017 | 0 |
| 38. | Diesel Fuel Saved, Mil Gal (TOS) | Fwd | 0 | 8.180 | 6.609 | 0 |
| 39. | | Rev | 0 | 7.812 | 8.284 | 0 |

FIGURE 4-21b. LINK DATA FORM, SHEET NO. 2

Railroad Name: URAIL    Seq. Number: 1    Link File: UR99977781

From-To: UTOWN YARD USA to UCITY USA (Helper)    Revision NR/Date: Orig. 9/22/82

| | DESCRIPTION | REV | DATA BY TYPE OF SERVICE OR NUMBER OF TRACKS* | | | |
|---|---|---|---|---|---|---|
| | | | BULK OR 1 TRACK | NORMAL OR 2 TRACKS | EXPEDITED OR 3 TRACKS | PASSENGER OR 4 TRACKS |
| 1. | Link File | | UR99977781 | URAIL: UTO | WN YARD USA | TO UCITY |
| 2. | | | USA | | | |
| 3. | Traffic Density, MGT/Yr (TOS) | Fwd | 0 | 9.79 | 6.81 | 0 |
| 4. | | Rev | 0 | 7.93 | 7.87 | 0 |
| 5. | Traffic Growth, % (TOS) | Fwd | 0 | 1.23 | 1.93 | 0 |
| 6. | | Rev | 0 | -0.33 | 0.95 | 0 |
| 7. | Schedule Time, Hrs (TOS) | Fwd | 0 | 0 | 0 | 0 |
| 8. | | Rev | 0 | 1.82 | 0 | 0 |
| 9. | Diesel Turnaround Time, Hrs (TOS) | | 0 | 0 | 0 | 0 |
| 10. | Catenary Service Class, Pass or Frt | | 2 | ---------- | ---------- | ---------- |
| 11. | Diesel Loco Life, Yrs | | 18 | ---------- | ---------- | ---------- |
| 12. | Operating Route Miles, Mi | | 18.2 | ---------- | ---------- | ---------- |
| 13. | Ruling Grade, % | Fwd | 1.0 | ---------- | ---------- | ---------- |
| 14. | | Rev | 1.8 | ---------- | ---------- | ---------- |
| 15. | Last Year of Traffic Growth Projection, Yr | | 1990 | ---------- | ---------- | ---------- |
| 16. | Sidings & Yards Track, Mi | | | ---------- | ---------- | ---------- |
| 17. | Main Line Track Wired, Route Miles (NOT) | Tangent | | | | |
| 18. | | Med Crv | | | | |
| 19. | | Hvy Crv | | | | |
| 20. | Substations, Number (NOT) | | | | | |

*Designation of a four-block record as having dependence on type of service or number of tracks is indicated in this record description by (TOS) and (NOT) respectively. Other records are dependent on neither.

FIGURE 4-22a. LINK DATA FORM, SHEET NO. 1

Railroad Name: URAIL    Seq. Number: 1    Link File: UR99977781

From-To: UTOWN YARD USA TO UCITY USA (Helper)    Revision NR/Date: Orig. 9/22/82

| | | | DATA BY TYPE OF SERVICE OR NUMBER OF TRACKS* | | | |
|---|---|---|---|---|---|---|
| | | REV | BULK OR 1 TRACK | NORMAL OR 2 TRACKS | EXPEDITED OR 3 TRACKS | PASSENGER OR 4 TRACKS |
| 21. | Tunnel Reconstruction, Ft (NOT) | | | | | |
| 22. | Bridge Reconstruction Number (NOT) | | | | | |
| 23. | Utility Connection, Mi | | | ---------- | ---------- | ---------- |
| 24. | Train-Activated Grade Xng Signals, Number | | | ---------- | ---------- | ---------- |
| 25. | Diesel Locos: Rail HP Pur/Fract Sold | | 407000 | 0.00 | ---------- | ---------- |
| 26. | Electric Loco Pwr, HP (TOS) | Fwd | | 0 | | |
| 27. | | Rev | | 2661 | | |
| 28. | Electric Loco Dispatch Level, Rail HP/GT (TOS) | Fwd | | 0 | | |
| 29. | | Rev | | 1.62 | | |
| 30. | Electric Loco Type, (TOS) | | | 3 | | |
| 31. | Diesel Loco Pwr, HP (TOS) | Fwd | | 0 | | |
| 32. | | Rev | | 1750 | | |
| 33. | Diesel Loco Dispatch Level, Rail HP/GT, (TOS) | Fwd | | 0 | | |
| 34. | | Rev | | 1.02 | | |
| 35. | Diesel Loco Type, (TOS) | | | 4 | | |
| 36. | Electric Energy Used, MWH/Yr (TOS) | Fwd | | 0 | | |
| 37. | | Rev | | 8028 | | |
| 38. | Diesel Fuel Saved, Mil Gal (TOS) | Fwd | | 0 | | |
| 39. | | Rev | | 0.573 | | |

FIGURE 4-22b. LINK DATA FORM, SHEET NO. 2

# 5. SUMMARY AND RECOMMENDATIONS

## 5.1 SUMMARY

An engineering model has been developed to simultaneously evaluate the economics of electrification of multiple route segments. The model is formulated to apply route-specific values of critical design and operating variables in order to obtain a comparison of the costs and benefits on each route. Such a model is useful in establishing which routes of a railroad should be electrified and in what sequence.

A procedure for readily obtaining the critical variables was developed that is sufficiently accurate for "first cut" comparison of the economics of individual route segments and for computation of network statistics. Data obtained from more thorough feasibility studies can also be used to improve the input data to the model.

Basic characteristics of the model are:

1. No tax or tax credits are considered;

2. An annual inflation factor is specified to account for general inflation; unit costs are specified for a currency base year; differential escalation of the price of diesel fuel and electric energy are specified;

3. Traffic density on a route segment is specified for a traffic base year by direction, type of service, and portion of the route segment traversed;

4. The predominant type of diesel and electric locomotives to be operated over a route segment are specified along with their directional power

requirements; the model establishes fleet size and accounts for differences in power requirements in the two directions;

5. Diesel locomotives released by electrification may be sold or transferred;

6. Items in a railroad's cash flows which would differ for diesel and electric operation are used to construct a differential cash flow over a specified study period; electrification is assumed to create no new business nor improve service to existing customers;

7. Fixed plant investment follows a prescribed design-construct-commission scenario; partial reinvestment in equipment is required during the study period; straight line depreciation is used to credit residual value at the end of the study period;

8. Equity rate of return is calculated in which initial investment is financed from railroad equity; as an option, a leveraged rate of return is calculated in which loans from a railroad electrification external fund and from the electric utility industry finance part of the initial investment.

The model has been used to analyze a hypothetical U.S. network that consists of 96 route segments totalling nearly 29,000 miles. Three of the major findings summarized in Section 2.1 are restated here:

1. For the base case analyzed, the rate of return for the network is 19 percent, a substantial increase over the previously reported results;

2. Variation in the rate of return between route segments can be large, depending on the combination of significant factors that exist;

3. A number of factors influence the rate of return, notably the traffic density, gradient, type of locomotives, and locomotive dispatch policy.

The best surrogate for identifying route segments with a high rate of return is the annual fuel consumption per route-mile on the route. However, there is still sufficient dependence on variables uncorrelated with fuel consumption (e.g., bridge clearance costs and signal and communication compatability) to require computation of the rate of return.

## 5.2 RECOMMENDATIONS

Sufficient study of the network was completed to conclude that the economic advantage of electrification over diesel operation is real and that, for many routes, it is substantial. One aspect that requires further study is the electric locomotive characteristics best suited to U.S. railroad operations. Some concensus early in a conversion program is expected to have a significant effect on the production and maintenance costs.

The next logical step would be for the individual railroads to initiate feasibility studies of routes that show a favorable rate of return. It may be desirable to make additional evaluations using the Railroad Electrification Assessment Model prior to initiating feasibility studies in order to better scope that work and to define the input data used in comparing individual route segments. One particular aspect that should be examined is the impact of the timing of conversion on the cash flow of the railroad.

Not all aspects of the model were fully utilized in analyzing the network. Addition of these refinements would not be expected to significantly change the national aspects of electrification. However, in order to make route comparisons on any railroad more precise, it is recommended that the input data preparation described in Section 4 be improved as follows:

1. Obtain a count of bridges and tunnels that do not have adequate clearance for the catenary and refine the cost algorithm to discriminate between clearance costs of 25KV and 50KV catenary;

2. Establish a more detailed estimate of the cost of diesel locomotive maintenance either by type of locomotive or by railroad to reflect the large variation observed in R-1 expense accounts;

3. Establish a more detailed estimate of the cost of electric locomotives consistent with the types and production levels at the time each route segment is electrified.

Model improvements cease when the user is satisfied with the accuracy of the results being produced. Three particular refinements are suggested which would improve the sensitivity of the model to route-specific variations.

1. The procedure for establishing the cost of achieving signal and communication system compatibility should be modified to account for route-specific input (e.g., number of track circuits, number of active grade crossings and type of communication system);

2. The procedure for establishing catenary voltage level should be decoupled from the Bureau of Census regions

and made a function of the civil reconstruction intensity of each route;

3. The cash flow should be established on a monthly basis to improve the accuracy of the discounted cash flows for high rate-of-returns.

