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Railroad Cost Performance Model

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This paper is one of a series of papers from the Transport Planning Models Study under the direction of Mr. Jan de Weille and Mr. Leon H. Miller. The overall objective of the Study is the continuing investigation of mathematical models developed for use in transport planning. The Study will analyze existing transport models, revise and extend the models where practical, and develop new models where needed. An evaluation of the models will include their application in transport planning studies and a critical review of the methodology.

This paper is based on Appendix 4 of the Harvard University Transport Research Program report "An Analysis of Investment Alternatives in the Colombian Transport System", by Paul O. Roberts, David T. Kresge, and John R. Meyer, (Cambridge, Massachusetts, September, 1968). The member of the Bank Study working on this portion of the study was Leon H. Miller. The Harvard presentation has been amplified by including sample computer inputs and outputs, a listing of the computational equations, and a dictionary of terms. Also, editorial and other changes in the text have been made to improve the presentation.

This paper is expository in nature; no attempt has been made to critically evaluate the model. A critique will be covered in a subsequent paper. Bank staff members are invited to make comments and suggestions for improvement of the model.

Sector and Projects Studies Division

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RAILROAD COST PERFORMANCE MODEL

I. THE MODEL

The Railroad cost performance model is used to develop the operational costs and performance measures for a single track rail link. The objective of the model is to transform the operational demands, physical characteristics of different road-links and the rail equipment into operational costs and the performance measures for a link. Performance measures are such things as travel time, waiting for service time, delivery time variability and probability of loss. The operational and performance results may be used to analyze alternative options for a particular link or may be used as input to a transportation network system model. The model is deterministic in that average values are used rather than random values for the model variables.

The model is designed to analyze the rail system on a link-to-link basis using the traffic demands, the individual link's characteristics, i.e. no. of sidings, ruling grade, average grade, and type of signalling and the associated rail equipment. With the model, the effect upon operating costs and performance measures can be obtained under the different conditions. Thus the model can be used to analyze present conditions along with alternative proposals - increased traffic, different locomotives, number of sidings, grades, etc.

A considerable number of trade-offs exist in determining the number of trains that can be operated in any one direction over an existing rail line. Unlike a highway, where flows in both directions are usually permitted, railroad flows are often uni-directional. Even where a single lane highway exists, passing requirements are less stringent since opposing vehicles may simply reduce speed and share the paved portion. In order to increase the potential for opposing rail traffic, siding spacing may be reduced, sidings lengthened or signal systems may be improved. At one extreme, a single track line may be operated entirely as a one way route, having neither signals nor sidings. At the other extreme, a continuous siding, i.e., second or third track, with centralized traffic control may be employed. The first case requires more rolling stock and locomotive power to handle a specified tonnage whereas in the second case, the rolling stock requirements are reduced at the expense of increased investment in sidings and signal equipment. Of course, intermediate cases exist, such as the use of a single track with sidings and trains proceeding under special orders and time table rules.

In most cases, the specifics of the situation, tonnage, nature of the cargo, topography, length of the line, and extent of the railroad system, will determine which technology or operating procedure is to be preferred. For this reason, it is difficult to generalize on railroad cost functions. The procedure to be followed in the following sections involves simulating the performance of a simple railroad line, operating over a stated distance without intermediate stops.1/

A. Computational Procedure

The procedure by which the data are combined to compute various performance characteristics for a particular rail link is described in flow chart form in Figure 1. This simulation model is designed to provide such performance measures as average cost per ton and average running times for all trains using the link as opposed to the specific details about particular train performance that can be obtained from a Train Performance Calculator.2/

Thus, calculations are made for an "average" size train, as determined by available locomotive power and ruling grade, even though in specific instances both larger and smaller trains might be operated in accordance with fluctuations in traffic volume.

Details of the computational procedure will be described later in the paper. Briefly, however, this procedure can be summarized by the following steps.

1. Allowable tonnage per train for the available locomotive power and ruling (maximum) grade of link is computed.
2. Given the characteristics of the cars available to haul each commodity group, such as tire weight and payload, the revenue load capacity of a single train is determined.

1/ Generalized work stops, delays, etc. could be included, however.

2/ Train Performance Calculators are used by some operating railroads to determine speed and time profiles and fuel consumption for a train of a specific make up (that is, number and horsepower of locomotives and number and weight of cars), operating over a line for which detailed profile and alignment information is available. Several such programs are available including programs developed by the Pennsylvania Railroad, Canadian National Railways, Canadian Pacific and the Southern Railroad.

3. The number of daily trains required for the time period under consideration is determined by dividing the revenue load capacity of a single train into the average daily traffic.
4. For a single train, the average running speed is calculated by determining the speed at which the tractive effort developed by the locomotive just equals the rolling and grade resistance encountered on the average grade.
5. Average running time over the link is adjusted to account for delays enroute. These delays depend upon daily traffic, length of link, number of sidings and type of signal system.
6. Rolling stock requirements are calculated on the basis of adjusted running time and terminal turnaround time.
7. Operating statistics, such as train-miles, train-hours and car-miles, are summarized for the link. Total costs of operation, maintenance and depreciation costs are then determined on the basis of these operating statistics.

The necessary link information and volume data are provided as exogenous input for the program. Other information, such as tire weight and payload of vehicles for each of the commodity groups, horsepower and weight of different locomotive types (also specified exogenously) and various operating cost coefficients are stored internal to the program in the form of data tables. A sample of this data is shown in Appendix A.

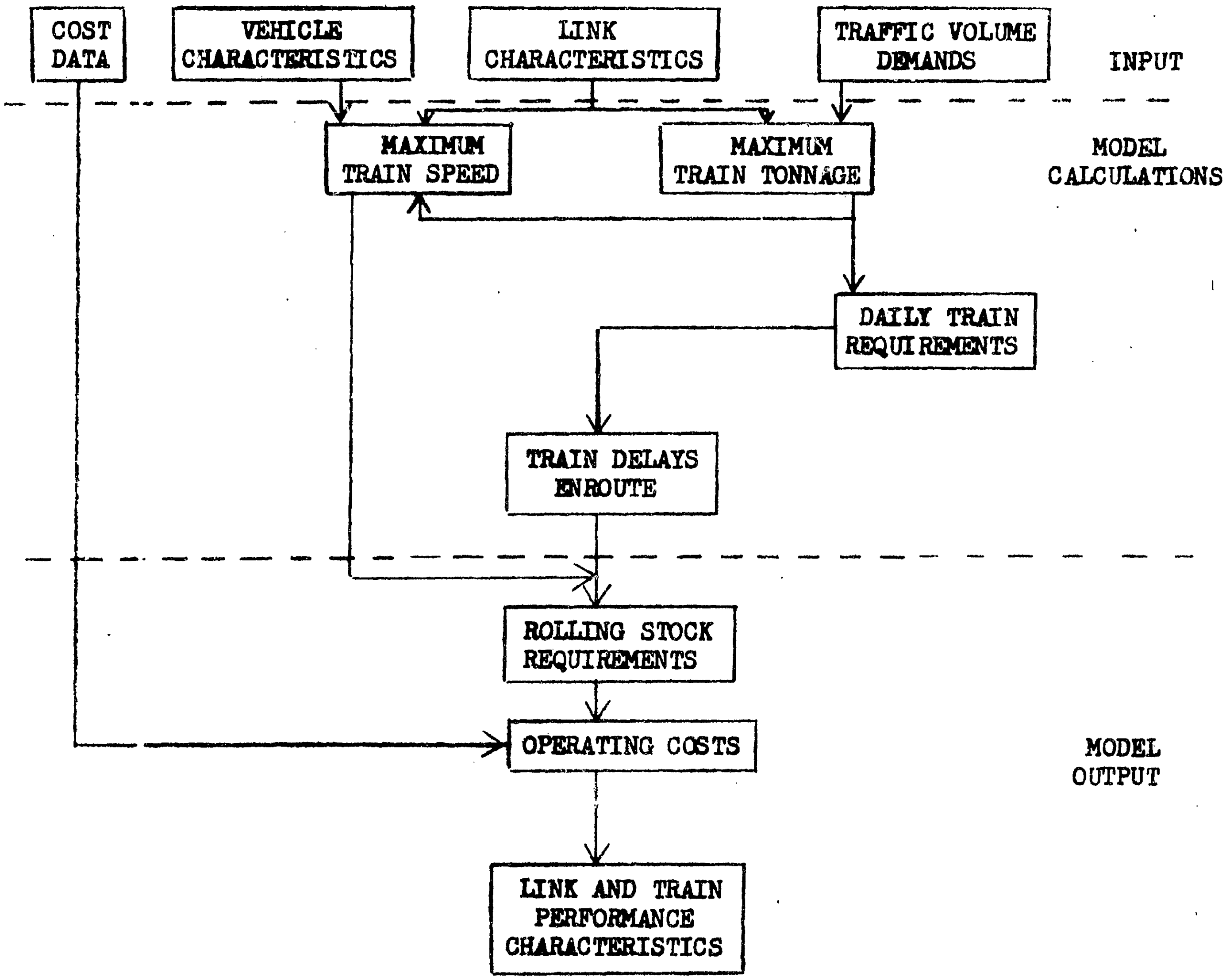
B. Input Data

The computational procedures for the model with the associated inputs were depicted in Figure 1. There are four general areas of data: 1) Vehicle Equipment Characteristics, 2) Link Characteristics, 3) Traffic Volume Data, 4) Cost Data. The volume of traffic data and the link characteristic data are input for each link analysis; whereas, the vehicle equipment and cost data are input to the basic program and remain constant for a particular set of runs.3/

3/ This design of the model is not essential. The program may be altered easily to take the equipment data as input and not part of the basic program.

