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Resistance of a Freight Train To Forward Motion - Volume III, Economic Analysis and Correlation of Predictions with Field Data

February 1981

FINAL REPORT

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16. Abstract

This final report is a supplement to two earlier FRA reports on train resistance and its impact upon fuel consumption. The portion of this effort reported herein was partly directed toward detailed correlation of predictions of fuel consumption from simulated runs with actual field measurement. In addition, computer simulations were made in an effort to corroborate some theoretical curves set forth in Volume II and other places in the literature. The economics of fuel savings effected through the use of light weight hopper cars in unit coal train service are examined in great detail, and various types of economic models which might be used to evaluate such savings and considerations concerning the proper selection of one of them are discussed in an appendix. Consideration is given to future investigations and conclusions are drawn. A second appendix explains the improvements made to the computer program since the version reported in Volume II and the modifications to the calculating routine to optimize the efficiency of the program and minimize operating time.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

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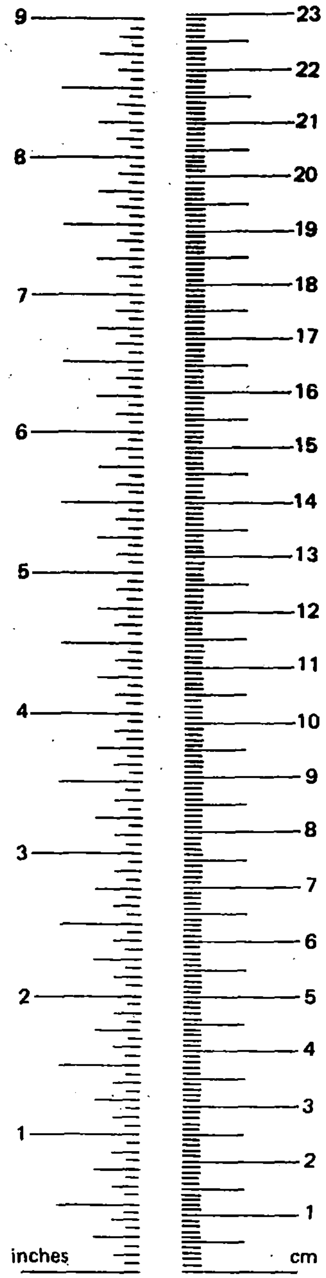
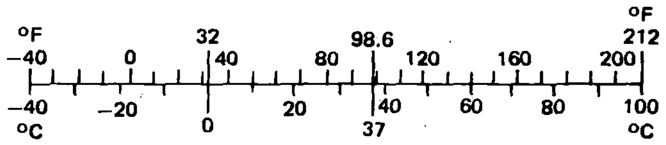
*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

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



ACKNOWLEDGEMENT

The author would like to acknowledge the significant contributions to this report of Horace Wuerdemann, from whose original economics report the material in the appendix describing the types of economic approaches which might be used to analyze investment in new technology was extracted almost verbatim and who performed the detailed analysis of the use of light weight equipment in unit train service described in the main body of the report.

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EXECUTIVE SUMMARY

This report summarizes the remainder of MITRE's efforts devoted to examination of fuel consumption of freight trains and its economic impact. Corresponding to the effort itself, the report is divided into three major portions, each relating to a certain area of the examination. These are, in turn: (1) efforts at establishing correlation between predictions by the computer program and actual measurements from the field; (2) a discussion of economic methods for analyzing investments and a detailed example of how one method is applied to evaluate the potential use of lightweight equipment in certain applications; and (3) an examination of certain aspects of operation of freight trains over undulating terrain and the impact of using lightweight equipment upon fuel consumption under such circumstances. Each of these areas and the conclusions deriving therefrom are discussed in more detail below.

CORRELATION EFFORTS

In the work described in Volume II of this series of reports an attempt was made to correlate the results from the program. The predictions of fuel consumption, while considerably higher than what would be predicted for operation over level tangent track, were nevertheless in both instances lower than the reported consumption.

More recent field data from an intermodal operation was subsequently made available to FRA by a western railroad and detailed results of a unit coal train operation on an eastern railroad was made available through TSC.

The results of recent wind tunnel testing of conventional railroad rolling stock were then introduced into the computer program and special care was taken to ensure the accuracy of the track data used. The results of running the final simulations were that predictions of fuel consumption were on the order of ten percent lower than the actual consumption. The discrepancy was attributed to unmodelled phenomena, such as a directional bias in the wind, cross winds, or train stretching. A budget for the estimated impact of each of these and certain additional but small contributors is given in the text.

ECONOMIC ANALYSIS

An examination of various methods of economic analysis available for use in making investment decisions, and in current use today was made. The four methods examined were the payback method, the rate of return (ROR) method, the internal rate of return (IRR) method, and the net present value (NPV) method. The latter two methods consider the time value of money; the former two do not.

The net present value (NPV) method was selected to illustrate in detail the selection of one investment possibility among three mutually exclusive projects. The example was based in part upon data derived from simulation of proposed train operations by the computer program. The investment decision involved the selection of equipment for a unit coal train operation, and the options were standard weight steel hopper cars, lightweight steel hopper cars, or aluminum high-sided gondolas. A detailed life cycle costing over the entire 25 year estimated life revealed that with the assumptions made both alternatives to the standard were favorable in comparison, while being comparatively equal. The modest advantage held by the aluminum car fleet was noted to be attributable to its higher salvage value and the avoidance of car rebuilding expenses during the 25 year service life. Should the second assumption be incorrect, this lightweight steel car fleet investment would be extremely competitive with the aluminum fleet option.

OPERATION OVER UNDULATING TERRAIN

An early investigation in Volume I of this series into the use of lightweight flatcars in intermodal service revealed that in steady state operation over level tangent track fuel savings were very modest.

Some further investigation of this matter was pursued in the second volume of this series, and some hypothetical curves were derived from fundamental considerations which could be used to predict the savings of fuel by means of lightweight equipment in operation over normal track, with grades and curves. The computer program was then used to simulate these operations. The predicted fuel consumption fell very close to the postulated curves, within the limit of the accuracy of the program at the time the simulations were run, thus confirming the accuracy of the assumptions underlying the curves. The results showed that in operation over normal tracks fuel savings attributable to the use of lightweight equipment are still modest unless the average grade exceeds a certain value. It was also shown that the certain value of this average grade was dependent upon the type of operation being conducted.

It is of interest to note that similar curves have been presented, without the author's being aware, prior to publication of Volume II, to a meeting of the Transportation Research Board. Since two authors arrived independently at similar curves, and since computer simulation confirmed them, the underlying assumptions and any conclusions drawn from them are probably valid.

SUMMARY

The program devised to calculate fuel consumption of a freight train operating over a specific route was validated within an acceptable level of accuracy. Inherent limitations in modeling place a limit on the accuracy which can be achieved. The predictions of fuel consumption were consistently below the actual usage because of unmodeled effects. This is to be preferred, however, to random variation of the prediction about both sides of the true value. Economic methods were presented for use in evaluating investment decisions, and a numerical example of a particular decision was given. Further examination of other potential design improvements or equipment modifications still remains to be performed, however. Hypothetical curves describing the likely fuel savings through the use of lightweight equipment were shown by means of computer simulation to be correct within the limits of the assumptions made. The curves offer a limited degree of rationality to replace previous intuition. Some remaining areas in which future research could be conducted were delineated.