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APPENDIX A

PARTICIPANTS IN THE ELECTRIFICATION COMMITTEE ACTIVITIES

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# APPENDIX B

# RECOMMENDATIONS OF THE PLANNING AND TECHNICAL AND OPERATIONS COMMITTEES INTEGRATED INTO THE MODEL/SUMMARY OF THE FINANCE AND ADMINISTRATION COMMITTEE RECOMMENDATIONS

## PLANNING/TECHNICAL AND OPERATIONS COMMITTEE RECOMMENDATIONS

During the period from December 1980 through September 1981 the planning committee was convened five times and the technical and operations committee three times to review model development and make recommendations regarding factors to be included. The following is a list of committee recommendations:

1. Make provision for route-specific traffic growth rates based on FRA projections that apply for the first ten years of the study period;

2. Use waybill data to estimate flow of traffic by commodity and direction over the network in the base year;

3. Omit the portion of traffic which would be hauled by diesels in electrified territory;

4. Make provision for specifying multiple operating sectors on each route segment;

5. Set electric locomotive maintenance at 60-65 percent of that of diesel locomotives.

## FINANCE AND ADMINISTRATION COMMITTEE RECOMMENDATIONS

While electrification might significantly reduce the costs of freight service for American railroads and therefore be economically attractive, we acknowledge that the significant expenditures associated with the initial construction of electrified track structure may be beyond the capital raising capability of many railroads.

We are interested in exploring various alternatives and forms of financing/ownership agreements to encourage railroads to electrify in the interests of energy conservation.

Financing Considerations

1. The railroads are not receptive to any financing/ownership alternatives which require the reflection of significant debt related to electrification on their balance sheet;

2. A funding corporation is considered for providing a large part of the necessary capital for the initial construction of an electrified track network and to assume the "risk of ownership" associated with the electrification system;

3. The funding corporation would anticipate capital recovery plus reasonable interest, through a rental (or other) charge based on KWH of electricity used by the railroads;

4. Tax incentives (ITS/accelerated depreciation, etc.) are considered to encourage participation by the railroads.

Financing Objectives

Structure a financing vehicle to accomplish the following (prioritized by significance):

1. Avoid reflecting any related debt (or capitalized lease obligations) on the balance sheet of participating railroads;

2. Structure the transaction to provide maximum tax advantages to the railroads as an incentive for participation;

3. Possibly provide for the transfer of ownership of the electrification system to the railroads after the funding corporation has recovered its investment and a reasonable return.

NOTE: The financing alternatives presented have not addressed the financing of locomotives or any changes in the existing signal and communications systems of railroads to be electrified which may require significant financing. Also not addressed are any political or legal implications of various alternatives. These issues are significant and must be addressed at an appropriate point in the evaluation of alternatives.

Preliminary Suggestions

Based on a preliminary review of alternative financing opportunities, it appears that options three or four, in Table B-1 warrant the most consideration and further evaluation.

Option Four anticipates the formation of a new private corporation, the stock of which would be issued to railroads participating in the electrification program for a nominal amount (one dollar). This corporation would construct (cause to have constructed) the desired electrification network and would utilize government guaranteed loan financing for 100 percent of the construction project plus any necessary operating funds.

TABLE B-1. FINANCING OPTIONS

| OPTIONS | OBJECTIVES | | | | COMMENTS |
|---|---|---|---|---|---|
| | TAX BENEFITS | | | | |
| | REQUIRES DEBT PRESENTATION | ITC | ACCEL. DEPR. | PROVIDE TRANSFER OWNERSHIP | |
| 1. Federal loan guarantees to individual RR for construction. | Y | Y | Y | Y | |
| 2. Ownership by FRA with rental charges to RR under: | | | | | ITC cannot be claimed on property owned (or used) by the Federal Government. |
| - Financing lease | Y | N | Y | Y | |
| - Operating lease | N | N | N | N | |
| 3. Formation of "joint venture" with nominal RR investment: | | | | | Must be structured to avoid constraints on government-owned property re: ITC |
| - Partnership structure with FRA as general partner 100 percent financing/loan guarantee and RR as limited partner. | N | Y | Y | Rateable* | |
| 4. Ownership through separate corporate entity 100 percent owned by participating railroads (nominal capital investment) with 100 percent loan guarantee by FRA for financing construction. Subsequent operating lease to individual railroads. | N | Y | N | Rateable* | Must be structured to avoid classification as a public utility to avoid limitations on ITC pass-through. |

*Assumes ownership structured to meet requirements of equity accounting.

The corporation would subsequently enter into operating lease agreements with individual railroads with a rental charge based on KWH. The operating lease would allow the [illegible] "pass-through" of ITC to the lessee and require that the lessee pay all costs related to maintaining and operating the electric network.

Operating rents received by the corporation would be used to meet interest and debt retirement obligations of the corporation. Assuming that operating rents received provide for repayment of all financing and operating costs of the corporation over a fixed period (say 20 years) which is shorter than the life of the system (say 40 years) the assets would be unencumbered upon retirement of the debt.

At the point in time that all property is free of debt, pieces of the network could possibly be transferred to the individual railroads for their equity investment.

Option Three could be structured similar to Option Four and accomplish similar objectives. Care and further analysis is required in determining the appropriate form of ownership. Option Three must be structured in a manner to avoid the exclusion of ITC on government owned property (IRC Reg. 1.48-i(j)). Option Four would appear to avoid this concern but raises an additional issue regarding possible classification as "Public Utility Property" which is subject to constraints on the flow-through of ITC.

All the preceding comments are based on a very preliminary and superficial analysis and are provided only in an effort to identify areas for possible direction for further analysis.

# APPENDIX C

## LIST OF ROUTE SEGMENTS COMPRISING THE HYPOTHETICAL NETWORK/CORRESPONDING FRA TRAFFIC FLOW LINKS

| LINK CODE | RAILROAD ROUTE SEGMENT (LINK) | TRAFFIC FLOW LINK(S) | CORRELATION FACTOR |
|---|---|---|---|
| | BESSEMER & LAKE ERIE | | |
| BL018 | Bessemer, PA to Conneaut, OH | * | * |
| | BURLINGTON NORTHERN | | |
| BN010 | Chicago, IL to Minneapolis, MN | 243, 54 | 3 |
| BN208 | Minneapolis, MN to Mandan/Gavin Yard, ND | 166, 168, 169 | 2 |
| BN232 | Northport, NE to Denver, CO | 231, 230 | 1 |
| BN442 | Alliance, NE to Reno, WY (via Northport) | 178 | 4 |
| BN533 | Mandan, NE to Forsyth, MT | 176 | 1 |
| BN558 | Alliance, NE to Reno, WY (via Donkey Creek) | 178 | 1 |
| BN572 | Havre, MT to Yardley, WA | 189 | 1 |
| BN641 | Gavin Yard, ND to Havre, MT | 189 | 1 |
| BN672 | Lincoln, NE to Aurora, IL | 171, 162, 160, 69, 56 | 2 |
| BN674 | Lincoln, NE to Kansas City, KS | 270, 165 | 2 |
| BN677 | Lincoln, NE to Alliance, NE | 178 | 1 |
| BN701 | Yardley, WA to Seattle, WA | 199 | 1 |
| BN714 | Seattle, WA to Portland, OR | 200 | 2 |

*Unique characteristics of the link resulted in a manual estimate of traffic growth being made.

| LINK CODE | RAILROAD ROUTE SEGMENT (LINK) | TRAFFIC FLOW LINK(S) | CORRELATION FACTOR |
|---|---|---|---|
| | CHESSIE SYSTEM | | |
| BX034 | Connellsville, PA to Willard, OH | 19, 20, 24 | 3 |
| BX051 | Baltimore/Washington, DC to Connellsville, PA | 264, 218, 215 | 1 |
| BX128 | Clifton Forge, VA to Newport News, VA | 224, 225 | 2 |
| BX188 | Russell, KY to Clifton Forge, VA | 28, 256 | 1 |
| BX195 | Big Sandy Junction, KY to Elkhorn City, KY | 251, 262 | 5 |
| BX218 | Toledo, OH to Russell, KY | 39, 36 | 2 |
| BX250 | Cumberland, MD to Grafton, WV | 216 | 1 |
| BX264 | Willard, OH to Chicago, IL | 268 | 3 |
| | CHICAGO & NORTHWESTERN | | |
| CH018 | Chicago, IL to Council Bluffs, IA | 56, 69, 160, 162 | 2 |
| | CONRAIL | | |
| PO018 | Buffalo, NY to Toledo, OH | 14, 24 | 2 |
| PO050 | Selkirk, NY to Oak Island, NJ | 4 | 1 |
| PO115 | Conway, PA to Crestline, OH | 267 | 1 |
| PO137 | Harrisburg, PA to Conway, PA | 21 | 1 |
| PO248 | Berea, OH to Indianapolis, IN | 25, 40, 46 | 1 |
| PO382 | Toledo, OH to Chicago, IL | 268 | 2 |
| PO439 | Indianapolis, IN to East St. Louis | 61, 76 | 1 |
| PO927 | Selkirk, NY to Buffalo, NY | 2, 7, 11 | 1 |
| | DULUTH MASSABE IRON RANGE | | |
| DM020 | Duluth, MN to Mountain Iron, MN | * | * |

[illegible]que characteristics of the link resulte[illegible] a manual estimate of traffic growth be[illegible] made.