Figure 1

Computational Procedure Employed in the Rail Simulation Model



C. Link Characteristics

The costs associated with moving a given quantity of cargo over a railroad link depend to some extent on the physical characteristics of that link and the makeup of trains. In particular, costs will depend upon:

1. Length of the link, DIS
2. Speed limitations due to excessive curvature, condition of the track or other physical features of the line that cause the train to travel at less than its maximum possible speed, VMAX
3. Minimum allowable speed which can be tolerated due to locomotive overheating, etc., VMIN
4. Ruling or maximum grade in each direction, GMAX
5. Average grade or rate of rise and fall in each direction, GAV
6. Number of sidings, NS
7. Signal system waiting time category, LSTD
8. Switching system waiting time category, ISC
9. Locomotive type, LT
10. Number of locomotives per train, TNL

Items 1 and 2 are more or less self-explanatory. Items 3 and 4 make it necessary to provide sufficient locomotive power to assure a minimum speed for the ruling grades. In such cases, it will usually be more efficient to reduce locomotive power for the overall line and provide helper locomotives on the ruling grade section. Item 5 is the average grade encountered over the link. Grade distinctions are indicated by direction. Item 6 gives the number of siding and items 7 and 8 give some indication of the quality of the signal and switching systems. The switching delay at sidings, for example, depends upon whether switches are operated manually or automatically by remote controlled power devices. By specifying switch and signal categories as inputs, appropriate coefficients for calculating delays are obtained from a data table that is part of the simulation program. See Table 1. A sample link characteristic input card is given in Appendix A.

D. Volume Characteristics

Because of differences in equipment requirements and the train make-up and classification times associated with different types of equipment, volume data are separated into commodity classifications. Three freight commodity categories are used as indicated by the appropriate index shown below in addition to one passenger category.

1. Bulk cargo, ICLAS = 1
2. General cargo, ICLAS = 2
3. Special cargo, ICLAS = 3
4. Passenger, ICLAS = 4

Bulk commodities are assumed to move in open gondola cars or flatcars, general cargo in box cars and special cargo in refrigerated, tank cars or other specialized equipment. For each category, volumes for the time period under consideration, such as annual or seasonal volumes, are specified in terms of average daily tonnages for each category, ADT (ICLAS). From the tonnage flows the vehicle requirements, ADV (ICLAS) are determined. A sample Traffic Volume data card is given in Appendix A. The traffic flow may also be input as vehicles required per day as well as in tons per day.

E. Vehicle Characteristics

Information on the equipment available for the make-up of trains is necessary for determining maximum train length, average train speed and overall equipment requirements. The following data are necessary:

1. Horsepower of each locomotive type, HP (LT)[4/]
2. Weight of locomotive, WL (LT)
3. Frontal area, A(LT)
4. Fuel consumption rate in gallons per h.p. - hour, FUEL (LT)
5. Number of driving axles, AXLES (LT)
6. Standard locomotive life, SLOCLF (LT)
7. Reserve factor for locomotives, RFLOC (LT)
8. Yard time for locomotives, YTL (LT)

4/ LT - Locomotive Type

9. Capital recovery factor for locomotives, CRFL (LT)
10. Weight of car by class, W(ICLAS)
11. Typical car life, CARLIF (ICLAS)
12. Car reserve factor, CARRF (ICLAS)
13. Typical yard time for cars, YTC (ICLAS)
14. Handling time by class of car, THAND (ICLAS)
15. Capital recovery factor for cars, CRF (ICLAS)

Sample values for vehicle characteristics are shown in Appendix A.

F. Cost Information

The necessary cost information for depreciation, operation and maintenance must be provided for the model. This data is broken down into the cost of locomotives and cars, fixed annual costs, variable costs, crews and fuels. Other factors included are ratios of overhead costs and lubricating oil consumption. These items are:

1. Cost of car (CARCST) (I)
2. Cost of locomotive (CSTLOC)
3. Annual fixed component of maintenance costs for other rolling stock (A1)
4. Annual fixed component of maintenance costs for locomotive (A2)
5. Annual track fixed component of maintenance costs in $/mile (A3)
6. Variable component of maintenance costs/car for other rolling stock per car-mile (B1)
7. Variable component of maintenance costs per locomotive, per locomotive-mile (B2)
8. Annual variable component of maintenance costs in $/gross ton-mile (B3)
9. Crew costs in dollars/train-mile (B4)
10. Fuel cost in $/gallon (B5)
11. Cost of lubricants in $/gallon (B6).
12. Ratio of traffic costs to total maintenance and operating cost (B7)
13. Ratio of overhead costs/total maintenance and operating costs (B8)
14. Oil ratio in gallons of fuel oil/gallon of lubricating oil (OR).

Sample values for the cost information are shown in Appendix A.

II. DETAILS OF MODEL COST PERFORMANCE CALCULATIONS

This section is devoted to the details of the calculations for determining the equipment requirements and the operating costs of the rail link being considered. Each of the model relationships is given below in computational sequence.

A. Computation of Allowable Train Tonnage[1/]

The maximum tonnage which can be hauled in one train depends upon the tractive effort which can be developed by the locomotive, the ruling grade and the minimum acceptable speed on that ruling grade and the physical characteristics of the locomotives and cars used, such as weight, number of axles and payload. Tractive effort depends upon the net rated horsepower[2/] of the locomotives and locomotive speed as given by the equation.

$$TE = \frac{375 \cdot (.82) \cdot (HP) \cdot (TNL)}{V}$$

$$= \frac{308\ (HP) \cdot (TNL)}{V} \qquad (1)$$

where,

.82	=	efficiency factor
TE	=	tractive effort in lbs.
HP	=	net horsepower of one locomotive
TNL	=	total number of locomotives per train
V	=	train speed in m.p.h.

In this case, tractive effort is computed for VMIN, the minimum acceptable train speed on the ruling grade.

1/ The references used to obtain the allowable train tonnages used American units - e.g. short tons, miles, mph, etc. and the equations are presented as such. However, the computer program is designed to use either metric units or American units in the input and output.

2/ net horsepower = rated output-horsepower furnished auxiliaries.

Tractive effort can be increased by reducing the minimum speed. For diesel-electric locomotives, however, the minimum speed is usually limited to about 10 m.p.h., due to overheating of electric motors at low speeds.

Level tangent rolling resistances for the first locomotive and successive locomotives are given by Equations 2 and 3 respectively. There is a difference in the two equations because the first locomotive encounters a higher air resistance than successive locomotives.

$$\text{SRR (1)} = 1.3 + \frac{29 \text{ AXLES}}{\text{WL}} + 0.03 \text{ V} + \frac{0.0024 \text{ A} \cdot \text{V}^2}{\text{WL}} \qquad (2)$$

$$\text{SRR (2)} = 1.3 + \frac{29 \text{ AXLES}}{\text{WL}} + 0.03 \text{ V} + \frac{0.0005 \text{ A} \cdot \text{V}^2}{\text{WL}} \qquad (3)$$

where,

SRR(1) = level tangent rolling resistance for the first locomotive, in pounds per ton,
SRR(2) = level tangent rolling resistance for each successive locomotive, in pounds per ton,
AXLES = number of driving axles on each locomotive,
WL = weight of the locomotive in tons and
A = cross section area of the locomotive, in square feet.

Net tractive effort available for hauling cars is given by Equation 4.

$$\text{SNETE} = \text{TE} - \text{WL} \left[\text{SRR(1)} + \text{SRR(2)} \cdot (\text{TNL} - 1) + 20\text{G} \cdot \text{TNL} \right] \qquad (4)$$

where,

SNETE = net tractive effort, in pounds and
G = grade, in percent.

For this computation, the ruling grade, GMAX, is used.

The total number of cars that can be hauled depends upon the resistance encountered by each car. Since cars used to carry the various commodity types differ with respect to their physical characteristics (tare weight and payload capacity), a weighted average resistance is computed, based on the relative numbers of each car type. Thus, for each car of Type 1,

$$\text{WEIGH(I)} = \text{W(I)} + \text{P(I)} \cdot \text{VLODFC(I)} \qquad (5)$$

$$TR(I) = 116.0 + 0.045V^2 + WEIGH(I) \, [1.3 + 0.045V + 20G] \tag{6}$$

where,

WEIGH(I) = combined weight, in tons,
W(I) = weight of car, in tons,
P(I) = payload capacity, in tons,
VLODFC(I) = load factor and
TR(I) = total resistance, in pounds.

If it is assumed that the relative proportion of different car types in an average train is related to the average daily volume for each commodity group weighted by the payload factor for that group, then the weighted average total resistance per car is given by Equation 7.

$$WTR = \sum_{I=1}^{N} \frac{ADT(I) \cdot TR(I)}{P(I) \cdot VLODFC(I) \cdot DENOM} \tag{7}$$

Furthermore,

$$TNCARS = \frac{SNETE}{WTR} \tag{8}$$

where,

WTR = weighted average total resistance per car, in pounds,

TNCARS = total number of cars per train,[1/]

$$DENOM = \sum_{I=1}^{N} \frac{ADT(I)}{P(I) \cdot VLODFC(I)} \tag{8a}$$

ADT(I) = average daily traffic for commodity group I and

1/ Because of line operating restrictions an absolute maximum number of cars per train may be imposed.