1.0 INTRODUCTION

Two previous reports(1,2) on the subject of train resistance and fuel consumption of freight trains constituted Volumes I and II of this three volume series. In this third and final volume the concluding efforts of this study are reported. A major portion of the effort was devoted to correlation of the predictions from the computer program to actual data recorded in the field and an examination of the causes of discrepancies observed. A second major effort was devoted to an examination of types of economic methods which could be utilized to make investment decisions and to a detailed analysis of a particular investment decision utilizing one specific economic method. Some effort was devoted to confirmation of some theoretical areas which had been espoused in Volume II(2) and elsewhere in the literature(3) and some suggestions and recommendations for future investigation are given. Various modifications and improvements to the computer program which were incorporated from time to time during the course of this effort and as the requisite information became available are reported in an appendix.

2.0 CORRELATION EFFORTS

2.1 Introduction

The problem of predicting the fuel consumption of freight trains when they were operated over track encountered in normal operations, i.e., including grades and curves, was addressed in Volume II.(2) While attention was directed to determining the sensitivity of fuel consumption to various equipment modifications or design improvements, before such determinations were made an initial attempt at correlating the predictions with actual field data was made. It was felt that the reported sensitivities would be more credible if the absolute predictions of fuel consumption were as accurate as possible. Not much information was readily available for establishing correlation, but comparisons were made with two actual runs from which fuel consumption had been reported in a previous report (4) and for which track data were available, as well as with the results of a simulation made by a computer program of a major railroad.

The results are reported in Table II of the referenced report.(2) Fuel consumption predicted by the two simulations were, on a gallons per gross-trailing-ton-mile basis, very close (within 3 percent), but the predicted fuel consumption for the actual runs fell short by 21 percent and 32 percent.

While accuracy was deemed suitable for the purposes of Volume II, it would be desirable to obtain a higher degree of correlation. As a consequence, track and detailed fuel consumption data for some longer runs were obtained and additional simulations were made. The initial results were equally discouraging, as the shortfalls in the predictions were of the same order of magnitude.

The remaining portions of this section address the assessment of apparent causes of such a discrepancy, adjustments made to the program to correct what were perceived as inaccuracies in the calculation, and the final results. A discussion of the relative magnitude of the various contributions to the remaining discrepancy is included.

2.2 Apparent Causes of Discrepancy

2.2.1 Initial Simulation

Fuel consumption data for an intermodal run had been received from a major western railroad and from TSC. These data were recorded during actual field tests. The TSC data had been recorded by the same railroad in early 1976 during some tests sponsored by the Federal Railraod Administration. The more recent railroad data were taken in 1978. The railroad data and the relevant portion of the TSC data concerned a 220 mile mid-western portion of a longer transcontinental run. The first sets of data from each of these sources were compared with the predictions from the MITRE fuel consumption program in a continuation of earlier efforts to establish correspondence between predictions and results. The effort made clear some of the difficulties involved in establishing such correspondence and also raised an additional question with regard to the accuracy of the modified Davis equation. This section serves to document those findings.

After appropriate train files had been generated and the MITRE program had been suitably modified to reflect the use of dynamic braking and the type of locomotive used in the field tests, the results of the MITRE program were compared with the field data from two actual runs. The data from the first set were supplied by TSC from data which had been collected under an earlier program, and fuel consumption was recorded each mile. The data from the second set consisted only of an overall result for fuel consumption for the entire 220 mile run and was obtained directly from the railroad through the efforts of FRA. The results were as follows:

Fuel Consumption as Reported by	Gallons
TSC	1739.5
Railroad	1662.4
MITRE Program (simulating the same run)	1361.12

While the calculated result was approximately 20 percent below the reported measurements, some deviation from field data is to be expected. "variability approaching ± 20 percent within each of the several test series for gross ton miles per gallon" was reported for the TSC fuel consumption measurements themselves.(5) In particular, while the average deviation of the TSC simulation predictions from the field measurements over six 1750 mile runs was reported to be only 5 percent, the average deviations of the same TSC simulations over the 220 mile portion of the runs, simulated in the MITRE program, were -25 percent and -13 percent for the two portions.(5) It might therefore have been from such considerations alone that the MITRE figure lay within the expected range of accuracy, but despite the possibility that such predictions may be inherently inaccurate, it appeared desirable to determine the reason for the discrepancy. Consequently the fuel and track data and the program itself were closely examined for possible causes, and several factors were found to be likely contributors.

(a) Effect of the Use of the Modified Davis Formula

The original Davis equation(6) for train resistance is well known. In absolute terms, the resistance of a four-axle railroad car in lbs. is given by

$$R = 1.3\ W_o + 116 + bW_oV + CAV^2$$

in which W_o = weight of car in tons

V = velocity in mph

b,C = empirical constants

A = cross-sectional area of car

Use of recommended values(6) for the constants would modify the equation to:

$$R(\text{lbs.}) = 1.3W_o + 116 + .045W_oV + .045V^2$$

The Canadian National Railway, on the basis of their own tests, modified the coefficients of this equation, and the "modified" Davis equation, put into the same form, became:

$$R(\text{lbs.}) = .6W_o + 80 + .01W_oV + .07V^2$$

The modification of the coefficients was ostensibly to reflect the use of modern equipment, as the Davis equation was originally advanced in 1926.

Both the TSC Train Performance Simulator and the MITRE program used the modified Davis formula in simulating the runs. Although the modified Davis formula is probably now used more widely than the original formula, it has not been completely established, for the purposes of this investigations that the modified formula leads to more accurate predictions of resistance than the original. Hammitt(7) discusses some anomalies with respect to its use and states that "the modified Davis formula may not be an improvement." It was also noted in the MITRE report(1) that "it is not clear what design improvement contributed to such a large reduction in the coefficient of the middle term from .045 to .01, although a plausible rationale was found for changes in the other terms. Luebke(8) suggested that "the error between the actual mechanical resistances [i.e., non-aerodynamic resistances] and the empirical values used in the Canadian National formula... can be as much as 8 percent." A report by Morlock(3) used a 0.1 value for the term for intermodal equipment, but this may have been a typographical error, as an investigation(9) of the report stated that no substantiation for the use of that value could be found. It seems clear at least that there is reasonable doubt as to the correct value to be used.

With these thoughts in mind, the MITRE program was altered to utilize the .045 value for the coefficient, as in the original Davis equation. This resulted in the calculated fuel consumption rising to 1615.01 gallons, a value within 3 percent of the reported measurement from the railroad.

Minor deviations must be expected for any simulation, as it is impossible to duplicate the velocity profile exactly, a parameter upon which fuel consumption is highly dependent. At best, one can adjust the permitted maximum speed until the average speed for the simulated trip is approximately the same as for the actual one. Still, even with the same average velocity, fuel consumption can vary significantly. Moreover, the operation is quite sensitive to changes in average velocity as well, and even on level tangent track at constant speed, a change in the average velocity of only 1 mph can for this operation result in a change of 32 gallons in fuel consumption, approximately 2 percent alone. It must therefore be concluded that the 3 percent error is well within the expected error. However, although considerable justification for reverting to the use of the former coefficient was demonstrated in this initial instance, this was not felt to be the sole answer to the discrepancy among the figures.