| LINK CODE | RAILROAD ROUTE SEGMENT (LINK) | TRAFFIC FLOW LINK(S) | CORRELATION FACTOR |
|---|---|---|---|
| | FAMILY LINES | | |
| FA001 | Cincinnati, OH to Corbin, KY | 47 | 2 |
| FA008 | Richmond, VA to Florence, SC | 219, 86 | 1 |
| FA013 | Erwin, NC to Spartanburg, SC | 212 | 4 |
| FA059 | Winchester, KY to Deane, KY | 47 | 4 |
| FA072 | Atlanta, GA to Waycross, GA | 102, 108 | 3 |
| FA076 | Elkhorn City, KY to Erwin, NC | 262 | 4 |
| FA080 | Corbin, KY to Atlanta, GA | 51, 266, 47 | 2 |
| FA152 | Florence, SC to Waycross, GA | 97, 98, 105 | 1 |
| FA214 | Nashville, TN to Birmingham, AL | 116, 118 | 2 |
| FA215 | Nashville, TN to Junta, GA | 82, 99 | 1 (82) & 2 (99) |
| FA232 | Evansville, IN to Nashville, TN | 271 | 1 |
| FA392 | Waycross, GA to Tampa, FL | 112, 113 | 2(112) & 1(113) |
| | ILLINOIS CENTRAL GULF | | |
| IC010 | Chicago, IL to Memphis, TN | 261, 246 | 1 |
| IC165 | Memphis, TN to New Orleans, LA | 124, 127 | 1 |
| | MISSOURI, KANSAS AND TEXAS (KATY) | | |
| MK065 | Fort Worth, TX to Houston, TX | 147, 148 | 2 |
| | MISSOURI PACIFIC | | |
| MP036 | Salem, IL and Memphis, TN to North Little Rock, AR | 73, 238, 239, 125 | 2 |
| MP245 | North Little Rock, AR to Longview, TX | 133, 142 | 2 |
| | NORFOLK & WESTERN | | |
| NW011 | Cleveland, OH to Ft. Wayne, IN | 25, 267 | 3 |
| NW048 | Ft. Wayne, IN to Chicago, IL | 42 | 2 |
| NW062 | Ft. Wayne, IN to Decatur, IL | 43, 58, 60 | 1 |
| NW155 | Portsmouth, OH to Iaeger, WV | 251 | 1 |
| NW269 | Iaeger, WV to Roanoke, VA | 233 | 1 |
| NW343 | Sandusky, OH to Portsmouth, OH | 39, 66 | 3 |
| NW393 | Norfolk, VA to Roanoke, VA | 224, 225 | 2 |

| LINK CODE | RAILROAD ROUTE SEGMENT (LINK) | TRAFFIC FLOW LINK(S) | CORRELATION FACTOR |
|---|---|---|---|
| | RICHMOND, FREDERICKSBURG & POTOMAC | | |
| RF001 | Alexandria, VA to Richmond, VA | 220 | 1 |
| | SANTA FE | | |
| SF036 | Cleburne, TX to Galveston, TX | 149 | 2 |
| SF058 | Clovis, NM to Barstow, CA | 210 | 1 |
| SF110 | Barstow, CA to Los Angeles, CA | 210 | 2 |
| SF130 | Chicago, IL to Kansas City, MO | 56, 170 | 2 |
| SF131 | Kansas City, MO to Clovis, NM | 154, 172, 165, 183 | 2 |
| SF224 | Augusta, KS to Cleburne, TX | 140, 173 | 2 |
| | SOUTHERN | | |
| SO001 | Alexandria, VA to Salisbury, NC | 221, 222 | 2 |
| SO038 | Harriman Jct, TN to Knoxville, TN | * | * |
| SO065 | Salisbury, NC to Atlanta, GA | 84, 91, 260 | 2 |
| SO128 | Danville, KY to Louisville, KY | 50 | 2 |
| SO256 | Sheffield, AL to Burmingham, AL | 118 | 2 |
| SO266 | Knoxville, TN to Asheville, NC | 87 | 1 |
| SO279 | Cincinnati, OH to Atlanta, GA | 47, 51, 266 | 2 |
| SO323 | Atlanta, GA to Birmingham, AL | 103 | 2 |
| SO325 | Atlanta, GA to Macon, GA | 102 | 1 |
| SO358 | Birmingham, AL to New Orleans, LA | 252 | 1 |



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[illegible]Unique characteristics of the link resul[illegible] in a manual estimate of traffic growth [illegible]ng made.

| LINK CODE | RAILROAD ROUTE SEGMENT (LINK) | TRAFFIC FLOW LINK(S) | CORRELATION FACTOR |
|---|---|---|---|
| | SOUTHERN PACIFIC | | |
| SP007 | Pine Bluff, AR to Dexter Jct, MO | 238, 239 | 2 |
| SP028 | Pine Bluff, AR to Corsicanna, TX | 133 | 2 |
| SP033 | El Paso, TX to Los Angeles, CA | 259, 197, 198 | 1 |
| SP037 | Roseville, CA to West Colton, CA | 207, 209 | 2 |
| SP148 | Sparks, NV to Roseville, CA | 205 | 2 |
| SP178 | Corsicanna, TX to Flatonia, TX | 234, 145 | 4 |
| SP261 | Ogden, UT to Sparks, NV | 205 | 2 |
| SP282 | New Orleans, LA to Houston, TX | 146, 135, 130 | 2 |
| SP298 | Houston, TX to San Antonio, TX | 234 | 2 |
| SP304 | San Antonio, TX to El Paso, TX | 186 | 1 |
| SP307 | Portland, OR to Klamath Falls, OR | 203 | 2 |
| SP318 | Klamath Falls, OR to Roseville, CA | 204 | 2 |
| | UNION PACIFIC | | |
| UP001 | Kansas City, MO to Gibbon, NE | 164, 270 | 5 |
| UP009 | North Platte, NE to Rawlins, WY | 233, 232 | 1 |
| UP031 | Pocatello, ID to Granger, WY | 191 | 3 |
| UP074 | Pocatello, ID to Nampa, ID | 202 | 1 |
| UP102 | Rawlins, WY to Ogden, UT | 232 | 1 |
| UP174 | Hinkle, OR to Portland, OR | 202 | 1 |
| UP180 | Nampa, ID to Hinkle, OR | 202 | 1 |
| UP190 | Las Vegas, NV to E. San Pedro, CA | 194 | 1 |
| UP202 | Salt Lake City, UT to Las Vegas, NV | 193 | 1 |
| UP205 | Salt Lake City, UT to Ogden, UT | 232 | 1 |
| UP256 | Council Bluffs, IA to North Platte, NE | 171, 233 | 1 |

Explanation of Correlation Factors used:

1 - One or more links along a corridor which at least closely coincides with the traffic flow links and over which the line studied for electrification is either the sole occupant or is unquestionably the dominant carrier.

2 - One or more links along a corridor that is shared by two or more carriers, neither of which clearly dominates.

3 - One or more links along a single corridor which does not closely coincide with the route being studied for electrification, but is a reasonable approximation.

4 - One or more links along a single corridor which, while fairly far-removed from the route being studied, is still the closest approximation available.

5 - One or more links along two or more corridors, none of which exactly describe the route being studied for electrification, so were averaged in an attempt to better estimate the flows over the route in question.

## APPENDIX D

## DEVELOPMENT OF THE NETWORK CONSTRUCTION SCHEDULE

A theoretical timescale for electrification of successive links was compiled, based on the use of a number of teams for construction. The first phase provided for moderate size projects with "learning curve" allowances for design and construction activity periods.

The second phase provided for large size projects undertaken by continuing deployment of same design - construct teams, again providing some "learning curve" allowance during expansion of the total team size and capability. Subsequent phases were in effect direct redeployment of design - construct teams on successive projects on an average cycle of two years.

The coordinated team approach included the following procedural assumptions:

1. The sponsoring railroad would have an in-house technical group to establish and provide essential engineering input including track plans and lines-to-be-electrified diagrams;

2. The basis of catenary and substation designs would be standard specifications and standard drawings provided in advance and giving at least three variations of major factors or components in order to be responsive to local requirements or cirumstances;

3. Scheduling of engineering input and design team output would be such as to permit a construction start six to nine months prior to design completion on a major route segment;

4. A total team would be essentially made up of three elements thus:

   a. Design Team;

   b. Foundations/Poles Team;

   c. Wiring/Tests Team.

The commissioning program assumed that a major route segment could have electric operation commissioned over one-half of the segment 6 to 12 months prior to completion of the project.

The utilization of contractor or in-house design-construct teams working on some positive incentive basis is a feasible means of accomplishing the construction rates outlined. This program contains no allowance for periods of team inactivity or under-utilization, nor does it allow for possible geographic or climatic discontinuity effects or less efficient working on small or complex project areas.

It does however establish the feasibility of a nation-wide program of railroad electrification on a cost-effective coordinated team basis.

# APPENDIX E

## CALCULATION OF DIESEL LOCOMOTIVE MAINTENANCE COSTS FOR CLASS I RAILROADS FROM ICC DATA

Accurate diesel road locomotive maintenance costs are necessary for the comparison of electric and diesel operation, since maintenance costs comprise one of the major yearly operating expenses. While electric locomotive maintenance costs must presently be estimated because of the limited use of electric traction, diesel locomotive maintenance costs can be established from actual expense accounts. This appendix sets forth the procedure used to calculate these costs using data contained in the R-1 reports submitted annually by each Class I railroad to the Interstate Commerce Commission.

Table E-1 contains the 1977 costs for each of the Class I railroads obtained using this procedure. The costs range from $0.40 to $1.99 per unit-mile for the large railroads and are even higher for the B&LE and the DMIR. After a search for correlation of this wide cost variation with factors such as locomotive type, usage and maintenance philosophy proved unfruitful, the decision was made to use an average cost for all railroads.

The details of the procedure are given in the following paragraphs. Expense data from an ICC summary report* is used to illustrate how the average cost of $1.33 per unit-mile was obtained.

*Ninety-first Annual Report - Transport Statistics in the United States December 31, 1977 by the Interstate Commerce Commission, Bureau of Accounts.

TABLE E-1. MAINTENANCE, INSPECTION AND SERVICING COST FOR DIESEL ROAD LOCOMOTIVE BASED ON 1977 ICC RECORDS

| RAILROAD | $/UNIT-MILE |
|---|---|
| ATSF | 1.20 |
| B&LE | 2.48 |
| B&N | 1.78 |
| Chessie | 1.64 |
| C&NW | 1.79 |
| Conrail | 1.99 |
| DMIR | 3.24 |
| ICG | N.C. |
| L&N | N.C. |
| Mo. Pac. | 1.25 |
| N&W | 1.42 |
| SCL | 1.50 |
| Southern | 0.40 |
| So. Pac. | 1.89 |
| UP | 1.14 |

Table E-2 lists the relevant items of the cost of diesel locomotive maintenance under three headings, maintenance of equipment, transportation-rail maintenance and maintenance of structures and way. Column 1 of the above table gives the ICC account numbers. The definitions of items included in the ICC account numbers are given in Table E-3.