N = NTYPES = number of commodity groups carried over the line.

For a particular group,

$$CARS(I) = \frac{ADT(I) \cdot TNCARS}{P(I) \cdot VLODFC(I) \cdot DENOM} \quad (9)$$

and

$$TOTLOD = \sum_{I} CARS(I) \cdot P(I) \cdot VLODFC(I) \quad (10)$$

where,

CARS(I) = number of cars of Type I per train and
TOTLOD = total tonnage per train.

The number of daily trains, DT, required to handle the average total daily traffic is thus given by Equation 11.

$$DT = \frac{\sum_{I=1}^{N} ADT(I)}{TOTLOD} \quad (11)$$

B. Computation of Minimum Running Time

Determination of train running speed involves a cubic equation, which is a function of tractive effort and train resistance for the average grade. Balancing speed is that speed at which the resistance to motion encountered by the train is just equal to the tractive effort developed by the locomotive. As previous equations have shown, an increase in train speed increases train resistance and decreases tractive effort. These computations are made on the basis of the average gradient encountered and a train composition determined by the ruling grade, as discussed in the preceding section. The cubic equation is developed from setting

$$SNETE = TRR \quad (12)$$

where SNETE is developed in Equation 4 and

$$TRR = \sum_{I} TR(I) \cdot CARS(I) \quad (13)$$

where,

TRR = total train resistance, in pounds and
TR(I) AND CARS(I) are obtained from Equations 6 and 9, respectively.

Both Equations 4 and 6 are functions of the unknown value V. Rearranging the terms which result from the equality defined by Equation 12 will produce an equation which is a cubic function of V. The value of the coefficients of this equation are such that only one real value of V exists that is greater than or equal to VMIN, namely VAV. Minimum running time is then determined from Equation 14,

$$TRO = \frac{DIS}{VAV} \tag{14}$$

where,

TRO = minimum running time in hours (outbound) and
VAV = average speed, in m.p.h., where Equation 12 holds.

A distinction is made between outbound and inbound running times for purposes of the train delay calculations discussed in the following section. Inbound running time is calculated in the same manner for average grade, ruling grade and daily traffic.

C. Train Delay Calculations

Calculations of delays encountered enroute due to traffic congestion are based on the assumption of a single track line with sidings sufficiently long to accommodate one train. Time-distance curves for inbound and outbound trains along such a line are shown in Figure 2. In the following equations, the suffixes "O" and "I" denote outbound and inbound directions respectively. In developing the model for train delays, the following symbols are used:

DTO, DTI = daily trains out; daily trains in,
TRO, TRI = minimum running times (as determined in the previous section), in hours,
TRAVO, TRAVI = average running times, in hours,
K = average delay per meet, in hours,
ST = switching time per train taking the siding, in hours,
WT = waiting time per train taking the siding, in hours, and
M = number of meets.

If an outbound train leaves at time $t = 0$, it will encounter two groups of inbound trains, namely (1) those inbound trains already on the line and (2) those inbound trains leaving after time $t = 0$ and before the outbound train has arrived at the other end, TRAVO hours later. The first group includes all trains leaving during the period $t = -$ TRAVI to $t = 0$. Assuming departures at both ends of the link are uniformly distributed over a 24 hour period, the total number of trains encountered by an outbound train is given by:

$$\text{Meets} = \frac{\text{DTI}}{24} \left[\text{TRAVI} + \text{TRAVO} \right] \tag{15}$$

$$\text{TRAVO} = \text{TRO} + \text{K} \cdot \text{M} \tag{16}$$

Thus,

$$\text{TRAVO} = \text{TRO} + \frac{\text{K} \cdot \text{DTI}}{24} \left[\text{TRAVI} + \text{TRAVO} \right] \tag{16a}$$

which reduces to

$$\text{TRAVO} = \frac{\text{TRO} + \frac{\text{K} \cdot \text{DTI}}{24} \left[\text{TRAVI} \right]}{1 - \frac{\text{K} \cdot \text{DTI}}{24}} \tag{16b}$$

Similarly,

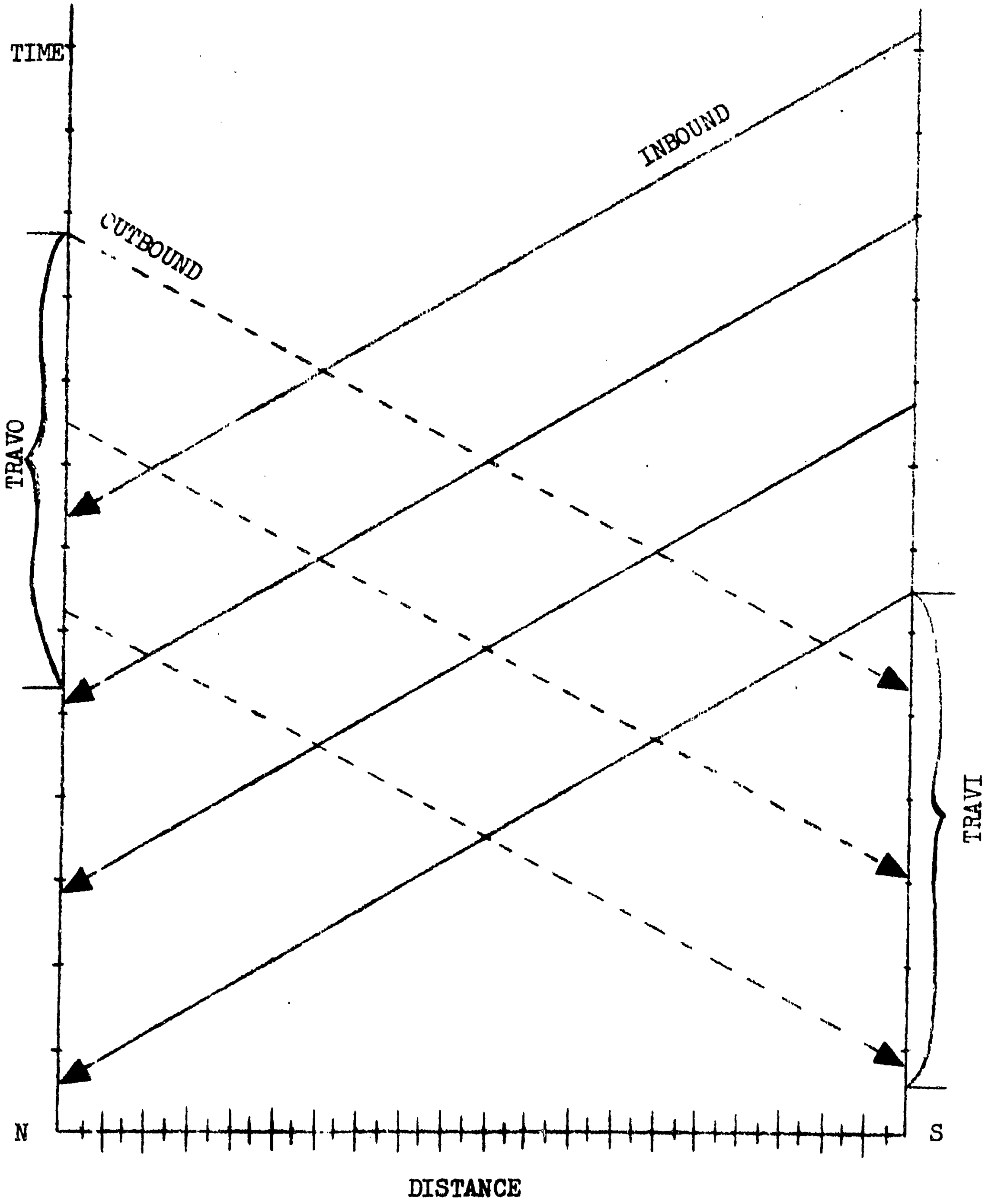
$$\text{TRAVI} = \text{TRI} + \text{K} \cdot \text{M} \tag{17}$$

$$\text{TRAVI} = \text{TRI} + \frac{\text{K} \cdot \text{DTO}}{24} \left[\text{TRAVO} + \text{TRAVI} \right] \tag{17a}$$

$$\text{TRAVI} = \frac{\text{TRI} + \frac{\text{K} \cdot \text{DTO}}{24} \left[\text{TRAVO} \right]}{1 - \frac{\text{K} \cdot \text{DTO}}{24}} \tag{17b}$$

Figure 2

Time-Distance Curves for a Single Track Line



Substituting Equation 17 in Equation 16b,

$$\text{TRAVO} = \frac{\text{TRO} + \left[\dfrac{K \cdot \text{DTI}}{24}\right] \cdot \left[\dfrac{\text{TRI} + \dfrac{K \cdot \text{DTO} \cdot \text{TRAVO}}{24}}{1 - \dfrac{K \cdot \text{DTO}}{24}}\right]}{1 - \dfrac{K \cdot \text{DTI}}{24}} \tag{18}$$

If the assumption is made that DTI = DTO = DT, then Equation 18 can be reduced to

$$\text{TRAVO} = \frac{576\ \text{TRO} + 24\ K \cdot \text{DT} \cdot [\text{TRI} - \text{TRO}]}{576 - 48\ K \cdot \text{DT}} \tag{19}$$

Similarly,

$$\text{TRAVI} = \frac{576\ \text{TRI} + 24\ K \cdot \text{DT} \cdot [\text{TRO} - \text{TRI}]}{576 - 48\ K \cdot \text{DT}} \tag{20}$$

The value of K, waiting time per meet, depends upon the nature of the signal system, the type of switches and the efficiency of the train dispatch. These characteristics are summarized by the two indices provided as input to the program, such that

$$K = ST(I) + WT(J) \tag{21}$$

where,

ST(I) = switching time associated with switch type I and
WT(J) = waiting time associated with signal system J.