(b) Comparison of Fuel Consumption on a Mile-by-Mile Basis

Since the fuel consumption results supplied by TSC were given in considerable detail, they were scrutinized carefully to determine where the MITRE predictions departed from them and why. Measurements were reported every mile by TSC and the MITRE program results were compared on the same basis as closely as the calculated data would permit. The findings illustrate the possible pitfalls in attempting to find correspondence between such field data and calculations and the necessity for examining closely the equivalence of the operations being compared. The cumulative fuel consumption values for both the actual run and the simulated run were found to be more revealing than others and are plotted in Figure 1 for the first 25 miles of the run. The elevation profile of the track over which the simulated run was made is shown to scale (with vertical scale exaggerated) at the top of the figure. The upper curve plots the cumulative fuel consumption as a function of the distance for the actual run as reported by TSC. The lower curve plots the same for the original MITRE calculation. The middle curve plots the same for the MITRE calculation corrected to use the .045 figure for the middle coefficient in the resistance formula, as discussed above. Three more contributors to the discrepancy revealed themselves as a result of examination of the figure and the fuel consumption measurements per mile.

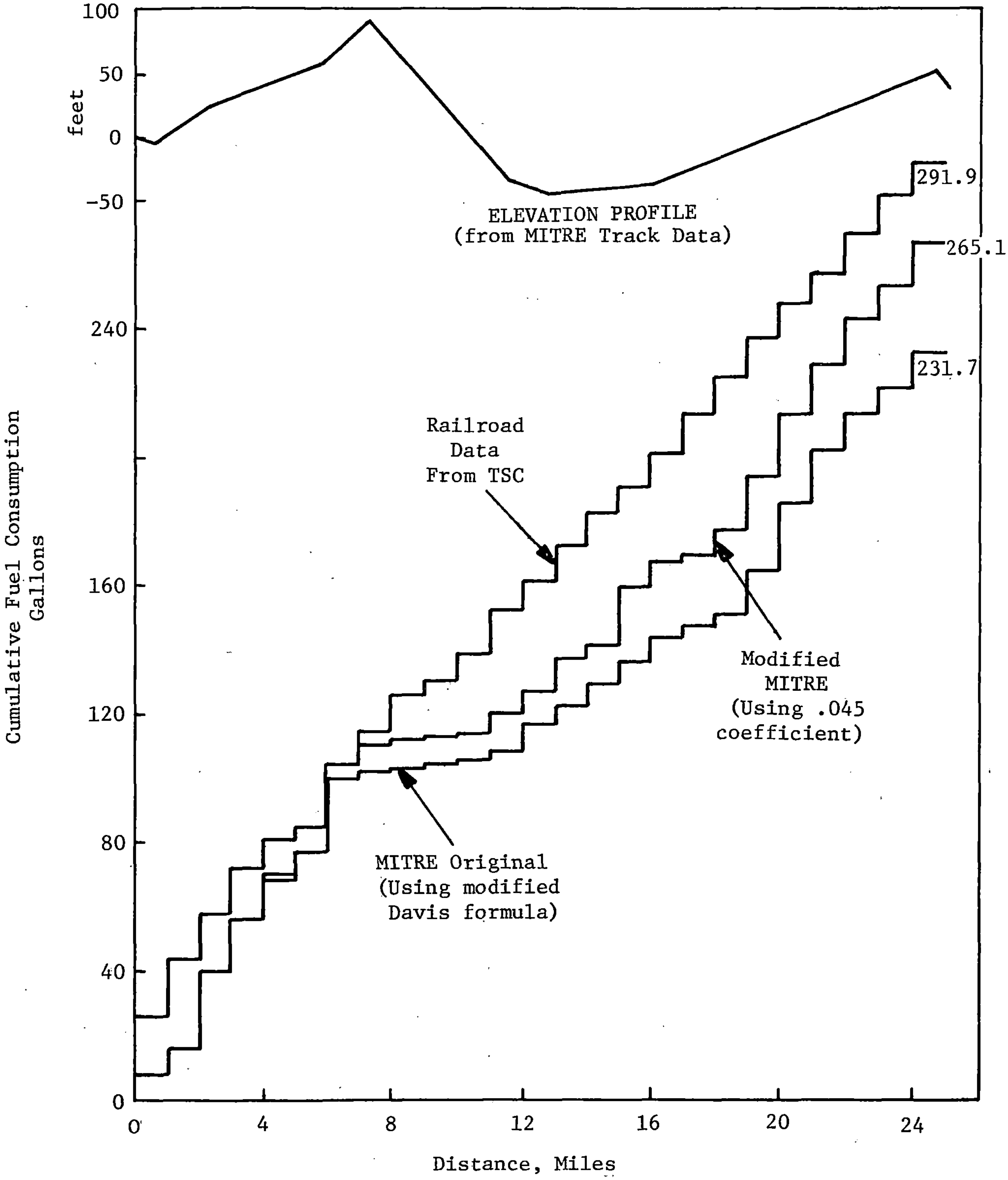

FIGURE 1
CUMULATIVE FUEL CONSUMPTION

(1) From examination of the fuel consumption measurements per mile and the times and velocities reported at the mileposts, it appears that a stop was made at approximately milepost #6 which was not simulated in the MITRE program. The kinetic energy of a train of that weight may be equivalent to the available energy content of thirty gallons of fuel, the major portion of which may be wasted by a stop of this nature.

(2) The MITRE track data include a speed limit restriction to 30 mph in the region of milepost #18 which, from the field measurements, does not appear to have been observed. The probability arises that the speed limit restriction was only temporary and has since been removed. The likelihood of such an occurrence was confirmed by a representative of the railroad. While the effect of a speed restriction is not as large as that of a full stop, fuel consumption on the first 25 miles of the above track with and without the single speed restriction to 30 mph for about three miles of track amounted to 294 and 316 gallons, respectively, an absolute difference of 22 gallons and a percentage difference of 7 percent.

(3) The MITRE program calculations plainly reflect the four mile long and comparatively steep downgrade from approximately mile post #7 to #11, during which descent locomotive engines are throttled back and the kinetic energy of the train is utilized in overcoming train resistance. During this time the contributions to cumulative fuel consumption are minimal, reflecting the idle rate or possibly the dynamic braking rate. In contrast, the fuel consumption measurements from the field show little, if any, such diminution in the fuel consumption rate. Note that virtually to the beginning of this downgrade the fuel consumption measurements and predictions are not notably different, and that much, if not most, of the final discrepancy is attributable to the difference in the figures between

these mileposts. This raised the distinct possibility that the track data used by MITRE was no longer valid and did not correspond with the track over which the train whose fuel consumption was reported was run. However, a check with the representative of the railroad on this point established that there was little likelihood that such a change in the nature of the track had taken place. He suggested, instead, that the difference in fuel consumption might be attributable to train handling, in particular over undulating terrain, where engineers often keep the train stretched by working the engines against the brakes. Since the major discrepancy which cannot be otherwise accounted for does actually occur at a point in the track where such a phenomenon might readily occur, it seems likely that this is the explanation, as the MITRE program does not presently model such phenomena as train stretching. The representative also suggested that steady winds, to which he believed that stretch of track is quite susceptible, may have had an adverse effect upon fuel consumption.