The major portion of the locomotive maintenance cost is included in account 311 (diesel locomotive repairs) and 400 (servicing train locomotives). These accounts are considered to be wholly chargeable to locomotive maintenance. Note that account 400 includes the cost of lubricants. Only a certain portion of the other cost items given in Column 3 is attributed to the locomotive maintenance cost. Column 4 of Table E-2 gives the portion as a factor called "the diesel related cost factor."

TABLE E-2. CALCULATION OF DIESEL LOCOMOTIVE MAINTENANCE COST FROM ICC DATA (1977) FOR CLASS I RAILROADS

| 1<br>ICC ACCOUNT NUMBER | 2<br>ITEM | 3<br>COST THOUS. $/Y | 4<br>DIESEL RELATED COST FACTOR | 5<br>DIESEL RELATED COST THOUS. $/Y |
|---|---|---|---|---|
| | Maintenance of Equipment | | | |
| 301 | Superintendence | 164,846 | .41 | 67,587 |
| 302 | Shop Machinery | 57,906 | .41 | 23,741 |
| 304 | Power Plant Machinery | 7,645 | .41 | 3,134 |
| 305 | Shop & Power Plant Deprec. | 10,676 | 0 | 0 |
| 306 | Dismantling Shop & PP Mach. | 210 | .41 | 86 |
| 311 | Diesel Loc. Repair (excl. yard) | 979,005 | 1.00 | 979,005 |
| 314 | Freight-train-cars-Repairs | 1,191,680 | 0 | 0 |
| 317 | Pass-train-card-Repairs | 205,965 | 0 | 0 |
| 318 | Hwy. Revenue Equip.-Repairs | 31,485 | 0 | 0 |
| 323 | Floating Equip.-Repairs | 2,334 | .41 | 957 |
| 326 | Work Equip.-Repairs | 40,821 | .41 | 16,737 |
| 328 | Misc. Equip.-Repairs | 46,723 | .41 | 19,156 |
| 329 | Dismantling Retired Equip. | 5,687 | .41 | 2,332 |
| 330 | Retirements - Equip. | -5,261 | 0 | 0 |
| 331 | Equip. Deprec. | 741,813 | 0 | 0 |
| 332 | Injuries to Persons | 52,239 | .41 | 21,418 |
| 333 | Insurance | 16,053 | .41 | 6,582 |
| 334 | Stationery & Printing | 4,466 | .41 | 1,831 |
| 335 | Employees' Health & Welfare Ben. | 101,960 | .41 | 41,803 |
| 339 | Other Expenses | 23,160 | .41 | 9,496 |
| 336 | Jt. Maint. of Equip. Dr. | 19,458 | .41 | 7,978 |
| 337 | Jt. Maint. of Equip. Cr. | 7,739 | .41 | 3,173 |
| | TOTAL M.O.E. (frt. only) | 3,475,421 | | 1,195,016 |

TABLE E-2. CALCULATION OF DIESEL LOCOMOTIVE MAINTENANCE COST FROM ICC DATA (1977) FOR CLASS I RAILROADS (CONT'D)

| 1<br>ICC ACCOUNT NUMBER | 2<br>ITEM | 3<br>COST THOUS. $/Y | 4<br>DIESEL RELATED COST FACTOR | 5<br>DIESEL RELATED COST THOUS. $/Y |
|---|---|---|---|---|
| | Transportation - Rail Line | | | |
| 371 | Superintendence | 355,173 | .08 | 28,414 |
| 394 | Train Fuel | 1,348,834 | .01 | 13,488 |
| 400 | Servicing Train Locos. | 184,902 | 1.00 | 184,907 |
| 409 | Employees Health & Welfare | 252,862 | .08 | 20,229 |
| 410 | Stationery & Printing | 33,251 | .08 | 2,660 |
| 411 | Other | 35,526 | .08 | 2,842 |
| 414 | Insurance | 48,504 | .08 | 3,880 |
| 420 | Injuries to Persons | 214,880 | .08 | 17,190 |
| | TOTAL TRANS - RAIL LINE (frt. only) | 7,523,258 | | 273,610 |

TABLE E-2. CALCULATION OF DIESEL LOCOMOTIVE MAINTENANCE COST FROM ICC DATA (1977) FOR CLASS I RAILROADS (CONT'D)

| 1<br>ICC ACCOUNT NUMBER | 2<br>ITEM | 3<br>COST THOUS. $/Y | 4<br>DIESEL RELATED COST FACTOR | 5<br>DIESEL RELATED COST THOUS. $/Y |
|---|---|---|---|---|
| | Maint. of Structures & Ways | | | |
| 231 | Water Stations | 2,423 | .41 | 993 |
| 233 | Fuel Stations | 4,109 | .41 | 1,685 |
| 235 | Shops & Engine Houses | 47,865 | .41 | 19,625 |
| | TOTAL M.O.W. | 54,397 | | 22,303 |
| | General Expense (Frt. Only) | (981,676)(.06)(.41) = | | 24,149 |
| | Grand Total Oper. Exp. (Sched. 320) | | | 1,515,073 |

Notes:

Diesel related cost factor Number 1:

$$\frac{\text{No. 311}}{\text{No. 311 + No. 314 + No. 317}} = \frac{979{,}005}{979{,}005 + 1{,}191{,}680 + 205{,}965} = 0.41$$

Diesel related cost factor Number 2:

$$\frac{\text{No. 400}}{\text{No. 400 + No. 392 + No. 401 + No. 404}} = 0.08$$

Diesel related cost factor Number 3:

$$\frac{\text{Gen. Oper. Exp.}}{\text{Grand Total Oper. Exp.}} = \frac{981{,}676}{15{,}693{,}506} = 0.06$$

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| 231 | Water Stations - Includes the cost of repairing water stations, fixtures, and appurtenances used by the carrier in its operation. |
| 233 | Fuel Stations - Includes the cost of repairing fuel stations, fixtures, and appurtenances used by the carrier in its operation. |
| 235 | Shops and Engine Houses - Includes the costs of repairing shop and engine house buildings, fixtures, and appurtenances and the cost of grounds' maintenance. |
| 301 | Superintendence - Includes officers' pay directly in charge of, or engaged in, the maintenance of equipment; the pay of clerks and other employees in the offices and on business; cars of officers whose pay is chargeable to this account and the office; other expenses of officers and employees whose pay is chargeable to this account. |
| 302 | Shop Machinery - Includes the cost of repairing machinery and other apparatus including special foundations in power plants and substation for generating and transforming power used for the operation of trains and cars or to furnish power, heat, and light for general purposes. |
| 304 | Power Plant Machinery |
| 305 | Shop and Power Plant Machinery Depreciation - Includes the amount of depreciation charges applicable to the accounting period for all classes of property includible as shop or power plant machinery. |
| 306 | Dismantling Retired Shop and Power Plant Machinery - Includes the cost of dismantling retired shop and power plant machinery and recovering the salvage therefrom. |
| 311 | Repairs to Yard and Other Steam Locomotives - Data for previous years included the cost of repairing transportation service locomotives and tenders, including appurtenances. |
| | Locomotives: Repairs - Includes the cost of repairing transportation service locomotives and tenders, including appurtenances (Diesel Locomotive Yard). |
| | Locomotives: Repairs - The same as above, except refers to Diesel Locomotives - Other Than Yard. |

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT (CONT'D)

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| | Locomotives: Repairs - The same as above, except refers to Other Than Diesel Locomotives-Yard. |
| | Locomotives: Repairs - The same as above, except refers to Other Than Diesel Locomotives-Other Than Yard. |
| 314 | Freight-Train Cars: Repairs - Includes the cost of repairing freight-train cars and appurtenances and the cost of repairing motor equipment affixed to freight-train cars engaged in transportation service; etc. |
| 317 | Passenger-Train Cars: Repairs - Includes the cost of repairing passenger-train cars and appurtenances and the cost of repairing motor equipment affixed to passenger-train cars used in transportation service. |
| 323 | Floating Equipment: Repairs - Includes the cost of repairing floating equipment (other than work equipment), including appurtenances and the cost of small hand tools used in repairs. |
| 326 | Work Equipment: Repairs - Includes the cost of repairing rail and floating work equipment, including appurtenances, and cost of small hand tools used in repairs. |
| 328 | Miscellaneous Equipment: Repairs - Includes the cost of repairing miscellaneous equipment and appurtenances; also the cost of small hand tools, materials, lubricants, and supplies used in repairs. |
| 329 | Dismantling Retired Equipment - Includes the cost of tearing down retired equipment and recovering the salvage therefrom. |
| 330 | Retirements-Equipment - When equipment previously subject to amortization accounting pursuant to rules in effect during the period 1941-1951 is retired, the difference between (1) the service value (ledger value less value of salvage and insurance recovered) thereof, and (2) the balance of amounts of accumulated past provisions for amortization of road and equipment defense projects after appropriate adjustment for any depreciation accrued thereon, is included in this account. |
| 331 | Equipment Depreciation - Includes the amount of depreciation charges applicable to the accounting period for all classes of equipment. |

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT (CONT'D)

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| 332 | Injuries to Persons - Includes expenses on account of injuries to persons which occur directly in connection with repairs of equipment. |
| 333 | Insurance - Includes premiums for insuring the carrier against loss through injuries to persons, damage, destruction or loss of property, whether caused by fire, accident, or other cause, when such loss to the carrier would be chargeable to maintenance of equipment. |
| 334 | Stationery and Printing - Includes the cost of stationery and printing used in connection with maintenance of equipment. |
| 335 | Employees Health and Welfare Benefits - Includes premiums on group and other insurance policies covering annuities and other benefits for employees engaged in maintenance of equipment. |
| 339 | Other Expenses - Includes expenses in connection with the maintenance of equipment not properly chargeable to other accounts for maintenance of equipment. |
| 336 | Joint Maintenance of Equipment Expenses-Dr. - Includes the carriers' proportion of expenses incurred by others in maintaining equipment used in the operation of joint facilities, including the carriers proportion of the expenses repairing such equipment damaged by accidents. |
| 337 | Joint Maintenance of Equipment Expenses-Cr. - Includes the amount chargeable to others as their proportion of expenses incurred by the carrier in maintaining equipment and in the operation of joint facilities, and for expenses of repairing equipment damaged by accidents. |
| 371 | Superintendence - Includes the pay of officers directly in charge of, or engaged in, conducting transportation; the pay of clerks and attendants employed in the offices and on business; cars of officials whose pay is chargeable to transportation; and office and other expenses of officers and other employees whose pay is chargeable to transportation. |