Under optimum conditions, trains would pass "on the run" and no train would be forced to stop at the siding. Under the worst conditions, inbound and outbound trains would arrive at opposite ends of the single track section simultaneously. In this case, one train would be forced to wait for the opposing train to travel the distance between the two sidings. Since only one train is forced to stop, on the average this waiting time would be one half the running time between successive sidings. For intermediate situations, train delays would range between zero and one-half the running time between sidings. The program now allows for three different signal and switch categories. The delays associated with each are extracted from a data table for the appropriate index provided as input, as shown in Table 1.

Table 1

Switching and Waiting Time Delays

Category	Siding Switching Delay in hours	Waiting Time in hours
I or J	ST(I)	WT(J)
1	0.10	TRO/10 (NS+1)
2	0.25	TRO/ 4 (NS+1)
3	0.25	TRO/ 2 (NS+1)

D. Determination of Equipment Requirements

Equipment requirements depend principally upon the daily tonnage of each commodity type, payload and load factor of the appropriate car and the time required for a car to make one trip. The latter is referred to as the block time and is given by

$$TBC(I) = TLU(I) + TRAVO + YTC(I) \tag{22}$$

where,

TBC(I) = block time for Type I cars, in hours,
TLU(I) = time to connect and/or disconnect the cars carrying Type I commodities, in hours,
= THAND (I) · CARS (I),

THAND(I) = average "handling" time for cars carrying Type I commodities, in hours and
YTC(I) = yard time for Type I cars, in hours.

Loading and unloading times depend upon the nature of the cargo and the ratio of backhaul to outbound cargo. Handling rates, THAND(I), are incorporated as internal data and are respectively 0.01, 0.10, and 0.01 hours per car for bulk, general and cargo requiring specialized equipment.

The number of "sets" of Type I cars is given by Equation 23, rounded to the next whole number, which is then used to determine the total number of cars required for each commodity group, as in Equation 24.

$$ANT\ (I) = DT\ \frac{TBC(I)}{24} \tag{23}$$

$$ANO\ (I) = ANT\ (I) \cdot CARS\ (I) \cdot [1 + CARRF\ (I)] \tag{24}$$

where,

ANT(I) = number of sets of Type I cars, where a "set" is defined as a group of cars of the same type in one train,
ANO(I) = total number of Type I cars required and
CARRF(I) = reserve factor for Type I cars to allow for routine maintenance periodic overhaul and stand-by expressed as a decimal fraction.

Values of CARRF are included in the internal data table. The total number of locomotives required to operate the line are determined in a similar manner. The relevant equations are:

$$TBL = TRAVO + YTL \tag{25}$$

$$STLOCS = DT\ \frac{TBL}{24} \tag{26}$$

$$TLOCOS = STLOCS \cdot TNL \cdot [1 + RFLOC] / LUF \tag{27}$$

where,

TBL = locomotive block time, in hours,
STLOCS = number of sets of locomotives,
TLOCOS = total number of locomotives and
RFLOC = locomotive reserve factor, expressed as a decimal fraction of TLOCOS.
LUF = Locomotive Utilization Factor

E. Operating Cost Calculations

Operating cost calculations are based on various operating statistics that can now be summarized from the above calculations. These operating statistics include gross ton-miles, train-miles and car-miles. These can be computed from the following equations:

$$TRAMIL = DT \cdot DIS \cdot DAYS \tag{28}$$

$$CARMIL = TNCARS \cdot TRAMIL \tag{29}$$

$$TLOCML = TNL \cdot TRAMIL \tag{30}$$

$$TGTN = DT \cdot DAYS \sum_{I=1}^{N} CARS(I) \cdot W(I) + P(I) \cdot VLODFC(I) \tag{31}$$

where,

TRAMIL = total number of train miles during the time period under consideration,

DAYS = number of days in the time period,

CARMIL = total number of car-miles in the time period and

NTYPES = total number of different commodity groups.

Using these operating statistics, operating cost calculations are broken down into the following categories: rolling stock depreciation, rolling stock maintenance costs, maintenance of way and structure, train operating costs and transportation and overhead costs.

Locomotive and other rolling stock depreciation costs are given by Equations 32 and 33 respectively. These equations are based on a straight ratio of days in the time period under consideration to the total number of operating days in the year, which is assumed to be 365. Thus, two time periods of equal length would produce the same depreciation charges, even though utilization of the equipment might be greater during one period than the other.

$$\text{DEPRLC} = \frac{\text{DAYS}}{365} \left[\text{TLOCOS} \cdot \text{CSTLOC (LT)} \cdot \text{CRFL(LT)} \right] \text{DFAC} \qquad (32)$$

$$\text{DEPRC(I)} = \frac{\text{DAYS}}{365} \left[\text{ANO(I)} \cdot \text{CARCST(I)} \cdot \text{CRF(I)} \right] \frac{\text{TBC(I)}}{24} \qquad (33)$$

where,

DEPRLC	=	total locomotive depreciation cost,
CSTLOC(LT)	=	initial cost of Type LT locomotive,
CRFL(LT)	=	capital recovery factor for Type LT locomotive,
DEPRC(I)	=	total depreciation cost of Type I car,
CARCST(I)	=	initial cost of Type I car and
CRF(I)	=	capital recovery factor for Type I car
DFAC	=	TBL/24 = percent of day locomotive was used on link
DAYS	=	no. of days in a season

The capital recovery factors for locomotives and rolling stock depend upon equipment life (in years) and the rate of interest used in amortizing the investment in rolling stock. These factors are included in the internal data table for each type of car.

Equipment maintenance costs for a single car or locomotive are comprised of an annual fixed component that is independent of car usage and a variable component that varies with usage (or car-miles per car). Total maintenance of equipment costs for the time period are given by

$$\text{CARMT} = \left[\text{A(1)} \cdot \frac{\text{DAYS}}{365} + \text{B(1)} \cdot \frac{\text{CARMIL}}{\sum_{I=1}^{N} \text{ANO(I)}} \right] \sum_{I=1}^{N} \text{ANO(I)} \qquad (34)$$

and

$$\text{SLOCMT} = \left[\text{A(2)} \cdot \frac{\text{DAYS}}{365} + \text{B(2)} \cdot \frac{\text{LOCMIL}}{\text{TLOCOS}} \right] \text{TLOCOS} \qquad (35)$$

where,

CARMT = total maintenance costs for rolling stock, excluding locomotives,

SLOCMT = total maintenance costs for locomotives,
A(1), A(2) = annual fixed component of maintenance costs for other rolling stock and locomotives respectively, per car-mile or locomotive-mile, in dollars and
B(1), B(2) = variable component of maintenance costs per car for other rolling stock and locomotives respectively, per car-mile or locomotive-mile, in dollars.

Values of A and B are provided as internal data.

Maintenance costs for track and structures also display a certain fixed component necessary to keep the line operative and a variable component that depends upon the traffic. For this cost category, the best measure of traffic appears to be gross ton-miles per mile of track. For the total length of the line then, maintenance of way costs are given by

$$\mathrm{WAYMT} = \mathrm{DIS}\,\left[A(3) \cdot \frac{\mathrm{DAYS}}{365} + B(3) \cdot \mathrm{TGTN}\right] \frac{\mathrm{ADT(ISW)}}{\mathrm{ADT}} \tag{36}$$

where

WAYMT = total maintenance of way costs, in dollars,

A_3 = annual fixed component of maintenance costs, in dollars per mile and

B_3 = annual variable component of maintenance costs, in dollars per gross ton-mile per mile.

Train operating costs include crew costs, fuel costs and oil costs, as given by Equations 37 to 39 respectively.

$$\mathrm{CRUSCT} = \mathrm{TRAMIL} \cdot B(4) = [\mathrm{DT} \times \mathrm{DIS} \times \mathrm{DAYS}]\, B(4) \tag{37}$$

$$\mathrm{FULCST} = \mathrm{TRAVO} \cdot \mathrm{DAYS} \cdot \mathrm{DT} \cdot \mathrm{FUEL\ (LT)} \cdot B(5) \cdot \mathrm{HP(LT)} \cdot \mathrm{TNL} \tag{38}$$

$$\mathrm{OILCST} = \frac{\mathrm{FULCST} \cdot B(6)}{\mathrm{OR} \cdot B(5)} \tag{39}$$

where

CRUCST = total cost of train operating crews, in dollars,

B(4) = crew costs in dollars per train-mile,
FULCST = total cost of fuel consumption, in dollars,
FUEL(LT) = rate of fuel consumption in gallons per HP-hour for Type LT locomotive,
B(5) = fuel cost in dollars per gallon,
OILCST = total cost of lubricating oils, in dollars,
OR = oil ratio in gallons of fuel oil per gallon of lubricating oil and
B(6) = cost of lubricants in dollars per gallon.

The first expression of Equation 38 involves converting train-miles and average speed information into train-hours.