It must be concluded from the above that making accurate predictions of fuel consumption will be difficult when human factors and random occurrences of nature not susceptible to simple modeling contribute heavily to variations in fuel consumption. Nevertheless, it was possible to offer a plausible explanation of the discrepancy.

2.2.2 Second Simulation

In a further effort to resolve the discrepancy between field data on fuel consumption of a freight train and predictions from MITRE's computer program, a simulation of a unit coal train run over some eastern tracks for a distance of about 200 miles was made. A unit coal train run was selected for the second simulation as a distinct contrast, from the standpoint of aerodynamic drag, to the previously simulated TOFC run. At least a portion of the discrepancy between fuel consumption figures reported for the TOFC run and the results of the MITRE simulation was believed to be attributable to relatively inaccurate simulation of the TOFC aerodynamic drag. It was anticipated that the results of the simulation of the unit coal train, whose aerodynamic characteristics were deemed more amenable to accurate simulation because of close coupling between cars and minimal turbulence in the air stream, would show closer correspondence to the actual figures than the TOFC simulation and would therefore isolate the cause of the discrepancy.

Simulation of the unit coal train run required track data. Data were supplied by TSC in punched card form; however, both speed limit and curvature data were lacking. The data were reformatted for use in the MITRE program, and in the absence of better information, curvature data corresponding to the track artificially generated in previous work from statistical data from all U. S. Class A mainline track was inserted. A train file corresponding to the simulated train was created and new locomotive performance curves for the GP-38 locomotive (idealized from the single curve available in Car and Locomotive Cyclopedia)(10) were generated for each notch position and inserted into the main program. Three other minor modifications formerly necessary when a different locomotive was simulated were also made. It later became evident because of the weight of the train and the steep grades that the 250,000 lb. tractive effort limitation which had been part of the program would have to be eliminated to simulate the run properly and the provision was deleted. The resistance of the train itself was carefully checked by means of a separate program, and the average aerodynamic coefficient was almost exactly .07, the value used in the modified Davis formula. Hence it was considered unlikely that aerodynamics would be a contributor if any discrepancy were noted.

Despite the initial confidence the results of the first simulation of the unit coal train run were 28 percent below the reported fuel consumption. An estimate for the additional fuel consumed if the mean curvature were equal to that of a comparatively mountainous eastern track for which data were available reduced the discrepancy only to 24 percent. Although some of the discrepancy could be attributed to differences in average velocity for the trip, it appeared that other factors must have been contributing.

2.2.2.1 Track Data Considerations

The track charts were therefore carefully examined to determine the extent of the information available and the accuracy with which the track data reflected this information. It was noted that considerable simplification had been made in compiling the data from the charts, as this is a very tedious procedure, and that grades had been approximated over long distances rather than calculated from every item of available elevation data. As noted before, in the original data the curvature had been omitted completely and artificial information had to be inserted for MITRE's simulation.

Because the possibility existed that the simplification and the lack of detailed curvature data might have contributed to the discrepancy, data from the first 20 miles of track charts were carefully extracted and compiled into a separate track file over which another simulation was run. This simulation showed a fuel consumption 24.6 percent greater than that using the simplified data. This result suggested that the effort be repeated on the next section of track. A similar increase in fuel consumption over the combined sections led to data reduction on a third section, making a total of 74 miles of track from which detailed data had been compiled. The 74 miles included both a long upgrade and a long downgrade. The final result was that the indicated fuel consumption was 19 percent greater over a 74 mile stretch when the detailed data were used instead of the simplified data. See Figure 2 in which the cumulative fuel consumption figures are given as a function of distance. Except for the first ten miles, in which the simplified track data had only two track records and the detailed data no less than 70, the indicated fuel consumption from the simulation was consistently higher, by some fifteen to twenty percent, than that indicated by the use of the simplified data. Since the extent of the original discrepancy for the entire trip was of the same order, it was clearly indicated that considerable responsibility for the discrepancy lay with the particular track data used.

2.2.2.2 Data Transcription Considerations

A representative portion of a track chart from the railroad used in the manual extraction of data discussed herein is illustrated in Figure 3. Because the transcription of data from the track charts into accurate data in a form suitable for use with a computer program is laborious, it is worth noting the steps which need to be taken and some of the problems which need to be considered. The steps are as follows:

(1) Extract elevation data from chart

(2) Extract curvature data from chart

(3) Extract speed limit data from chart (when available; usually separate from track charts)

(4) Arrange data in geographical sequence by merging

(5) Type punched cards or insert data into system from terminal

(6) Run data through an ancillary program to add milepost numbers and to calculate grades between points.