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT (CONT'D)

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| 372 | Dispatching Trains - Includes the pay of chief and other train dispatchers, their clerks, copying operators, and attendants, and pay of operators on the line whose duties are confined to directing train movements; also the office, traveling, and other expenses of such employees. |
| 373 | Station Employees - Includes the pay of agents, clerks, and attendants in charge of or engaged in the operation of stations, stockyards, wharves, and piers located in the carriers' line. |
| 374 | Weighing Inspection and Demurrage Bureaus - Includes the cost to the carrier of its participation in joing weighing inspection, demurrage, and car distribution bureaus and associations. |
| 375 | Coal and Ore Wharves - Includes the cost of operating docks, wharves, piers, and other marine, lake or river landings, and the machinery located thereon, used in connection with the transportation of coal and ore. |
| 376 | Station Supplies and Expenses - Includes heating, lighting, and other miscellaneous station supplies and expenses. |
| 377 | Yardmasters and Yard Clerks - Includes the pay of yardmasters, yard clerks, and attendants in yards where regular switching service is maintained and in terminal switching and transfer service. |
| 378 | Yard Conductors and Brakemen - Includes the pay of yard conductors and brakemen handling cars in passenger and freight yards where regular switching service is maintained, and in terminal switching and transfer service. |
| 379 | Yard Switch and Signal Tenders - Includes the pay of employees in yards where regular switching service is maintained, who are engaged in the operation of yard switches and signals (including interlockers). |
| 380 | Yard Enginemen - Includes the pay of yard enginemen while engaged in yards where regular switching service is maintained and terminal switching and transfer service, including pay of such employees while deadheading in connection with yard service. |

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT (CONT'D)

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| 382 | Yard Switching Fuel - Includes the cost, delivered on locomotives or motor cars, of coal, coke, oil, wood, and other fuels consumed in switching service in yards where regular switching service is maintained, and in terminal switching of transfer service, including a suitable proportion of the pay of fuel agents, fuel inspectors, fuel weighers, and clerks engaged in accounting for fuel at fuel stations. |
| 383 | Yard Switching Power Produced - Includes the cost of the production and distribution of electric power used in operating locomotives and cars in switching service in yards where regular switching service is maintained and in terminal switching and transfer service. |
| 383 | Yard Switching Power Purchased - Includes the cost of electric power purchased for the propulsion of engines and cars in switching service in yards where regular switching service is maintained, and in terminal switching and transfer service. |
| 314 | Charges for Work Done by Others |
| | Water for Yard Locomotives |
| | Lubricants for Yard Locomotives |
| | Other Supplies for Yard Locomotives |
| | Enginehouse Expenses-Yard |
| 389 | Yard Supplies and Expenses - Includes the cost of supplies (except locomotive supplies) used in yard service, yard signal, and interlocker supplies; and miscellaneous yard expenses for yards where regular switching service is maintained. |
| 392 | Train Enginemen - Includes the pay of enginemen while engaged in transportation train service or while dead heading in connection therewith and pay of such enginemen engaged in piloting trains over home lines. |
| 394 | Train Fuel - Includes the cost, delivered on locomotives or motor cars, of coal, coke, oil, wood, and other fuel for propulsion of trains in transportation train service, including a suitable proportion for the pay of fuel agents. |

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT (CONT'D)

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| 395 | Train Power Produced - Includes the cost of producing and distributing electric power for the propulsion of electric locomotives and cars in transportation train service. |
| 396 | Train Power Purchased - Includes the cost of electric power purchased for the propulsion of locomotives and cars in transportation train service. |
| 400 | Water, Lubricants and Other Supplies for Train Locomotives |
| 401 | Trainmen - Includes the pay of conductors; of train auditors, ticket collectors, and others engaged in lifting or examining authorities for transportation. |
| 402 | Train Supplies and Expenses - Includes miscellaneous expenses of transportation service trains and the cost of all supplies other than locomotive supplies. |
| 403 | Operating Sleeping Cars - Includes the cost of operating sleeping car service on trains; also the pay of employees attributable to the operation of such service. |
| 404 | Signal and Interlocker Operation - Includes the cost of operating signals and interlockers other than those solely or principally used for governing all movements of locomotives and trains between main and yard tracks, movements of locomotives between yard tracks and enginehouses, and yard switching movements. |
| 405 | Crossing Protection - Includes the pay of street and highway crossing gatekeepers and flagmen, and the cost of supplies used. |
| 406 | Drawbridge Operation - Includes the cost of operating drawbridges, the pay of employees engaged in the operation of drawbridges and expenses incurred attributable to drawbridge operation. |
| 407 | Communication System Operation - Includes the cost of operating communication systems not provided for elsewhere. |
| 408 | Operating Floating Equipment - Includes the cost of operating floating equipment in water transfer (ferriage, lighterage, and floatage). |

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT (CONT'D)

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| 409 | Employees Health and Welfare Benefits - Includes premiums on group and other insurance policies covering annuities and other benefits for employees (or their beneficiaries) engaged in conducting transportation operations. |
| 410 | Stationery and Printing - Includes the cost of stationery and printing used in connection with rail line transportation, including the operation of floating equipment. |
| 411 | Other Expenses - Includes all expenses in connection with rail line transportation not properly chargeable to other transportation accounts. |
| 414 | Insurance - Includes the cost of premiums for insuring the carrier against loss through injuries to persons, damage, destruction or loss of propery, whether caused by fire, accident or other cause, when such loss to the carrier would be chargeable to rail line transportation. |
| 415 | Clearing Wrecks - Includes the costs of labor, train service, and other supplies and expenses incurred in the clearing of wrecks other than wrecks of work trains. |
| 416 | Damage to Property - Includes payments and expenses from damages to the property of others, whether by fire, collision, flood, or other cause, with the exception of payments and expenses from damage to property entrusted to the carrier for transportation, and for damage to stock on right-of-way. |
| 417 | Damage to Livestock on Right-of-Way - Includes payments of cattle and other livestock killed or injured while crossing of trespassing on the right-of-way, including cost of removing and burying the same. |
| 418 | Loss and Damage: Freight - Includes payments and expenses from loss, destruction, damage, or delays to revenue freight shipments, including locomotives, cars, and highway revenue equipment transported as freight, express matter, milk shipments, and livestock, and expenses incurred from such payments. |
| 419 | Loss and Damage: Baggage - Includes payments for loss, destruction, damage, or delays to baggage and other personal property carried as baggage, and damage to personal apparel; also expenses on account of such or damage. |

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT (CONT'D)

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| 420 | Injuries to Persons - Includes expenses of injuries to persons which occur directly in connection with transportation service, including damages for ejectment of passengers. |
| 390 | Operating Joint Yards and Terminals-Dr. - Includes the carriers' proportion of the costs incurred by others in their operation of joint yards and terminals, including signals, interlockers, and other facilities at such joint yards and terminals. |
| 391 | Operating Joint Yards and Terminals-Cr.- Includes amounts chargeable to others as their proportions of the costs incurred by the carrier in the operation of joint yards and terminals, including signals, interlockers, and other facilities at such joint yards and terminals. |
| 412 | Operating Joint Tracks and Facilities-Dr. - Includes the carriers' proportion of the transportation expenses incurred by others in the operation of joint tracks, interlockers, and other facilities which are not included in ICC Account Number 390. |
| 413 | Operating Joint Tracks and Facilities-Cr. - Includes amounts chargeable to others as their proportions of transportation expenses incurred by the carrier in the operation of joint tracks, interlockers, and other facilities which are not provided for in ICC Account Number 391. |
| 451 | Salaries and Expenses of General Officers - Includes the pay of all general officers not otherwise provided for, including salaries and fees of receivers and commissions paid to general officers in lieu of salaries; also the traveling and other expenses of officers whose pay is included in this item. |
| 452 | Salaries and Expenses of Clerks and Attendants - Includes the pay and expenses of clerks and attendants of the officers whose salaries are includible in ICC Account Number 451. |
| 453 | General Office Supplies and Expenses - Includes the office expenses of officers designated in ICC Account Number 451. |
| 454 | Law Expenses - Includes the pay and the office and other expenses of officers and employees of the law department, when not provided for elsewhere, the cost of suits, and the payments of special law fees. |

TABLE E-3. DEFINITION OF MAINTENANCE COST ACCOUNT NUMBERS IN ICC REPORT (CONT'D)

| ICC ACCOUNT NUMBER | DEFINITION |
|---|---|
| 455 | Insurance - Includes premiums for insuring the carrier against loss through injuries to persons or damage to or destruction of loss of property, whether caused by fire, accident, or other cause. |
| 456 | Employees Health and Welfare Benefits - Includes premiums on group and other insurance policies covering annuities and other benefits for employees (or their beneficiaries) engaged in accounting, law and other general administration. |
| 402 | Refrigeration and Heater Service - Includes: a) Gross charges for refrigeration service; b) Credits for refrigeration service; c) Gross charges for heater service; and d) Credits for heater service. |
| 457 | Pensions - Includes amounts payable for the current year to trustees under pension plans for pension costs computed on basis of employees services in the year, and for pension costs computed on the basis of credits for past services. |
| 458 | Stationery and Printing - Includes the cost of postage, stationery, and printing used in general offices and not chargeable to other accounts. |
| 460 | Other Expenses - Includes incidental genral expenses which have not been properly includable in any of the previous data items. |
| 461 | General Joint Facilities-Dr. - Includes the carriers' proportion of general expenses by others incident to maintaining and operating tracks, yards, terminals, and other facilities used jointly. |
| 462 | General Joint Facilities-Cr. - Includes amounts chargeable to others as their proportions of general expenses incurred by the carrier incident to maintaining and operating tracks, yards, terminals, and other facilities used jointly. |

The factor for other accounts under Maintenance of Equipment and Maintenance of Way is established by the ratio of accounts 311 to the total of all major accounts under Maintenance of Equipment. A similar factor is developed for accounts appearing under the heading Transportation-Rail Line, by using the ratio of the account 400 (servicing train locomotives) to the total of all major accounts under the category. Calculation of the diesel related cost factors is shown at the end of Table E-2. The cost of fueling diesel locomotives is assumed to be one percent of the cost of diesel fuel (account 394).