Total basic cost is given by the sum of the costs determined above, as in Equation 40.

$$\text{BASE} = \text{CARMT} + \text{SLOCMT} + \text{WAYMT} + \text{CRUCST} + \text{FULCST} + \text{OILCST} \tag{40}$$

Traffic costs (advertising, management, ticketing, billing and so on) and overhead costs are then related to this basic cost, as in Equations 41 and 42.

$$\text{TRACST} = B(7) \cdot \text{BASE} \tag{41}$$

$$\text{OVHCST} = B(8) \cdot \text{BASE} \tag{42}$$

where,

BASE = total maintenance and operating costs, in dollars,
TRACST = traffic cost, in dollars,
B(7) = ratio of traffic costs to total maintenance and operating costs and
B(8) = ratio of overhead costs to total maintenance and operating costs.

Total costs of operation, maintenance, overhead and traffic are given by Equation 43. Thus,

$$\text{TOEMT} = \text{BASE} + \text{OVHCST} + \text{TRACST} \tag{43}$$

For each commodity group, this cost is distributed in proportion to the relative traffic volumes for each type. Locomotive depreciation costs are also allocated in a similar manner so that

$$\text{TOEM(I)} = \frac{\text{ADT(I)}}{\sum_{I=1}^{N} \text{ADT(I)}} \left[\text{TOEMT} + \text{DEPRLC}\right] + \text{DEPRC(I)} \tag{44}$$

$$UC(I) = \frac{TOEM(I)}{ADT(I) \cdot DIS} \quad (45)$$

where

TOEM(I) = total costs of rail transport for Type I commodity, in dollars per time period and
UC(I) = unit costs for Type I commodity, for the time period under consideration, in dollars per ton-mile.

F. Model Output

The program has two main outputs. The first section is the train operating cost components measures; the second section gives the Link Performance Measures in the same format as in the Highway and Transfer Model. The Link Performance Measure output is described in detail in Appendix B.

The operating cost and the train make-up output includes for each direction on a link the following:

1. net tractive effort of the locomotive(s) for the ruling grade;
2. average tractive resistance for an average train up the ruling grade;
3. cars required to carry each volume;
4. cars per train of each class;
5. required number of trains per day;
6. average speed of each train;
7. rolling stock depreciation costs for a season by class of car and for locomotives;
8. operating and maintenance costs for rolling stock for a season;
9. fuel costs per season;
10. oil costs per season;
11. crew costs per season;
12. overhead costs per season;
13. maintenance of way costs per season;

Train Performance Measures include a wide variety of indications of the way in which the rail link is being operated and the resulting consequences. The trains per day, the number of cars of each type, the net and average tractive resistance, the number of average cars and train speed are all summarized in the output. The specific measures included in this portion by shipping class, are:

1. Costs/ton-mile
2. Total Handling Time
3. Total Yard Time
4. Total Block Time

5. Travel Time
6. Waiting Time
7. Time Variability
8. Probability of Loss

Items 5-8 are transferred to the Link Performance Vector (LPV) along with the shipping charge. This LPV is the source of the mode measures used in the System Transportation Model to analyze the total transportation system.

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Hay, William W., Railroad Engineering, Vol. 1, John Wiley and Sons, Inc, New York, N.Y., 1953.

Appendix A

A.1 Colombian Rail-Vehicle Characteristics

Characteristics	Class Bulk cargo	General cargo	Special cargo	Passenger
Weight of car (W) Tons (2204 lbs.)	13.8	13.8	15.2	17.8
Cost of car (CARCST) '69 Col. Pesos	90,000	86,000	103,000	258,000
Typical car life (CARLIF) (years)	30	30	30	30
Car reserve factor (CARRF)	0.15	0.15	0.15	0.33
Typical yard time for cars (YTC) (Hours)	6.0	12.0	6.0	1.0
Capital recovery factor for cars (CRF)	0.09	0.09	0.09	0.09
Handling time by class of car (THAND) (hours)	1.0	2.0	1.0	.5
Capacity of cars (PAYLOAD)	31.5	24.5	28.	17.5

A.2 Colombian Railroad Model

Factors and Costs Input

Characteristics	Locomotive type I	II	III
Horsepower (HP)	2,000	1,350	950
Weight of locomotive (WL) (tons = 2204 lbs.)	91.4	91.4	61.0
Fuel consumption Rate in liters per h.p.-hour (FUEL) (LT)	.045	.053	.045
Frontal area (A) m^2	8.826	8.826	8.826
Cost of locomotive by type (CSTLOC) 1969 Col. Pesos	3,096,000	2,773,500	2,752,000
Number of driving axles (AXLES)	6	6	4
Standard locomotive life (SLOCLF)	20	20	20
Reserve factor for locomotive (RFLOC)	0.25	0.22	0.23
Yard time for locomotive (YTL) hours	1.0	1.0	2.0
Capital recovery factor for locomotive (CRFL)	0.10	0.10	0.10
Switching time (ST) hours	0.15	0.15	0.15

A.3 Other Rail Factors and Costs

A1 = annual fixed component of maintenance costs for other rolling stock, (per car-year), in dollars = US$ 76 dollars/year. $ Col. (69) 1,307 PS/year

A2 = annual fixed component of maintenance costs for locomotive per (locomotive-year), in dollars = US $4,000 dollars/year. $ Col. (69) = 68,800 PS/year.

A3 = annual track fixed component of maintenance costs
$ Col. (69) = 24,080 PS/mile
$ Col. (69) = 14,963 PS/KM

B1 = variable component of maintenance costs/car for other rolling stock
$ Col. (69) = 0.157 PS/mile
$ Col. (69) = 0.098 PS/KM

B2 = variable component of maintenance costs per locomotive

$ Col. (69) = 1.08 PS/mile
$ Col. (69) = 0.67 PS/KM.

B3 = annual variable component of way maintenance costs

$ Col. (69) = 0.0134 PS/Ton-mile
$ Col. (69) = 0.0083 PS/Ton-KM.

B4 = crew costs = $ Col. (69) 1.73 PS/train-mile
$ Col. (69) 1.08 PS/train-KM.

B5 = fuel cost = $ Col. (69) 1.64 PS/gallon
$ Col. (69) .433 PS/liter

B6 = cost of lubricants = $Col. (69) 7 PS/gallon
$Col. (69) 1.849 PS/liter

B7 = ratio of traffic costs to total maintenance and operating cost = 0.012

B8 = ratio of overhead costs/total maintenance and costs = 0.088

OR = oil ratio in gallons of fuel oil/gallon of lubricating oil = 130

BEGINNING NODE, END NODE, MODE, LINK DISTANCE, VMAX, VMIN, GRADE, GRADE, NO. SIDINGS, TYPE SIGNALING, TYPE LOCO., NO LOCO

```
YRS 1969 1969
LINK 20 21 33400.00 60.00 10.00  2.50  1.50 10.00  2.00  2.00  3.00  1.00      -0.00 -0.00 -0.00
LINK 21 20 33400.00 60.00 10.00  2.50  1.50 10.00  2.00  2.00  3.00  1.00      -0.00 -0.00 -0.00
VOL  20 21   600.00-0.00  1800.00-0.00   600.00-0.00   -0.00-0.00   -0.00-0.00   -0.    T   A***
VOL  21 20   200.00-0.00   600.00-0.00   200.00-0.00   -0.00-0.00   -0.00-0.00   -0.    T   A***
ENDL
```

BEGINNING NODE, END NODE, VOLUME COMM 1, VOLUME COMM 2, VOLUME COMM 3, VOLUME COMM 4

INPUT TO SPECIFY YEARS TO BE RUN

Appendix B

Details of the Computer Print-Out

Symbol Number		Explanation
1.	Direction of the traffic	1 = Outbound 2 = Inbound
2.	Equation 4	
3.	Equation 7	
4.	Equation 8	
5.	Obtained by solving the cubic equation for V with equation 12 holding.	
6.	Equation 8a without the operator for each class (I) cars.	
7.	Equation 9.	
8.	Input data - Link Characteristic Vector	
9.	Equation 11	
10.	Total tons per year. MTONS = DAILY TONNAGE X 365 DAYS	
11.	Number of days considered. (LOCO)	
12.	Equation 27 - rounded to next whole number for locomotives. (BULK, GENERAL, SPECIAL, PASS) Equation 24 - rounded to next whole number.	
13.	Loco Equation 32 Cars Equation 33	
14.	(Loco) Equation 35 (Cars) Equation 34	
15.	Input - Load Factor VLODFC	

16. $$\text{USEFAC(I)} = \frac{\text{average daily tonnage (by commodity group)}}{\text{total number of cars required (by type)} \times \text{payload(I)} \times \dfrac{24}{\text{block time for cars}}}$$

This equation expresses what part of the day cars are spending in the block.

17. The FC 3 column represents each of the numbers in the SEASON COST column divided by total 3 - i.e. the percentage distribution of all the individual items in column SEASON COST.
The FC 2 column represents FC3 items X TOTAL 3/TOTAL 2 - i.e. the percentage distribution of all the individual items in SEASON COST except WAYMNT.
The FC 1 column represents FC 3 items X TOTAL 3/TOTAL 1 - i.e. the percentage distribution of the first 7 items in SEASON COST (excludes overhead and way MAINTENANCE).

18. Sums of DEPREC above for 4 classes of vehicles.
19. Equation 34
20. Equation 32
21. Equation 35
22. Equation 38
23. Equation 39
24. Equation 37
25. Sums the above 7 factors.
26. OVH = B7 (CARMT + SLOCMT + WAYMT + CRUCST + FULCST + OILCST) +
    B8 (CARMT + SLOCMT + WAYMT + CRUCST + OILCST) + FULCST

NOTE B7 = ratio of traffic costs to total maintenance and operating costs.
B8 = ratio of overhead costs to total maintenance and operating costs.