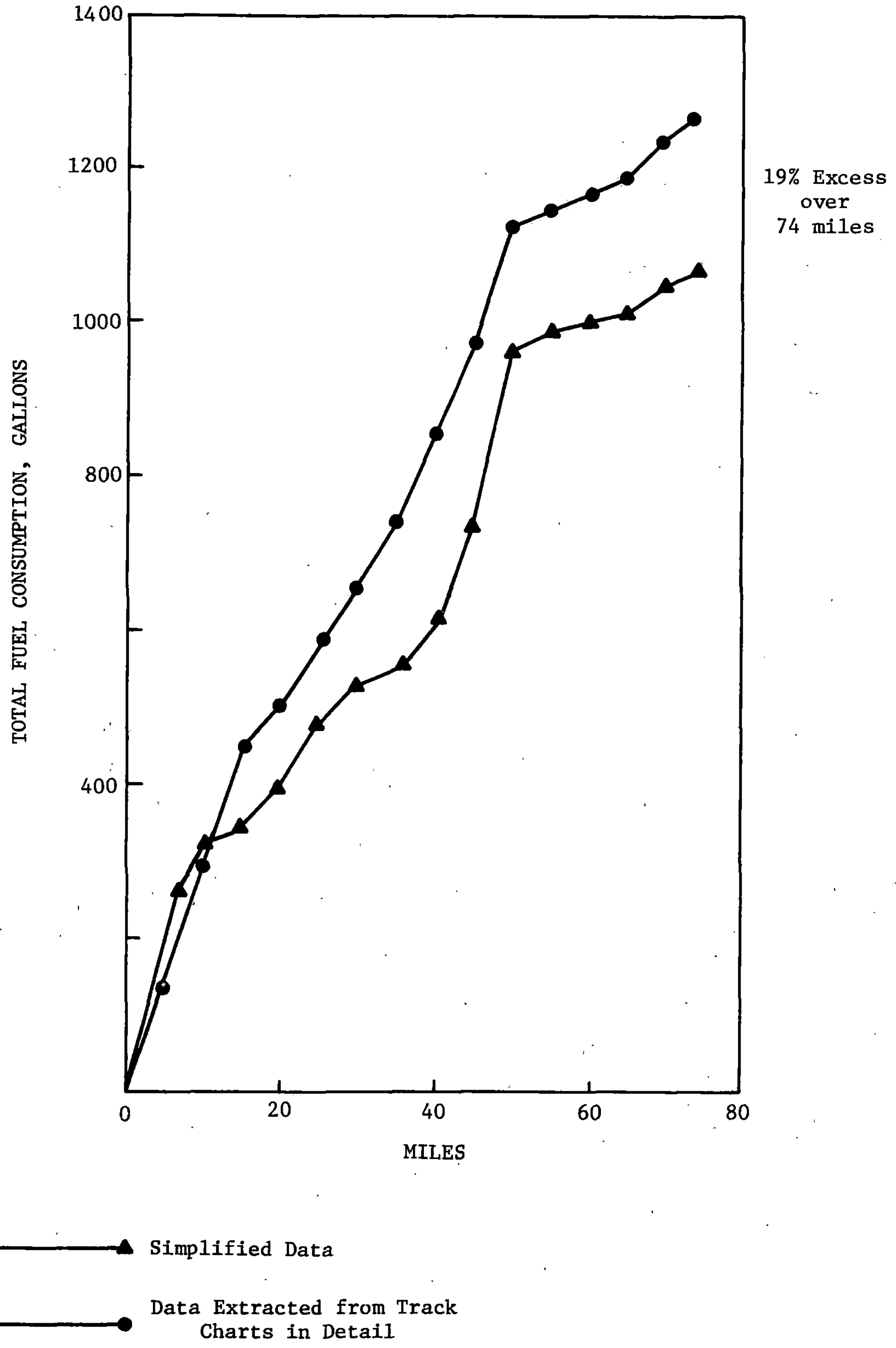

FIGURE 2
TOTAL FUEL CONSUMPTION FOR SAME TRACK, USING DIFFERENT COMPLEXITY OF DATA

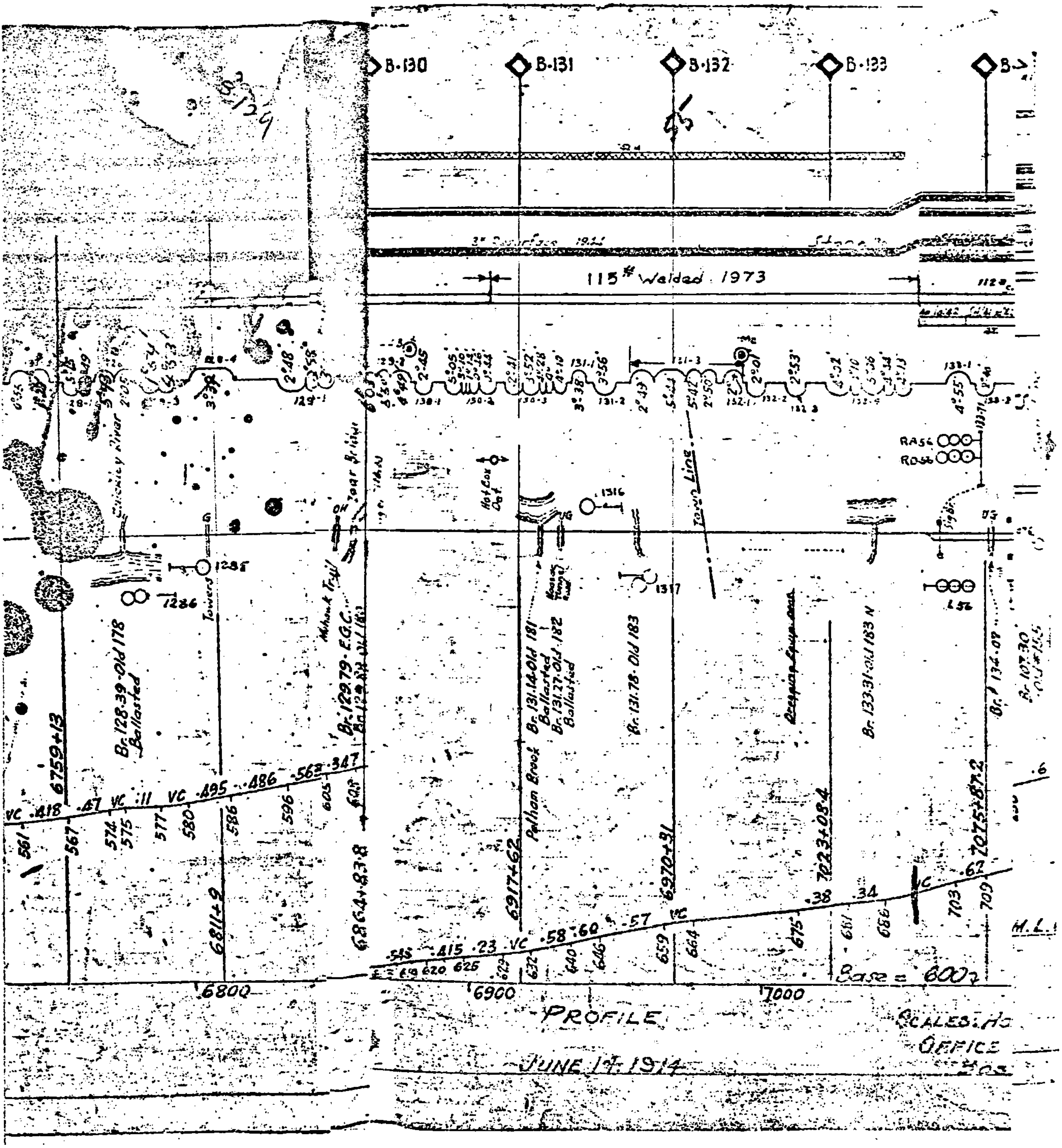

FIGURE 3
TYPICAL TRACK CHART

Figure 4 illustrates data compiled from the track charts after the merging into geographical sequence has been completed and the data entered into the system. Note that in this sample no speed limit information was available and that curvature has been converted to its grade equivalent. Figure 5 illustrates the data after it has been reformatted by the ancillary program so that it is suitable for use with the main program. The ancillary program is illustrated for reference in Figure 6.

The labor involved in extracting data to the illustrated level of detail amounted to one man-day per fourteen miles of track. This number did not include insertion of speed limit data, as none was available. Speed limit information was subsequently added by the computer program which reformatted the data. The effort to create the ancillary program was also not included in the one man-day per fourteen mile figure.

Some of the problems relating to the accuracy of track data which has been manually transcribed are discussed below. The problems mentioned are related to the particular track charts examined, but it is likely that most of them would be related to track charts from other railroads and many of them are related only to the process itself.