The numbers shown in the left hand side of the equal sign refer to the ICC account numbers. The costs given in Column 5 of Table E-2 are the products of the total cost in Column 3 and the diesel related cost factor.

The total maintenance cost is 1,515,073 thousand dollars (1977 dollars) (end of Column 5 of Table E-2). The total diesel locomotive unit-miles is calculated from Table 6 and Table 7 of the ICC report as 1,347,590 unit-miles (the total locomotive mileage of Table 6 for road and train switching, 1,361,202 unit-miles, is portioned between electric and diesel according to the fleet sizes as reported in Table 7).

The average maintenance cost in 1977 dollars is therefore $1.12/unit-mile.

The above procedures for calculating the maintenance cost were repeated using Conrail R-1 data. The result was a cost of $1.92/unit-mile for diesel locomotives. For the same routes, figures of $1.99/unit-mile in 1977 dollars, and $2.27/unit-mile in 1980 dollars are given in reference[18].

The R-1 estimates were scaled by the cost ratio $1.99/$1.92 to account for the slight deviation of the R-1 estimate from the reference[18] estimate and then escalated to 1980 dollars using the ratio $2.27/$1.99. The average diesel locomotive maintenance cost for all railroads in 1980 dollars was calculated to be $1.33/unit-mile.

APPENDIX F

INSTRUCTIONS FOR COMPLETION OF THE RAILROAD QUESTIONNAIRE

Q1. - The percent change in revenue tonnage on the route segment from 1978 to 1990 has been projected by direction for 15 commodity groupings and is recorded in the two rows of question 1. The projection is based on the FRA rail commodity projections between 129 regions of the U.S. and assumes that traffic on all parallel rail lines between regions would grow uniformly in any given commodity grouping. Commodities included in each of the 15 groupings are listed in Table A (not included here. See Table 4-6). Please note at the bottom of the questionnaire any comments you have with regard to the projection. If you have alternate data for this time period that you believe is more appropriate, write it in the appropriate blocks.

Q2. - The percent of 1978 revenue tonnage in each of 15 commodity groupings is recorded in the two rows of Item 2. The percentages for all commodities and both directions sum to 100%. Item 2 is based on the "Princeton Model" which predicts the routing of commodities between junction points using data obtained from a 1% waybill sampling. Since a route segment being considered for electrification, in general, contains many waybill junction points, the percent revenue tonnage data of Item 2 is based on average commodity flow over the segment, weighted by the distance between junction points.

Your comment at the bottom of the questionnaire, on whether this data generally characterizes traffic over the route segment, would be appreciated.

Q3. - For each of the 15 commodities indicate which of the following three (or less) service categories best describe the manner in which that commodity is transported. If any commodity must be split to make such categorization please indicate the corresponding tonnage split.

Expedited Service - Includes those commodities for which consideration of delivery time by the shipper or receiver is significant enough to warrant special operational provisions by the railroad to speed delivery. TOFC/COFC trains and produce trains are examples of expedited service where the operational provisions to minimize delivery time might include such factors as increased dispatch level for locomotives, schedule superiority of trains, and by-pass of intermediate yards.

Bulk Movement - Includes those commodities for which a significant requirement of the shipper or receiver is the regularity of delivery of the commodity but for which speed of delivery of any particular carload is not significant. Unit trains which haul coal, grain or chemicals are typical examples of bulk movement. The significant operational characteristic is a rather low average speed which results from factors such as speed restrictions, low train priority enroute, and a dispatch level only sufficient for tractive effort on the ruling grade.

Normal Service - Includes all commodities for which no special operational provisions are made that effect delivery time. Normal service typically includes mixed commodities on any train with routine reclassification at intermediate yards and nominal dispatch levels.

Q4-6. - For each of the service categories on the route segment, record the consist characteristics of the the most typical train including dispatch level in each direction (nameplate horsepower per ton of train), diesel road locomotive type (mfrs. model no.), and the run time in each direction (in hours). The dispatch level should be that which appears in the dispatchers manual and defines power and/or traction requirements per trailing gross ton on each route segment. Do not use the actual locomotive dispatch obtained from traffic records as this contains additional dispatch for fleet balancing. If helper locomotives are used on the segment, record their characteristics separately for the appropriate type(s) of service and direction(s).

Q7. - Record the ruling grade in each direction in percent of ruling grade for trains in normal service.

Q8. - Record the actual gross tonnage in calendar year 1980 and indicate whether it is trailing or total.

Q9. - Estimate the percent of tonnage in each direction that is moved as expedited traffic.

Q10. - Estimate the percent of traffic on the sector which will be hauled by electric locomotives after conversion.

# APPENDIX G

## COMPUTATION OF TRAFFIC DENSITY AND GROWTH BY DIRECTION AND SERVICE CATEGORY

Definitions:

$G_f$ = 1978 gross traffic density in forward direction, including locomotives.

$G_r$ = 1978 gross traffic density in reverse direction, including locomotives.

$R_f$ = 1978 revenue traffic density in forward direction.

$R_r$ = 1978 revenue traffic density in reverse direction.

a = ratio of empty car weight to average revenue weight per carload.

b = ratio of empty to loaded car miles.

c = ratio of locomotive weight to trailing train weight.

d = index which assigns commodity groups to service categories (0 or 1).

' = superscript indicating parameter value in 1990.

i = subscript indicating parameter value associated with commodity i(i=1-16).

j = subscript indicating parameter value associated with service category j(j=1-4).

$r_f = \frac{R'_f}{R_f}$ = ratio of 1990 revenue tonnage forward to 1978 revenue tonnage, forward.

$r_r = \frac{R'_r}{R_r}$ = ratio of 1990 revenue tonnage reverse to 1978 revenue tonnage reverse.

g = annual growth of gross traffic density from 1978 to 1990.

## Analytic Equations

The 1978 gross traffic densities for each commodity group in the forward and reverse directions are given, respectively, by:

$$(1)\quad \begin{aligned} G_{Fi} &= [R_{Fi}(1 + a_i) + a_i b_i R_{Ri}] (1 + c_i) \\ G_{Ri} &= [R_{Ri}(1 + a_i) + a_i b_i R_{Fi}] (1 + c_i) \end{aligned}$$

and the 1990 gross traffic densities are given by:

$$(2)\quad \begin{aligned} G'_{Fi} &= [R_{Fi} (1 + a_i) r_{Fi} + a_i b_i R_{Ri} r_{Ri}] (1 + c_i) \\ G'_{Ri} &= [R_{Ri} (1 + a_i) r_{Ri} + a_i b_i R_{Fi} r_{Fi}] (1 + c_i) \end{aligned}$$

To establish the gross traffic density of the four service categories, bulk, normal, expedited and passenger, in the forward and reverse directions, sum the gross traffic density of the relevant commodity groups (index d is determined from question 3 of the Railroad Questionnaire).

$$(3)\quad \begin{aligned} G_{Fj} &= \sum_i d_{ij} G_{Fi} \\ G_{Rj} &= \sum_i d_{ij} G_{Ri} \\ G'_{Fj} &= \sum_i d_{ij} G'_{Fi} \\ G'_{Rj} &= \sum_i d_{ij} G'_{Ri} \end{aligned}$$

The annual compound growth rate in percent for each of the four service categories in the forward and reverse direction is given by:

$$(4)\quad \begin{aligned} g_{Fj} &= 100 [(G'_{Fj}/G_{Fj})^{1/12} - 1] \\ g_{Rj} &= 100 [(G'_{Rj}/G_{Rj})^{1/12} - 1] \end{aligned}$$

If $R_f$ and $R_r$ are input in tons per year, the 1978 gross traffic densities computed by equations (1), (2), and (3) are in tons per year. The total traffic density on the route segment is given by:

$$(5) \quad G = G_f + G_r = \sum_j (G_{fj} + G_{rj})$$

which can be compared with existing ICC data on total 1978 traffic on the route*.

The ratio of equation (3) to equation (5) can be used to portion the ICC traffic density if use of that total density is preferable. Defining the ICC traffic density in 1978 as $G_I$

$$(6) \quad \begin{aligned} G_{Ifj} &= (G_{fj}/G)\ G_I \\ G_{Irj} &= (G_{fr}/G)\ G_I \end{aligned}$$

If $R_F$ and $R_R$ are not available in tons per year but rather as a fraction of total revenue tonnage on the route (per question # 2 of the Railroad Questionnaire) then equation (6) must be used to generate gross tons per year by service category and direction. With $R_F$ and $R_R$ input as ratios, the definition of $G_F$ and $G_R$ becomes the ratios of gross to revenue traffic.

## Assumptions of Traffic Forecast Formulation

The following assumptions were made in formulating equations (1)-(6):

a) The growth in revenue tonnage by commodity and direction on a route segment is uniform over the 12 years of the forecast.

---

*If the ICC data are available in some other base year, then equation (3) must be escalated to that year using equation (4) in order to make the comparison using equation 5.

b) National statistics on the ratios of empty to loaded car weight and car-miles for each commodity group apply in either direction and on any route segment.