27. Sum of TOTAL 1 and OVHEAD
28. Equation 36
29. Sum of TOTAL 2 and WAYMNT
30. Equation 45
31. Handling time proportional to cars in each class = THAND X CARS

input

32. Input
33. Equation 22
34. TRAV + YTC

Equation 19 or 20 input

TTIME = travel time (in or out) plus yard time

eq. 20 eq. 19 input

35. = 12/DT(ISW) number of daily trains
36. = 0.1 (TTIME) + 0.1 (WAITT)

#34 on comment sheet

#35 on comment sheet

37. = (.000001) (TTIME) + (.0001) (WAITT)

```
         1                 2                             3                            4                        5
DIR 1   NET TRACTIVE EFFORT =    19900.35 KG AVG TRACT. RESIST =      993.12 KG CAN CARRY    20.04 "AVERAGE" CARS AT 15.7 KMPH
      ADVMAX(I)  CARS(I.ISW)
        19.048         3.350
   6    73.469        12.920    7
        21.429         3.768
         0.000         0.000
DIR 2   NET TRACTIVE EFFORT =    19900.35 KG AVG TRACT. RESIST =      582.47 KG CAN CARRY    20.04 "AVERAGE" CARS AT 24.6 KMPH
      ADVMAX(I)  CARS(I.ISW)
        19.048         3.350
        73.469        12.920
        21.429         3.768
   8     0.000         0.000
LINK CHARACTERISTICS FROM 20 TO 21 400.000  60.000  10.000   2.500   1.500  10.000   2.000   2.000   3.000   1.000
 9 5.656 TRAINS/DAY CONTAIN THE FOLLOWING UNITS AND COSTS/SEASON   (AVG. SPEED = 15.7 KMPH)     (MIN. REQUIRED TRAINS = 0.00)

10                  LOCOS (       BULK       GENERAL       SPECIAL   PASSENGER)  TOTALCARS   SEASON TOTAL (365. DAYS OF A 365. DAY YEAR)
   MTONS            0.000 (  219000.00     657000.00     219000.00        0.00) 1095000.00
12 U.CRRY           8.000 (      39.00        268.00         44.00        0.00)     351.00       11
13 U.NEED           8.000 (      39.00        268.00         44.00        0.00)     351.00
   DEPREC     1722056.304 (  378878.57    4723617.25     494532.75        0.00) 5597028.58     7319084.88
14 OP+MNT      627589.135 ( 2185341.59    6556024.76    2185341.59        0.00) 10926707.93   11554297.07
                                                                                             --------------
15 LODFAC           0.000 (       1.00          1.00          1.00        0.00)       1.00   18873381.95
16 USEFAC           0.000 (       0.78          0.83          0.79        0.00)       0.82

                18          SEASON COST  (FC3) (FC2) (FC1) (SEASON = 365. DAYS OF A 365. DAY YEAR)
             19   CARDEP     5597028.58  0.297 0.363 0.390  17
                  CARMNT     1285374.64  0.068 0.084 0.090
              20  LOCDEP     1722056.30  0.091 0.112 0.120
            21    LOCMNT      627589.13  0.033 0.041 0.044
              22  FUEL       4462762.60  0.236 0.290 0.311
            23    OIL         146591.72  0.008 0.010 0.010
              24  CREW        519340.89  0.028 0.034 0.036
                  ------
            25    TOTAL1    14363743.88  0.761 0.932 1.000
                  TRACST      126046.88  0.007 0.008
            26    OVHEAD      924343.77  0.049 0.060
                  ------
             27   TOTAL2    15414134.52  0.817 1.000
             28   WAYMNT     3459247.43  0.183
                  ------
               29 TOTAL3    18873381.95  1.000

   30 TRAIN MEASURES------------
                            BULK    GENERAL    SPECIAL    PASSNGR
  31  COSTS/MTON-KM       0.0557     0.0777     0.0579     0.0000
  32  TOT HANDLNG TME     3.3497    25.8401     3.7684     0.0000
      TOTAL YARD TIME     6.0000    12.0000     6.0000     1.0000
  33  TOTAL BLCK TIME    38.3796    72.8700    38.7983    26.0299
      LOAD-UNLOD TIME     6.0000    12.0000     6.0000     2.0000
  34  TRAVEL TIME        42.4802    48.4802    42.4802    37.4802
  35  WAIT TIME           2.1103     2.1103     2.1103     2.1103
  36  TIME VARIABILTY     4.4591     5.0591     4.4591     3.9591
      PROB. OF LOSS       0.0003     0.0003     0.0003     0.0002
  37  LINK CHARACTERISTICS FROM 21 TO 20 400.000  60.000  10.000   2.500   1.500  10.000   2.000   2.000   3.000   1.000
        5.656 TRAINS/DAY CONTAIN THE FOLLOWING UNITS AND COSTS/SEASON   (AVG. SPEED = 24.6 KMPH)     (MIN. REQUIRED TRAINS = 0.00)
```

Appendix C

Mode Summary Table

A summary table of the costs and link performance measures are computed for each link - both directions - and for each mode.* This summary table computes the details of each cost and breaks out the tax revenue and foreign exchange components. These charts are computed each year for a link but the chart is divided into five columns:

1) "PRESENT WORTH TO ________"

   Present Worth of the cost discounted back to the beginning year.

2) "ACCUMULATED PW THRU ________"

   This is the accumulated Present Worth through the present year.

3) "CURRENT VALUE (IN _______)

   This is the current cost of the items considered.

4) "AVERAGE VALUE PER TON SHIPPED".

   This is the cost given in the "CURRENT VALUE" column divided by the total tons shipped over the link.

5) "RELATIONSHIPS"

   This divides the components a) Total costs, b) Operations Costs, c) Tax Revenue, and d) Foreign Exchange into percentages.

The following explanation for each row, corresponding to the row number as given in the output, are presented in terms of the "CURRENT VALUE" column.

---

* This is a general format output for all modes. Therefore some items for a particular mode - such as TIRES on Railway will not apply. In the case where the item does not apply the entry will be (0.0).

The other elements of the row are calculated from the current value as discussed above.

Row	Item	Explanation
1.	TOTAL COST	Sum of the WAYMNT + RFAC
2.	WAYMNT	WAY MNT is calculated by Equation 36.
3.	RFAC	Sum of rows 4-8 which are the components of the RFACTOR.
4.	WTIME	$\sum_{I=1}^{4}$ WAIT TIME (I) X W TIME COST (I)
5.	TTIME	$\sum_{I=1}^{4}$ TRAVEL TIME (I) X TRAVEL COST(I)
6.	VTIME	$\sum_{I=1}^{4}$ TIME VARIABILITY (I) X VTIME COST(I)
7.	PRLOSS	$\sum_{I=1}^{4}$ PROB OF LOSS (I) X PROB-LOSS COST (I)
8.	CHRGE	$\sum_{I=1}^{4}$ TONS (I) X RATE(I)
9.	OPER	Sum of the operation cost components. Rows 10-16.
10.	CREW	Sum of the link CREW cost for both directions.
11.	FUELEW	Sum of link FUEL cost for both directions.
12.	LUBE	Sum of link LUBE cost for both directions.
13.	TIRES	Sum of TIRES in both directions.
14.	REPAIR	Sum of the vehicle MNT in both directions. Does not include WAYMNT.
15.	DEPR	Sum of the veh DEP in both directions.

Row	Item	Explanation
16.	OTHER	Sum of the remaining items contributing to the operating costs in both directions.
17.	TAX REVENUE	Sum of the taxes - Rows 18-24.
18.	FUELTX	FULCST/(1 + TAX (8)) TAX(8).
19.	LUBETX	OILCST/(1 + TAX (9)) TAX (9).
20.	TIRETX	
21.	VEHTX	DEPRLC/(1 + TAX (4)) TAX (4)
22.	PRTSTX	(.2x CARMT + .1 x SLOCMT)/(1+ TAX(3)) TAX(3)
23.	REGSTX	
24.	INCMTX	(CRUCST + .5B(8) [CARMT + SLOCMT + WAYMT + CRUCST + OILCST]) x ADT/ ADTOTC x TAX (10)
25.	FOREIGN EXC.	Sum of foreign exchange components Rows 26-30.
26.	FUELXC	FULCST/(1 + TAX (8)) X FRNEXC(8)
27.	LUBEXC	OILCST X (1 + TAX (9)) X FRNEXC(9)
28.	TIRSXC	
29.	PRTSXC	[.2 (CARMT) + .1 SLOCMT] / (1 + TAX (3) FRNEXC (3)
30.	DEPRXC	DEPRLC/(1 + TAX(4) FRNEXC (4) + SCRDEP (FRNEXC (5))
31.		Total tons moved.