The position at which the curve begins or at which the elevation is measured must be scaled off from a starting point. Inaccuracies are incurred from both the drawing of the point originally and in measuring its position. Prints are not necessarily to scale and errors may be incurred by the distortion introduced by the reproduction process.

```
FILE:TRACKBMQ DATA      A

          Distance Elevation*G.E.C**
          (miles)   (feet)
           52.17    743.0    .00
           52.25      0.0    .09
           52.40    733.0    .09
           52.46      0.0    .00
           52.50      0.0    .23
           52.64      0.0    .24
           52.76      0.0    .00
           52.90      0.0    .11
           53.00    709.0    .11
           53.06      0.0    .00
           53.12      0.0    .20
           53.20    703.0    .20
           53.27      0.0    .00
           53.50      0.0    .18
           53.65    686.0    .18
           53.88    681.0    .18
           54.03      0.0    .00
           54.15      0.0    .12
           54.19    675.0    .12
           54.28      0.0    .00
           54.40      0.0    .08
           54.55      0.0    .08
           54.68      0.0    .00
           54.70      0.0    .11
           54.82      0.0    .23
           54.87    664.0    .23
           54.92      0.0    .23
           55.06    659.0    .23
           55.10      0.0    .11
           55.25      0.0    .00
           55.35      0.0    .16
           55.46    646.0    .16
           55.52      0.0    .00
           55.56      0.0    .14
           55.65      0.0    .00
           55.66    640.0    .00
           55.68      0.0    .22
           55.92    632.0    .22
           56.08      0.0    .00
```

* Zeros indicate no information at that point.

** Grade Equivalent Curvature

FIGURE 4
SAMPLE OF RAW DATA AS COMPILED FROM TRACK CHARTS

Milepost	Distance (Miles)	Grade	G.E.C.	Speed Limit
406	52.17	-0.82	0.0	30.0
407	52.25	-0.82	0.09	30.0
408	52.40	-0.76	0.09	30.0
409	52.46	-0.76	0.0	30.0
410	52.50	-0.76	0.23	30.0
411	52.64	-0.76	0.24	30.0
412	52.76	-0.76	0.0	30.0
413	52.90	-0.76	0.11	30.0
414	53.00	-0.57	0.11	30.0
415	53.06	-0.57	0.0	30.0
416	53.12	-0.57	0.20	30.0
417	53.20	-0.72	0.20	30.0
418	53.27	-0.72	0.0	30.0
419	53.50	-0.72	0.18	30.0
420	53.65	-0.41	0.18	30.0
421	53.88	-0.37	0.18	30.0
422	54.03	-0.37	0.0	30.0
423	54.15	-0.37	0.12	30.0
424	54.19	-0.31	0.12	30.0
425	54.28	-0.31	0.0	30.0
426	54.40	-0.31	0.08	30.0
427	54.55	-0.31	0.08	30.0
428	54.68	-0.31	0.0	30.0
429	54.70	-0.31	0.11	30.0
430	54.82	-0.31	0.23	30.0
431	54.87	-0.50	0.23	30.0
432	54.92	-0.50	0.23	30.0
433	55.06	-0.62	0.23	30.0
434	55.10	-0.62	0.11	30.0
435	55.25	-0.62	0.0	30.0
436	55.35	-0.62	0.16	30.0
437	55.46	-0.57	0.16	30.0
438	55.52	-0.57	0.0	30.0
439	55.56	-0.57	0.14	30.0
440	55.65	-0.57	0.0	30.0
441	55.66	-0.58	0.0	30.0
442	55.68	-0.58	0.22	30.0
443	55.92	-0.30	0.22	30.0
444	56.08	-0.30	0.0	30.0

FIGURE 5
SAME SAMPLE OF DATA REFORMATTED

```
FILE: ALTER5   FORTRAN  A                   CONVERSATIONAL MONITOR SYSTEM

      DIMENSION TRACK(500,4),D(500,4),E(500)                               ALT00010
      DIMENSION LINE(500)                                                  ALT00020
      WRITE(6,12)                                                          ALT00030
      WRITE(7,12)                                                          ALT00040
   12 FORMAT (1X, 'INPUT, NO. OF TRACK RECORDS (3 DIGITS)')                ALT00050
      READ (5,13) NTR                                                      ALT00060
      WRITE (7,13) NTR                                                     ALT00070
   13 FORMAT (I3)                                                          ALT00080
      READ (3,10) ((D(M,N),N=1,3),M=1,NTR)                                 ALT00090
   10 FORMAT (6X,F5.2,3X,F5.1,3X,F3.2)                                     ALT00100
      DO 20 I = 1,NTR                                                      ALT00110
      LINE(I) = 616+I                                                      ALT00120
      TRACK(I,1) = D(I,1)                                                  ALT00130
      IF (I.EQ.NTR) GO TO 400                                              ALT00140
      TRACK(I,3) = D(I,3)                                                  ALT00150
      TRACK(I,4) = 30.0                                                    ALT00160
      N = I+1                                                              ALT00170
  100 J = I+1                                                              ALT00180
      IF(D(N,2).NE.0.0.AND.N.EQ.J) GO TO 500                               ALT00190
  200 N = N+1                                                              ALT00200
      IF (D(N,2).EQ.0.0) GO TO 200                                         ALT00210
      IF (D(N,2).NE.0.0) GO TO 300                                         ALT00220
  300 E(I+1) = D(I,2)+(D(N,2)-D(I,2))*(D((I+1),1)-D(I,1))                  ALT00230
     1 /(D(N,1)-D(I,1))                                                    ALT00240
      TRACK(I,2) = 100.0*(E(I+1)-D(I,2))/((D((I+1),1)-D(I,1))*5280.0)      ALT00250
      D((I+1),2) = E(I+1)                                                  ALT00260
      GO TO 20                                                             ALT00270
  500 TRACK(I,2) = 100.0*(D((I+1),2)-D(I,2))/((D((I+1),1)-D(I,1))*         ALT00280
     1 5280.0)                                                             ALT00290
      GO TO 20                                                             ALT00300
  400 TRACK(I,2) = 0.0                                                     ALT00310
      TRACK(I,3) = 0.0                                                     ALT00320
      TRACK(I,4) = 0.0                                                     ALT00330
   20 CONTINUE                                                             ALT00340
      WRITE(7,25) ((LINE(K),(TRACK(K,L),L=1,4)),K=1,NTR)                   ALT00350
   25 FORMAT (I3,1X,3F9.2,F9.1)                                            ALT00360
      STOP                                                                 ALT00370
      END                                                                  ALT00380
```

FIGURE 6
COMPUTER PROGRAM USED TO REFORMAT TRACK DATA

Elevation values are rounded off to the nearest foot. When the points are close and the difference in elevation is only one or two feet, the error in grade between the points may be large.

The length of curves is indicated by an extended semicircle. If the curve is short enough, the curve may be indicated simply by a semicircle. For drafting purposes, the semicircle must have a minimum size. Thus in scaling the length, each individual curve will of necessity have a minimum length. Where curves follow upon curves, it is virtually impossible to show or measure the individual lengths on the chart and one can only take the length for the total and divide it in some arbitrary fashion. Again, problems of scaling the length arise as with scaling the position.

Many times the reproduction process has reduced some of the curve information to illegibility. Also, clerical errors unfortunately are highly likely when digital information is transferred manually. Since all the charts are periodically updated, there is always in addition the possibility that the information on them is out of date.