<u>Computer Program For Calculating The Traffic Split & Growth Rates by Type of Service</u>

There is an optional fortran program available to assist the user in preparing link data files. If no trailing traffic densities are known by type of service, and if no composite growth rates are known by type of service, then this auxilliary program may be helpful. However, the user will still need the following kind of information:

For each link -

1. A figure for the gross total tons of traffic density for some input year of data.

2. Revenue ton percentages by 16 commodities in each direction.

3. Growth rates by link for each of the 16 commodities in each direction.

For all links -

4. Constants for converting revenue tons into gross tons and year of tonnage data.

This information must be prepared in data files similar to the utility files of the economic model. The auxilliary program will then generate, for each link prepared:

1. Eight gross total* traffic densities, by type of service and direction, for the year 1980, and

2. Eight annual growth rates by type of service and direction,

There will also be some intermediate gross ton commodity information between the reprinted input and final output.

The Input Files

The first file that this program needs is "ABC.DAT", referred to by item 4 above. There are three types of constants needed for converting from revenue tons to gross tons. The first two are commodity specific, the last is service category specific. They are:

The "A" Constants - Ratio of empty car weight to average revenue weight per car by commodity.

The "B" Constants - Ratio of empty to loaded car miles by commodity.

The "C" Constants - Ratio of total train weight to trailing gross weight.

The figures used for the DOT study were as follows for the 16 commodities listed:

*Note: As it happened, this program generated total train weight and the model ultimately used trailing weight, necessitating dividing the output totals by the "C" constants.

| Commodity | A | B |
|---|---|---|
| Coal | .359 | .910 |
| Chemicals | .466 | 1.060 |
| Grain | .412 | .910 |
| Iron Ore | .359 | .910 |
| Forest Products | .359 | .910 |
| Non-Metallic Minerals | .359 | .910 |
| Pulp & Paper | .881 | .694 |
| Metals | .397 | .858 |
| Stone | .359 | .910 |
| Cement | .558 | .776 |
| Grain Mill Products | .881 | .694 |
| Food | 1.240 | .771 |
| Transportation Equipment | .967 | .940 |
| Lumber | 1.370 | .880 |
| Other Products | .881 | .694 |
| Passenger | ----- | ----- |

The locomotive weight factors were all 1.08 for each type of service.

To convert directional revenue percentages, XF and XR, of traffic forward and reverse into a share of the gross traffic total, the program separates the commodity traffic into four parts:

1. Loaded forward cars travelling forward;

2. Loaded reverse cars travelling reverse;

3. Empty forward cars travelling reverse;

4. Empty reverse cars travelling forward.

The factors are combined algebraically as follows:

For 1. We have $(1 + A) * XF$

For 2. We have $(1 + A) * XR$

For 3. We have A*B * XF

For 4. We have A*B * XR

Then the total forward is:

(1 + A) * XF + A*B * XR

and the total reverse is:

(1 + A) * XR + A*B * XF

These two values are then each multiplied by C (= 1.08) to add in the locomotive weight.

The A's are entered in 16 blocks of 5 columns as are the B's. The last digit should be in the rightmost column of each block. The C's are entered in 4 blocks of five columns with their digits rightmost as well. The appearance of the DOT values in the data file is shown by the following table:

ABC.DAT

Column number across -

| 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .359 | .466 | .412 | .359 | .359 | .359 | .881 | .397 | .359 | .558 | .881 | 1.24 | .967 | 1.37 | .881 | .000 |
| .910 | 1.06 | .910 | .910 | .910 | .910 | .694 | .858 | .910 | .776 | .694 | .771 | .940 | .880 | .694 | .000 |
| 1.08 | 1.08 | 1.08 | 1.08 | | | | | | | | | | | | |

The second file needed by the auxilliary program is the file containing the link information - "RRQSTN.DAT" - the two-letter ID code, the node numbers, the 1980 total traffic density, and the 16 directional revenue splits and growth rates for each link prepared. The total length of the file for each link is 17 records.

The letters, nodes and 1980 traffic density for each link are entered in three blocks of the first record. The first two are five columns long containing the letters and numbers anywhere within them. However, it is suggested that they be coded in the way described in Section 4.2.3, the link data input section. Then cross referencing is faster between the two files. The density is then entered in a block of 10 columns with the last digit or decimal point entered in column number 20. This 1980 density need only be in millions, e.g., 23.4 for 23,400,000. If several different densities may be tried, a 1.00 should be entered which will yield multipliers at the bottom of the output instead of densities.

The last 16 records are all entered the same way - in four blocks of 10 columns with the last digit or decimal point in the tenth column of each block. Each record corresponds in order to each of the 16 commodities as listed. The four values for each record/commodity are: 1. The forward growth rate; 2. The reverse growth rate; 3 The commodity's share of forward traffic; and 4. The commodity's share of reverse traffic.

The revenue shares can be in tons, in percent, or any other way as long as the relative proportions of weight in each direction are preserved.

The following table is a sample for a link prepared for this auxiliary program ("RRQSTN.DAT"):

Column number across -

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 1 | 2 | 2 | 3 | 3 | 4 |
| 1 | 5 | 0 | 5 | 0 | 5 | 0 | 5 | 0 |

| | | | |
|---|---|---|---|
| RR 83172 1.0000 | | | |
| 0.1 | 0.1 | 0.6 | 29.6 |
| 2.3 | 0 | 16.4 | 1.2 |
| 3.1 | 2.4 | 2.2 | 6.5 |
| 0 | 0 | 0 | 0 |
| 2.0 | 0 | 0.4 | 0 |
| 0 | 0 | 0.1 | 0.2 |
| 0 | 0 | 0.1 | 0.6 |
| -0.1 | -0.5 | 0.9 | 2.1 |
| 0.9 | 0 | 1.5 | 1.4 |
| 0 | 0.4 | 2.7 | 0.8 |
| 2.5 | 3.1 | 1.9 | 6.7 |
| 2.7 | -0.3 | 2.5 | 1.0 |
| 3.7 | 2.1 | 1.9 | 0 |
| 0.3 | 0.7 | 0.6 | 2.7 |
| 4.1 | 2.6 | 3.3 | 2.3 |
| 4.1 | 2.6 | 3.3 | 6.0 |

## The Output

The output for each link prepared and run is printed on a single sheet. There are three divisions of the output. The first is an echoing back of the link inputs for verification. The service category assigned to each commodity is printed in digit code from 1 to 4:

1. Bulk type of service;
2. Normal type of service;
3. Expedited type of service;
4. Passenger type of service

The values echoed back are in the same order as those read from the link input file, "RRQSTN.DAT". Although any order is allowed for the A'S, B'S, and link commodity data, they must agree with each other throughout the program. To alter the service category assigned to each commodity requires a programmer to change and recompile the program. The order currently expected in relation to this assignment is the order listed on Page G-5.

The second part contains gross tonnage information for each commodity that does not have a meaningful total, but does have relative weight for each commodity presented. This is useful for checking individual commodities.

The bottom of the page contains the two lines needed for the rail electrification assessment model. Each set of four numbers corresponds to the service categories in the order of bulk, normal, expedited, and passenger. The final eight traffic densities have been scaled to total to the input 1980 density listed at the top. These densities include locomotive weight.

The page of output appears in Figure G-1 for the sample route segment.

Program Operation

The user follows several steps to generate the results. First, the input files, ABC.DAT and RRQSTN.DAT, must be created and ready on disk.

Second, any file names "RRLINK.DAT" should be renamed to avoid being replaced by the output file of this program:

(.)RENAME RRLNK2.DAT=RRLINK.DAT

Third, the program "GROWTD.FOR" must exist - either copied off of the DOT study tape or entered line by line by a programmer (see program code, Table G-1, at end of this appendix).

LINK: UR999 UTOWN YARD TO UCITY, USA

1980 INPUT TRAFFIC DENSITY: 1,000 (MRT/YR)

FORWARD

| REVENUE % | GROWTH % | SERVICE |
|---|---|---|
| 0.380 | -69.0 | 2 |
| 15.910 | 75.3 | 2 |
| 2.340 | 39.0 | 2 |
| 0.050 | 0.0 | 2 |
| 0.120 | 22.2 | 2 |
| 0.310 | 32.2 | 2 |
| 0.980 | 0.0 | 2 |
| 1.730 | -8.9 | 2 |
| 1.210 | -1.8 | 3 |
| 1.060 | 17.4 | 2 |
| 1.490 | 30.8 | 2 |
| 1.880 | 21.5 | 2 |
| 0.590 | 40.2 | 3 |
| 0.940 | -6.3 | 2 |
| 7.110 | 43.0 | 3 |
| 3.660 | 43.0 | 2 |

FORWARD

| GROSS 1979 | GROSS 1990 | GROWTH % |
|---|---|---|
| 0.558 | 0.191 | -9.299 |
| 25.797 | 42.122 | 4.558 |
| 3.988 | 5.340 | 2.691 |
| 0.391 | 0.391 | 0.000 |
| 0.206 | 0.270 | 2.418 |
| 0.963 | 1.236 | 2.292 |
| 1.544 | 1.522 | -0.131 |
| 3.187 | 2.939 | -0.732 |
| 8.007 | 7.449 | -0.655 |
| 2.180 | 2.520 | 1.328 |
| 6.781 | 9.090 | 2.696 |
| 4.477 | 5.268 | 1.489 |
| 2.363 | 3.046 | 2.335 |
| 44.944 | 35.901 | -2.021 |
| 16.233 | 22.351 | 2.950 |
| 8.082 | 11.153 | 2.971 |

SERVICE LEVEL GROWTH RATES (%):
FORWARD

| | | | |
|---|---|---|---|
| 0.0000 | 1.2301 | 1.9348 | 0.0000 |

1980 SERVICE LEVEL TRAFFIC DENSITIES (MGT/YR):
FORWARD

| | | | |
|---|---|---|---|
| 0.0000 | 0.3619 | 0.0940 | 0.0000 |
| BULK | NORMAL | EXPD. | PASS.* |

FIGURE G-1.