Row	ITEM	Explanation
32.		Total number of vehicles/days required (CARS) (DT) X 365 DAYS X 2
33.	SUMMARY OF APW	Accumulated Present Worth
34.	RFAC	Accumulated PW cost to the SHIPPER
35.	OPER	Accumulated PW to the TRANSPORTER
36.	TAXR	Accumulated PW Tax revenue
37.	FRNX	Accumulated PW Foreign Exchange

Taxes on Specific Items Related to Transportation

TAX (1) = IMPORT TAX ON AUTOS AND TRUCKS
TAX (2) = IMPORT TAX ON TIRES FOR AUTOS AND TRUCKS
TAX (3) = IMPORT TAX ON PARTS FOR REPAIRS
TAX (4) = IMPORT TAX ON LOCOMOTIVES
TAX (5) = IMPORT TAX ON RAILCARS
TAX (6) = IMPORT TAX ON DOCK EQUIPMENT
TAX (7) = GASOLINE TAX
TAX (8) = FUEL OIL TAX (RAIL)
TAX (9) = LUBE OIL TAX
TAX (10) = INCOME TAX (AVERAGE ON WAGES)
TAX (11) = REGISTRATION FEE ON CLASS 1 HIGHWAY VEHICLES
TAX (12) = REGISTRATION FEE ON CLASS 2 HIGHWAY VEHICLES
TAX (13) = REGISTRATION FEE ON CLASS 3 HIGHWAY VEHICLES
TAX (14) = REGISTRATION FEE ON CLASS 4 HIGHWAY VEHICLES
TAX (15) = REGISTRATION FEE ON CLASS 5 HIGHWAY VEHICLES

FRNEXC(N) = FOREIGN EXCHANGE PER $ (NO TAXES IN $) SPENT ON ITEM "N"

FRNEXC (1)= F. E. ON PURCHASE OF AUTOS AND TRUCKS
FRNEXC (2)= F. E. ON PURCHASE OF TIRES FOR AUTOS AND TRUCKS
FRNEXC (3)= F. E. ON PURCHASE OF PART FOR REPAIRS
FRNEXC (4)= F. E. ON PURCHASE OF LOCOMOTIVES
FRNEXC (5)= F. E. ON PURCHASE OF RAIL CARS
FRNEXC (6)= F. E. ON PURCHASE OF DOCK EQUIPMENT
FRNEXC (7)= F. E. ON PURCHASE OF GASOLINE
FRNEXC (8)= F. E. ON PURCHASE OF FUEL OIL (RAIL)
FRNEXC (9)= F. E. ON PURCHASE OF LUBE OIL

R-FACTOR, LINE 4 IN HOURS = 8441.10

R-FACTOR, LINE 5 IN HOURS = 170870.62

R-FACTOR, LINE 6 IN HOURS = 17931.17

R-FACTOR, LINE 7 IN HOURS = 1.01

R-FACTOR, LINE 8 IN HOURS = 229760.00

YEAR 1969, LINK BETWEEN 20 AND 21, MODE 33

	PRESENT WORTH TO 1969	ACCUMULATED PW THRU 1969	CURRENT VALUE (IN 1969)	AVERAGE VALUE PER TON SHIPPED	RELATIONSHIPS
1. TOTAL COST	125863.94	125863.94	125863.94	86.21	
2. WAYMNT....	4378.37	4378.37	4378.37	3.00	
3. RFAC.......	121485.57	121485.57	121485.57	83.21	1.00
4. WTIME...	1269.37	1269.37	1269.37	0.87	0.01
5. TTIME...	35730.50	35730.50	35730.50	24.47	0.29
6. VTIME...	373.87	373.87	373.87	0.26	0.00
7. PRLOSS..	249.42	249.42	249.42	0.17	0.00
8. CHRGE...	83862.40	83862.40	83862.40	57.44	0.69
9. OPER....	24451.86	24451.86	24451.86	16.75	1.00
10. CREW..	692.45	692.45	692.45	0.47	0.03
11. FUELEW..	5410.98	5410.98	5410.98	3.71	0.22
12. LUBE..	177.74	177.74	177.74	0.12	0.01
13. TIRES..	0.00	0.00	0.00	0.00	0.00
14. REPAIR	2697.81	2697.81	2697.81	1.85	0.11
15. DEPR..	9758.78	9758.78	9758.78	6.68	0.40
16. OTHER.	5714.10	5714.10	5714.10	3.91	0.23
17. TAX REVENUE.	2296.23	2296.23	2296.23	1.57	1.00
18. FUELTX....	491.91	491.91	491.91	0.34	0.21
19. LUBETX....	8.46	8.46	8.46	0.01	0.00
20. TIRETX....	0.00	0.00	0.00	0.00	0.00
21. VEHTAX....	1626.46	1626.46	1626.46	1.11	0.71
22. PRTSTX....	88.31	88.31	88.31	0.06	0.04
23. REGSTX....	0.00	0.00	0.00	0.00	0.00
24. INCMTX....	81.08	81.08	81.08	0.06	0.04
25. FOREIGN EXC.	11038.42	11038.42	11038.42	7.56	1.00
26. FUELXC....	2459.53	2459.53	2459.53	1.68	0.22
27. LUBEXC....	93.31	93.31	93.31	0.06	0.01
28. TIRSXC....	0.00	0.00	0.00	0.00	0.00
29. PRTSXC....	353.25	353.25	353.25	0.24	0.03
30. DEPRXC....	8132.32	8132.32	8132.32	5.57	0.74
31.		1460. TONS	1460. TONS		
32.		83. VEHS	83. VEHS		

------------------ALL VALUES DIVIDED BY 1000.------------------

THE VALUES PRESENTED ASSUME EACH LINK OPERATED 365 DAYS PER YEAR

(PESOS)

33. SUMMARY OF APW
34. RFAC 121485.57(SHIPPER)
35. OPER 24451.86(TRANSPORTER)

36.	TAXR	2296.23(GOV T REVENUE)
37.	FRNX	11038.42(FOREIGN EXCNG)

Appendix D

Railways Dictionary

A(1), A(2)	annual fixed component of maintenance costs for other rolling stock and locomotives respectively, per car-mile or locomotive-mile, in dollars
A3	annual fixed component of maintenance costs, in dollars per mile
A(LT)	frontal area, i.e. cross section of the locomotive in square feet
ADT(I)	average daily traffic for commodity group I 1. Bulk 2. General 3. Special 4. Passenger-commercial 5. Passenger-private
ADT(ICLAS)	average daily tonnage
ADV(ICLAS)	average daily vehicle requirement
ANO(I)	total number of Type I cars required
ANT(I)	number of sets of Type I cars, where a "set" is defined as a group of cars of the same type in one train
AXLES (LT)	number of driving axles on each locomotive
B(1), B(2)	variable component of maintenance costs per car for other rolling stock and locomotives respectively, per car-mile or locomotive-mile in dollars
B3	annual variable components of maintenance costs in dollars per gross ton-mile per mile
B(4)	crew costs in dollars per train-mile
B(5)	fuel cost in dollars per gallon
B(6)	cost of lubricants in dollars per gallon
B(7)	ratio of traffic costs to total maintenance and operating costs
B(8)	ratio of overhead costs to total maintenance and operating costs
BASE	total maintenance and operating costs in dollars
CARCST(ICLAS)	initial cost of car by class
CARLIF(ICLAS)	typical car life
CARMIL	total number of car-miles in the time period
CARMT	total maintenance costs for rolling stock, excluding locomotives

CARRF(I)	reserve factor for Type I cars to allow for routine maintenance and periodic overhaul, expressed as a decimal fraction.
CARS(I)	number of cars of type I per train
CARRF(ICLAS)	car reserve factor
COST(ICLAS)	cost of providing the service per ton
CRF(ICLAS)	capital recovery factor for cars
CRFL(LT)	capital recovery factor for locomotives
CRUCST	total cost of train operating crews, in dollars
CSTLOC(LT)	initial cost of locomotive by type
DAYS	number of days in the time period
DENOM	$\sum_{I=1}^{N} \frac{ADT(I)}{P(I) \cdot VLODFC(I)}$
DEPRC(I)	total depreciation cost of Type I car
DEPRLC	total locomotive depreciation cost
DIS	length of the link
DT	Number of daily trains
DTI	daily trains inbound
DTO	daily trains outbound
FUEL(LT)	fuel consumption rate in gallons per h.p. hour
FULCST	total cost of fuel consumption, in dollars
G	grade, in percent
GAV	average grade or rate of rise and fall in each direction
GMAX	ruling or maximum grade in each direction
HP	rated horsepower of one locomotive
HP (LT)	horsepower of each locomotive type
ICLAS=1	bulk cargo
ICLAS=2	general cargo
ICLAS=3	special cargo
ICLAS=4	passenger
ISC	switching system waiting time category
K	average delay per meet, in hours
LT	locomotive type
LSTD	signal system waiting time category
M	number of meets
N=NTYPES	number of commodity groups carried over the line

NS	number of sidings
OILCST	total cost of lubricating oils, in dollars
OR	oil ratio in gallons of fuel oil per gallon of lubricating oil
OVHCST	overhead costs
P(I)	payload capacity, in tons
PROBLO(ICLAS)	probability of loss of one ton of the shipment
RFLOC(LT)	reserve factors for locomotives, expressed as a decimal fraction of TLOCOS
SLOCLF(LT)	standard locomotive life
SLOCMT	total maintenance costs for locomotives
SNETE	net tractive effort in pounds
SRR(1)	level tangent rolling resistance for the first locomotive, in pounds per ton
SRR(2)	level tangent rolling resistance for each successive locomotive, in pounds per ton
ST	switching time per train taking the siding, in hours
STLOCS	number of sets of locomotives
TBC(I)	block time for Type I cars, in hours
TBL	locomotive block time, in hours
TE	tractive effort in pounds
TGTN	total gross ton-km.
THAND(I)	average "handling" time for cars carrying Type I commodities, in hours
TLOCML =	TNL · TRAMIL
TLOCOS	total number of locomotives
TLU(I)	time to connect and/or disconnect the cars carrying Type I commodities, in hours
TNCARS	total number of cars per train
TNL	total number of locomotives
TOEM(I)	total costs of rail transport for Type I commodity, in dollars per time period
TOEMT	total cost of operation, maintenance, overhead, and traffic
TOTLOD	total tonnage per train
TR(I)	total resistance in pounds
TRACST	traffic cost, in dollars
TRAMIL	total number of train miles during the time period under consideration
TRAV(ICLAS)	travel time on the link from station to station, in hours
TRAVI	average running times inbound, in hours
TRAVO	average running times outbound, in hours
TRI	minimum running time inbound, in hours
TRO	minimum running time outbound, in hours