All the above contribute ultimately to the inherent inaccuracy of the data. As an unfortunate result, it is virtually impossible to obtain completely accurate data, even if one is willing to spend the time. Nevertheless, the accuracy of the individual data point is probably less critical than the fact that a data point has been established for that location rather than ignored. Thus it is more important for the purposes of computing fuel consumption that a track record be entered to note a new elevation or the beginning or end of a curve than whether the curve is 500 ft. or 493 ft. long or whether the elevation was measured at milepost 53.6 or 53.28. The point to be emphasized is that while there may be inaccuracies in the data which contribute to a limited extent to inaccuracies in the fuel consumption prediction, the level of detail in the data, particularly in the curvature data, appears to be more significant. Unfortunately, the labor intensiveness is created by the level of detail in the transcription of the data and not by the accuracy with which the data are transcribed.

An unfortunate aspect of the use of detailed data with many track records is that computing time is increased correspondingly. As an example, the number of track records in the sample 74 mile run rose to 517 from the 32 in the original data and as a consequence the number of iterations necessary to perform the calculation rose from 400 to 1083. Thus there exists an inherent tradeoff between an accurate result and cost: relative accuracy of the fuel consumption prediction can be obtained only at the expense of generating detailed track data and incurring additional computational costs. For certain railroads, or for certain operations on a particular railroad, it may not be justifiable to invest the labor nor the additional computer time merely to improve the accuracy of fuel consumption predictions.

2.2.2.3 Conclusions from Second Simulation

A unit coal train operation was simulated in the hope that the prediction of fuel consumption would be more accurate than that for a unit TOFC train. It was felt that the aerodynamic drag of such conventional equipment was better understood, and therefore that either no discrepancy between predictions and measurements would exist or any discrepancy would be attributable to other causes. A discrepancy of magnitude similar to that observed on the TOFC simulation resulted. This led to an examination of the track data and the observation that the data used had been considerably simplified from the information available on the track charts. New data was therefore compiled for the first 74 miles of the run directly from the track charts and the run was again simulated using the new data. The new fuel consumption was higher by approximately the same percentage that the former predicted consumption fell beneath the measured consumption for the entire trip. Since care had been taken to perform the changes in the track data in three separate steps so that possible transcription errors incurred in one would not be inadvertently repeated in the others, the fact that the use of each led to that same conclusion suggests that a large portion of the discrepancies observed in the fuel consumption predictions for both the TOFC and unit coal train runs were attributable to the use of insufficiently detailed track data.

2.2.3 Modification to Aerodynamic Drag Calculation

Although it was found that there were several likely contributors to the discrepancies besides an inaccurate aerodynamic drag calculation, it was believed initially that only the TOFC aerodynamic drag calculation would be found to be inaccurate, as the early wind tunnel tests had demonstrated that the shielding of TOFC cars from the air stream was not as effective as the wind tunnel tests on wooden blocks representing box cars had indicated. Block tests had indicated that the drag on the metric blocks in the shielded condition, where the ratio of gap spacing to block width was less than 0.4, was substantially less than the drag in the unshielded condition, approximately one-tenth of the value. This was consistent with earlier beliefs regarding the comparative resistance of freight cars in a train of similar cars and in an isolated condition (see Reference (1), p. 44, and references cited therein, in which it is noted that "anywhere from five to ten cars contribute in skin friction the equivalent of the pressure drag from the leading and trailing vehicles"). It was therefore decided, because of the desire to establish a consistent rationale for the calculation of aerodynamic drag for all freight equipment, that the calculation would be based upon the drag area, estimated or derived from tests, in the unshielded condition. This drag area would be modified by proximity considerations, so that in the shielded configuration the pressure drag would diminish as shown in the wind tunnel tests on blocks. The theoretical skin friction drag would be separately calculated and added to this, and would not be affected by proximity calculations.

After some attempts at correlating the results from certain TOFC runs with predictions from the program had revealed the discrepancy, it was suspected that among other causes the value calculated for the TOFC air drag was not sufficiently large. Examination of the original wind tunnel tests of TOFC equipment revealed that the drop in drag in the shielded condition was not nearly as great as one would expect from consideration of the block tests, and it was felt that some special accommodation would have to be made solely for such special items of equipment in this calculation.

In retrospect it can be seen that the original procedure incurred certain errors in the calculation of the aerodynamic drag and contributed partially to the 20 percent shortfall in the fuel consumption predition for all trains. In the absence of wind tunnel data for conventional equipment, drag areas had been estimated, the ratio of front and rear pressure drags had arbitrarily been made equal to unity, and skin friction based upon theoretical considerations added. In addition, it became clear that basing the TOFC aerodynamic drag on the reported drag area for the unshielded condition did not result in the reported figure for the unshielded condition as a result of the methodology employed.

In a subsequent effort to pinpoint the source of this discrepancy, a unit hopper car train for which fuel consumption figures were also available was selected for simulation. It was expected that because it was more conventional equipment and the aerodynamics of such equipment were better understood, the discrepancy would be eliminated. However, the same discrepancy, or even a larger one, occurred. While it was found that there were other contributing causes, it appeared that the aerodynamic drag calculation for even conventional equipment was contributing to the discrepancy, and that the calculation for all equipment must be modified to reflect the results of wind tunnel tests which had just been made available from an extensive series of tests on conventional and unconventional equipment by Hammit Associates(11) for FRA.

Consequently it was decided to revise the aerodynamic calculation so that the results would be in correspondence with the wind tunnel data in both the shielded and unshielded condition. The methodology for treating the in-between condition was also revised to be as consistent as possible with the wind tunnel results. The revised approach is outlined and discussed in Appendix B, along with other modifications to the program made subsequent to the publication of Volume II.

2.3 Final Results

This section describes the results of the final simulations of runs of both the western TOFC run and the eastern unit coal train run. Fuel consumption data on the actual runs were available for all runs simulated. The runs were made after adjustment of the aerodynamic drag data (11) and calculation* on the basis of the wind tunnel tests. The drag data for a loaded hopper car was also introduced into the data bank for the program, as it was deemed

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*See Appendix B.

essential to distinguish between loaded and unloaded hopper cars. A minor adjustment in the locomotive aerodynamic drag calculation to reflect the slight difference between two and three axle trucks not hitherto reported was also made prior to making the runs.

It is felt that the results of the simulations are presently as accurate as available knowledge will permit, and that any discrepancies between predicted values and measured consumption must now be attributed to causes not simulated, not predictable, or not amenable to analysis. Both the results and probable and possible causes of the discrepancies are discussed in some detail in the paragraph below.

2.3.1 Discussion of Results

The runs were simulated several times until the average velocity for the trip was deemed to be close enough to the actual average velocity so that differences in fuel consumption attributable to differences in average velocity would be insignificant.