DISTANCE: 501.3 (MI)

REVERSE

| | | REVENUE % | GROWTH % | SERVICE |
|---|---|---|---|---|
| COAL | INPUT* | 0.000 | 0.0 | 2 |
| GRAIN | | 3.790 | 0.0 | 2 |
| CHMCL | | 0.530 | 16.3 | 2 |
| IRON | | 0.900 | 0.0 | 2 |
| GRVL& | | 0.090 | 95.5 | 2 |
| NMETL | | 1.440 | 30.4 | 2 |
| FORPD | | 0.300 | -22.5 | 2 |
| GLSS& | | 0.590 | -3.6 | 2 |
| FOOD | | 4.920 | -10.9 | 3 |
| MLLPD | | 0.040 | -3.3 | 2 |
| PAPER | | 5.690 | 43.1 | 2 |
| METAL | | 4.460 | 15.8 | 2 |
| TRANP | | 1.130 | 22.6 | 3 |
| LMBER | | 32.670 | -22.6 | 2 |
| MISFR | | 2.710 | 31.7 | 3 |
| OTHER | | 0.980 | 31.7 | 2 |

REVERSE

| | | GROSS 1979 | GROSS 1990 | GROWTH % |
|---|---|---|---|---|
| COAL | INTERMEDIATE* CALCULATION OF GROSS TONS AND GROWTH IN GROSS TONS BY COMMODITY | 0.134 | 0.046 | -9.299 |
| GRAIN | | 12.222 | 16.557 | 2.798 |
| CHMCL | | 2.087 | 2.667 | 2.253 |
| IRON | | 1.339 | 1.339 | 0.000 |
| GRVL& | | 0.174 | 0.295 | 4.896 |
| NMETL | | 2.223 | 2.837 | 2.242 |
| FORPD | | 0.786 | 0.694 | -1.122 |
| GLSS& | | 1.802 | 1.703 | -0.513 |
| FOOD | | 13.152 | 11.936 | -0.878 |
| MLLPD | | 0.781 | 0.890 | 1.188 |
| PAPER | | 12.543 | 17.313 | 2.973 |
| METAL | | 7.421 | 8.524 | 1.269 |
| TRANP | | 2.980 | 3.683 | 1.945 |
| LMBER | | 84.846 | 67.273 | -2.088 |
| MISFR | | 10.200 | 13.603 | 2.651 |
| OTHER | | 4.408 | 5.917 | 2.713 |

*Explanation added, does *not appear* on printout

OUTPUT*

| | | | | |
|---|---|---|---|---|
| REVERSE | 0.0000 | -0.3330 | 0.9512 | 0.0000 |
| REVERSE | 0.0000 | 0.4519 | 0.0922 | 0.0000 |
| | *BULK | NORMAL | EXPD. | PASS. |

SAMPLE COMPUTER RESULTS

Then the program must be compiled:

```
(.)COMP GROWTD.FOR
```

Fifth, the program is executed. During the execution, the program will ask the user (or programmer) at the terminal to "enter year of tonnage data". At this point, the person at the terminal types in the four digit year that the revenue data was prepared for:

```
(.)EX GROWTD.REL
(LINK:  LOADING)
([LNKXCT GROWTD EXECUTION])

(ENTER YEAR OF TONNAGE DATA:)
1979

(STOP)

(END OF EXECUTION)
(CPU TIME: 2.44   ELAPSED TIME: 17.28)
(EXIT)
```

Now the file "RRLINK.DAT" is ready for printing:

```
(.)PRINT RRLINK.DAT
(LPT01:RRLINK=/SEQ:2321/LIMIT:86, 1 FILE)
```

In the above system, session lines, the characters inside the parentheses, are printed for you. All you type are the characters after the right parenthesis.

TABLE G-1. LISTING OF FORTRAN CODE FOR TRAFFIC MODEL

```
      INTEGER ID(2),L(8)
      REAL A(16),B(16),C(4),TRFDEN(4,2)
      REAL U(2,16),V(2,16),F(2,16)
      REAL UF(4),LF(4),UR(4),LR(4),G(4,2)
      OPEN(UNIT=1,FILE='ABC.DAT')
      OPEN(UNIT=20,FILE='RRQSTN.DAT')
      OPEN(UNIT=22,FILE='RRLINK.DAT')
      WRITE(5,1)
    1 FORMAT(1X,'ENTER YEAR OF TONNAGE DATA:')
      READ(5,*) IY
      Y=1990-IY
      YINV=1./Y
      X=Y-10.
      READ(1,2) A,B,C
    2 FORMAT(16F5.0)
    3 READ(20,4,END-28) ID,DENSTY
    4 FORMAT(2A5,G10.4)
      WRITE(22,5) ID,DENSTY
    5 FORMAT(1H1/1X'LINK: '2A5'   1980 INPUT TRAFFIC DENSITY: 'F10.3)
      DO 6 J=1,4
      TRFDEN(J,1)=0.
      TRFDEN(J,2)=0.
      UF(J)=0.
      LF(J)=0.
      UR(J)=0.
    6 LR(J)=0.
      WRITE(22,7)
    7 FORMAT(/1X,'FORWARD'T66'REVERSE'/6X'REVENUE %'12X,'GROWTH %',
     1 '     SERVICE'T66,6X'REVENUE %'10X'  GROWTH %       SERVICE')
      DO 12 J=1,16
      READ(20,8,END=26) SF,SR,RF,RR
    8 FORMAT(4F10.2)
C
C     PROGRAMMER NOTE: THE COMMODITIES ARE ASSIGNED TO SERVICE CATEGORIES
C     IN THE FOLLOWING LINES.  CHANGES SHOULD BE MADE HERE....
C
      KF=2
      IF(J.EQ.9.OR.J.EQ.13.OR.J.EQ.15) KF=3
      KR=KF
C
      SF2=(SF*.01+1.)**Y
      SR2=(SF*.01+1.)**Y
      AF=C(KF)*(1.+A(J))
      AR=C(KR)*(1.+A(J))
      BF=C(KF)*A(J)*B(J)
      BR=C(KR)*A(J)*B(J)
      U(1,J)=RF*AF+RR*BR
      U(2,J)=RR*AR+RF*BF
```

TABLE G-1. LISTING OF FORTRAN CODE FOR TRAFFIC MODEL (CONT'D)

```
      V(1,J)=SF2*RF*AF+SR2*RR*BR
      V(2,J)=SR2*RR*AR+SF2*RF*BF
      F1=1.
      IF(U(1,J).EQ.0)GOTO 9
      F1=V(1,J)/U(1,J)
      F1=F1**YINV
 9    F2=1.
      IF(U(2,J).EQ.0)GOTO 10
      F2=V(2,J)/U(2,J)
      F2=F2**YINV
 10   F(1,J)=F1*100.-100.
      F(2,J)=F2*100.-100.
      TRFDEN(KF,1)=TRFDEN(KF,1) + U(1,J)
      TRFDEN(KR,2)=TRFDEN(KR,2) + U(2,J)
      UF(KF)=UF(KF) + V(1,J)
      LF(KF)=LF(KF) + U(1,J)
      UR(KR)=UR(KR) + V(2,J)
      LR(KR)=LR(KR) + U(2,J)
      WRITE(22,11) RF,SF,KF,RR,SR,KR
 11   FORMAT(6X,F10.3,10X,F10.2,I10,T66,6X,F10.3,10X,F10.2,I10)
 12   CONTINUE
      WRITE(22,13) IY,IY
 13   FORMAT(/1X'FORWARD'T66'REVERSE'/6X'GROSS 'I4'  GROSS 1990',
     1 '  GROWTH %'T66,6X,'GROSS 'I4'  GROSS 1990  GROWTH %')
      DO 14 J=1,16
 14   WRITE(22,15)((U(K,J),V(K,J),F(K,J))K=1,2)
 15   FORMAT(6X,3F10.3,T66,6X,3F10.3)
      DO 18 J=1,4
      G1=1.
      IF(LF(J).EQ.0)GOTO 16
      G1=UF(J)/LF(J)
      G1=G1**YINV
 16   G2=1.
      IF(LR(J).EQ.0)GOTO 17
      G2=UR(J)/LR(J)
      G2=G2**YINV
 17   G(J,1)=G1-1.
 18   G(J,2)=G2-1.
      WRITE(22,19) G
 19   FORMAT(/1X'SERVICE TYPE GROWTH RATES (%):'/1X,'FORWARD',
     1 T66,'REVERSE'/6X,2P4F10.4,T66,6X,2P4F10.4)
      WRITE(22,20)
 20   FORMAT(12X'BULK'4X'NORMAL EXPEDITED PASSENGER',T66,12X,
     1 'BULK'4X'NORMAL EXPEDITED PASSENGER')
      SUMTRF=0.
      DO 21 J=1,4
      DO 21 I=1,2
      TRFDEN(J,1)=TRFDEN(J,1)*(1.+G(J,I))**X
```

TABLE G-1. LISTING OF FORTRAN CODE FOR TRAFFIC MODEL (CONT'D)

```
21   SUMTRF=SUMTRF+TRFDEN(J,1)
     IF(SUMTRF.EQ.0)GOTO 23
     DO 22 J=1,4
     DO 22 I=1,2
22   TRFDEN(J,1)=TRFDEN(J,1)*DENSTY/SUMTRF
23   WRITE(22,24) TRFDEN
24   FORMAT(/1X,'1980 TRAFFIC DENSITIES BY TYPE OF SERVICE:',
    1 /1X'FORWARD',T66,'REVERSE'/6X,4F10.4,T66,6X,4F10.4)
     WRITE(22,20)
     IF(DENSTY,EQ.0)WRITE(22,25) SUMTRF
25   FORMAT(1X,'TOTAL 1980 GROSS TRAFFIC DENSITY:'F10.3)
     GOTO 3
26   WRITE(22,27) ID
27   FORMAT(1X,'FILE ENDED EARLY FOR ',2A5)
28   STOP
     END
```

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