TRR	total train resistance, in pounds
UC(I)	unit costs for Type I commodity, for the time period under consideration, in dollars per ton-mile
V	train speed in m.p.h.
VARTIM (ICLAS)	travel time variability, in hours
VAV	average speed, in mph, where SNETE=TRR
VLODFC(ICLAS)	vehicle load factors
VMAX	speed limitations due to excessive curvature, condition of the track or other physical features of the line that cause the train to travel at less than its maximum possible speed
VMIN	minimum allowable speed which can be tolerated due to locomotive overheating, etc., the minimum acceptable train speed on the ruling grade
W(ICLAS)	weight of car by class in tons
WAIT(ICLAS)	waiting time on the link which includes switching time but not loading and unloading time, in hours
WAYMT	total maintenance of way costs, in dollars
WEIGHT(I)	combined weight, in tons
WL(LT)	weight of locomotive in tons
WT	waiting time per train taking the siding, in hours
WTR	weighted average total resistance per car, in pounds
YTC(I)	yard time for Type I cars, in hours
YTL (LT)	yard time for locomotives

Appendix E

Railroad Model Equations

1. Tractive Effort:

$$TE = \frac{308\ (HP)\ (TNL)}{V}$$

308 = 375 x 82.2% efficiency

2. Level Tangent Rolling Resistance:

$$SRR(1) = 1.3 + \frac{29\ AXLES}{WL} + 0.03V + \frac{0.0024\ A \cdot V^2}{WL}$$

3. $$SRR(2) = 1.3 + \frac{29\ AXLES}{WL} + 0.03V + \frac{0.0005\ A \cdot V^2}{WL}$$

4. Net Tractive Effort:

$$SNETE = TE - WL\ [SRR(1) + SRR(2) \cdot (TNL - 1) + 20\ G \cdot TNL]$$

G = GMAX: ruling grade

5. Combined Weights:

$$WEIGH(I) = W(I) + P(I) \cdot VLODFC(I)$$

6. Total Resistance:

$$TR(I) = 116.0 + 0.045V^2 + WEIGH(I)\ [1.3 + 0.045V + 20G]$$

7. Weighted Average Total Resistance:

$$WTR = \sum_{I=1}^{N} \frac{ADT(I) \cdot TR(I)}{P(I) \cdot VLODFC(I) \cdot DENOM}$$

7a. $$DENOM = \sum_{I=1}^{N} \frac{ADT(I)}{P(I)\ VLODFC(I)}$$

8. Total No. of Cars per Train:

$$TNCARS = \frac{SNETE}{WTR}$$

8a. $$DENOM = \sum_{I=1}^{N} \frac{ADT(I)}{P(I) \cdot VLODFC(I)}$$

9. No. of Cars of Type I per Train:

$$CARS(I) = \frac{ADT(I) \cdot TNCARS}{P(I) \cdot VLODFC(I) \cdot DENOM}$$

10. Total Tonnage per Train:

$$TOTLOD = \sum_{I} CARS(I) \cdot P(I) \cdot VLODFC(I)$$

11. No. of Daily Trains:

$$DT = \frac{\sum ADT(I)}{TOTLOD}$$

<u>MINIMUM RUNNING TIME</u>

12. Tractive Effort:

$$SNETE = TRR$$

13. Total Train Resistance:

$$TRR = \sum_{I} TR(I) \cdot CARS(I)$$

14. Minimum Running Time:

$$TRO = \frac{DIS}{VAV}$$

TRAIN DELAY CALCULATIONS

15. No. of Trains Encountered by an Outbound Train:

$$M = \frac{DTI}{24} \left[TRAVI + TRAVO \right]$$

16. $$TRAVO = TRO + K \cdot M$$

16a. $$TRAVO = TRO + \frac{K \cdot DTI}{24} \left[TRAVI + TRAVO \right]$$

16b. or $$\frac{TRO + K \cdot DTI \left[TRAVI \right]}{1 - \frac{K \cdot DTI}{24}}$$

17. and $$TRAVI = \frac{TRI + \frac{K \cdot DTO}{24} \left[TRAVO \right]}{1 - \frac{K \cdot DTO}{24}}$$

18. $$TRAVO = \frac{TRO + \left[\frac{K \cdot DTI}{24} \right] \left[\frac{TRI + \frac{K \cdot DTO}{24} \cdot TRAVO}{1 - \frac{K \cdot DTO}{24}} \right]}{1 - \frac{K \cdot DTI}{24}}$$

19. When DTI = DTO = DT

$$TRAVO = \frac{576\ TRO + 24\ K \cdot DT \cdot \left[TRI - TRO \right]}{576 - 48\ K \cdot DT}$$

20. $$TRAVI = \frac{576\ TRI + 24\ K \cdot DT \cdot [TRO - TRI]}{576 - 48\ K \cdot DT}$$

21. Waiting Time per Meet:

$$K = ST\ (I) + WT\ (J)$$

DETERMINATION OF EQUIPMENT REQUIREMENTS

22. Car Block Time:

$$TBC\ (I) = TLU\ (I) + TRAVO + YTC\ (I)$$

23. No. of Sets of Cars:

$$ANT(I) = DT\ \frac{TBC(I)}{24}$$ Rounded to next whole number

24. Total No. of Type I Cars Required:

$$ANO(I) = ANT(I) \cdot CARS\ (I)\ [1 + CARRF\ (I)]$$ Rounded to next whole number

25. Locomotive Block Time:

$$TBL = TRAVO + YTL$$

26. No. of Sets of Locomotives:

$$STLOCS = DT\ \frac{TBL}{24}$$

27. Total No. of Locomotives:

$$TLOCOS = STLOCS \cdot TNL \cdot [1 + RFLOC]$$

OPERATING COST CALCULATIONS

28. Total No. of Train Miles per season:

$$TRAMIL = DT \cdot DIS \cdot DAYS$$

29. Total No. of Car Miles:

$$CARMIL = TNCARS \cdot TRAMIL$$

30. Total No. of Loco. Miles

$$TLOCML = TNL \cdot TRAMIL$$

31. Total Gross Tons

$$TGTN = DT \cdot DAYS \sum_{I=1}^{N} CARS\ (I) \cdot W\ (I) + P\ (I) \cdot VLODFC\ (I)$$

32. Total Locomotive Depreciation Cost:

$$DEPRLC = \frac{DAYS}{310} \left[TLOCOS \cdot CSTLOC\ (LT) \cdot CRFL(LT) \right] \cdot DFAC$$

$$DFAC = \frac{TBL}{24}$$

33. Total Depreciation Cost of Type I Car:

$$DEPRC(I) = \frac{DAYS}{310} \left[ANO(I) \cdot CARCST(I) \cdot CRF(I) \right] \cdot DFAC(I)$$

$$DFAC(I) = \frac{TBC(I)}{24}$$

34. Total Maintenance Cost of Equipment for Time Period - less Locomotives:

$$CARMT = \left[A(1) \cdot \frac{DAYS}{310} + B(1) \cdot \frac{CARMIL}{\sum ANO(I)} \right] \sum ANO(I) \quad .$$

35. Total Maintenance Cost of Locomotives:

$$SLOCMT = \left[A(2) \cdot \frac{DAYS}{310} + B(2) \cdot \frac{LOCMIL}{TLOCOS} \right] TLOCOS$$

36. Total Roadway Maintenance Cost:

$$WAYMT = DIS \cdot \left[A(3) \cdot \frac{DAYS}{310} + B(3)\ TGTM \right] \cdot \frac{ADT(ISW)}{ADT}$$

37. Total Cost of Train Operating Crews:

$$CRUCST = TRAMIL \cdot B(4)$$

38. Total Cost of Fuel Consumption:

$$FULCST = TRAVO \cdot DAYS \cdot DT \cdot FUEL\ (LT) \cdot B(5) \cdot HP(LT) \cdot TNL$$

39. Total Cost of Lubricating Oils:

$$OILCST = \frac{FULCST \cdot B(6)}{OR \cdot B(5)}$$

40. Total Cost of Basic System:

$$BASE = CARMT + SLOCMT + WAYMT + CRUCST + FULCST + OILCST$$

41. Traffic Costs:

$$TRACST = B(7) \cdot BASE$$

42. Overhead Cost:

$$OVHCST = B(8) \cdot BASE$$

43. Total Cost of Operation, Maintenance, Overhead, and Traffic:

$$TOEMT = BASE + OVHCST + TRACST$$

44. Total Cost of Rail Transport for Type I Commodity:

$$TOEM(I) = \frac{ADT(I)}{\sum ADT(I)} \left[TOEMT + DEPRLC \right] + DEPRC(I)$$

45. Unit Costs for Type I Commodity:

$$UC(I) = \frac{TOEM\ (I)}{ADT(I)\ .\ DIS}$$