The results are listed in Table I, along with the measured fuel consumption. For the TOFC runs, the listed fuel consumption and the predicted value were for a complete trip. For the unit coal train runs, because track data in what was deemed sufficient detail was not available for more than a portion of the complete run, the fuel consumption and prediction pertain to only the western portion of the track for which detailed track data had been manually compiled directly from track charts. Both eastbound and westbound runs were simulated, and because the westbound simulation of the TOFC run was so much farther from the true value than the eastbound run it was suspected that a headwind, or a cross wind equivalent in effect, might have contributed to the larger

TABLE I

SIMULATION RESULTS

Run No.	RR	Type of Operation	Direction	Miles	Simulated		Actual		Prediction Shortfall (Percent of Actual Consumption)
					Fuel Consumption (Gallons)	Average Velocity (mph)	Fuel Consumption (Gallons)	Average Velocity (mph)	
1	Santa Fe	TOFC	EB	220.8	1659.1	48.21	1662.4	47.69	0.2
2	Santa Fe	TOFC	WB	220.8	1719.3	43.33	1970.1	43.49	12.7
3	Santa Fe	TOFC	WB*	220.8	2055.5	43.26			-4.3
4	Boston & Maine	Unit Coal Train (Loaded)	EB	89.76	1525.5	17.70	1753.0	17.37	13.0
5	Boston & Maine	Unit Coal Train (Empty)	WB	85.43**	610.3	17.31	788.0	16.53	22.6
6	Boston & Maine	Unit Coal Train (Empty)	WB*	85.43	648.0	17.54			17.8

*With simulated 10 MPH headwind.

**The reported terminal point in the return direction at which fuel consumption was measured was not the same as the starting point for the loaded train.

discrepancy, and a further run against a 10 mph headwind was simulated on the westbound runs of both operations.

Several observations based upon the results are worth noting. It is coincidental that the prediction for Run #1 is so close to the actual consumption. It is not intended to convey the impression that the prediction by the MITRE program, or by any program, is as accurate as those figures imply. The best accuracy ultimately possible is probably no better than ± 5 percent.

It can be seen from the results of Runs #2 and #3 that the simulation in the westbound direction was not as accurate as the eastbound and that the simulation of a headwind of 10 mph added a significant amount to the predicted fuel consumption, enough to bring the prediction within what might be considered the acceptable range of accuracy. It is certainly arguable that the prevailing winds in the Kansas plains are from the west, and that the equivalent aerodynamic effect of a 10 mph headwind, possibly contributed by a lesser crosswind*, is indeed generally encountered by westbound operations. The TOFC operation being relatively high-speed, it is more susceptible to aerodynamic anomalies than unit coal train operations would be. Had the runs actually experienced a directional bias from wind conditions, however, one would have expected the consumption for the actual eastbound operation, assisted by the wind, to fall slightly beneath the prediction, while for the westbound the actual consumption would be larger than expected. A simulation with a -5 mph headwind in the eastbound operation (i.e., a 5 mph tailwind) and a +5 mph headwind

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*In approximate figures, an 8 mph wind at right angles to the track will create a yaw angle of 10° and an increase in effective drag area of about 50%, equivalent to the effect of a 10 mph headwind on this 48 mph train.

in the westbound operation might have produced such a straddle in predictions. Unfortunately, further investigations of this phenomenon must be left for the future.

Two observations can be made about the results of the unit coal train simulations, Runs #4, #5, and #6. First, the prediction shortfall is substantially larger than for the TOFC run. It seems unlikely that inaccuracies in the prediction of aerodynamic drag for such a low speed operation contributed to the relative inaccuracy, even if the TOFC mode had the advantage of correlation of wind tunnel measurements with full scale test results. With aerodynamics eliminated, it appears that the mechanical and velocity-dependent resistances are being underestimated. It is conceivable that the resistance of the track contributed more heavily to this low speed operation than to the TOFC one and is being underestimated, or that curve resistance is actually higher than the .8 lbs. per ton per degree of curvature normally used. Establishment of the validity of such speculations must be the subject of future work.

Second, the effect of the simulated headwind was not nearly as great as for the TOFC operation. However, this was to be expected, as aerodynamics plays a much smaller role in the low speed coal train operation. It is easy to speculate that in operation in comparatively rolling terrain, including in some portions actual mountains, the wind might readily be quite gusty, varying widely in angle of attack and velocity, and might produce a more adverse effect, more like a crosswind, than a simple steady headwind. However, only a thorough study of wind conditions over the particular terrain might confirm this.

2.3.2 Discussion of Discrepancies

In an effort to minimize the discrepancy between predictions and measurement, diligent efforts to investigate possible causes and to eliminate them have been made. As a result, the shortfall in the predictions, which originally was in the region of twenty to twenty-five percent(2), has been reduced to something of the order of ten percent. It had been hoped that predictions would be made within five percent, although it was realized that there were practical limits to the accuracy which could be attained. It appears that unless more extreme care is taken in controlling certain aspects of both operation and the modeling thereof, ten percent is a more reasonable goal to be achieved.

The fact that the predictions consistently have been smaller than the actual consumption is to a certain extent encouraging, as it lends credence to the belief that there are simply detailed effects which are not being taken into consideration due to the lack of available information or the degree of difficulty associated with obtaining it. Certainly the situation is preferable to one in which the predicted consumption might with equal likelihood be significantly larger than the actual consumption. With the present situation there always remains the expectation that with the expenditure of more effort to model the operation more carefully, the discrepancy can be made smaller.

Reasons for the discrepancies can be readily segregated into three categories: those for which an estimate of the size of the contribution can or has been made; those which are known to contribute a certain inaccuracy although the size may be uncertain; and finally, those which are suspected of contributing to the discrepancy and upon which the remaining discrepancy must be blamed.

It will be assumed for the purposes of budgeting the discrepancy among the various contributing factors that the original discrepancy which was to be eliminated or accounted for 20 percent. The figures below accordingly sum to that figure.

In the first category are the level of detail of curvature data, the averaging of grade information, and the sensitivity of the program itself to the level of detail of track information. It was estimated that the change in the average curvature (in grade equivalent from .027 to .072 accounted for 38 percent of the discrepancy. A separate investigation revealed that averaging of grade information was not significant and contributed a discrepancy of only 2.6 percent. Examination of program sensitivity to level of detail in the track data was made by comparing the predicted consumption for two separate runs over the same 12 mile artificially operated track, one set of data with 9 track records and the other with 61 records. Use of the more detailed record generated a prediction 3.9 percent higher. This figure is attributable to the more detailed calculations made by the program under such circumstances.

In the second category are two parameters whose values are not accurately known. One is the aerodynamic drag, in calm air, as measured by wind tunnel tests. An attempt at correlation of the results of wind tunnel tests and field measurements(12) was reasonably successful, but it is estimated that the drag areas may not be more accurate than 10 percent. In addition, there is considerable doubt raised in current literature regarding the accuracy of the terms in the present formulas representing mechanical resistance, to say nothing of discrepancies among the various formulas in the values of these terms. The accuracy of the calculation is further affected by the ratio of the number of cars equipped with roller bearings in the particular train. Hence it is reasonable to assign a portion of the discrepancy to these factors, although assigning a magnitude is difficult. The fact that the discrepancy for the unit coal train was substantially larger than for the TOFC operation leads one to believe that, because of the relative importance of mechanical drag in such an operation, the estimate of mechanical resistance is in some way indeed too low. It seems possible that at least 3 percent out of the 20 percent might be attributable to inherent inaccuracies in these parameters.

In the third category are contributing factors which will undeniably cause an increase in fuel consumption but the magnitude of the impact of which is unknown. Examples of these are such phenomena as train stretching and crosswinds, both of which can contribute substantially to fuel consumption. An estimate of the additional consumption attributable to train stretching based upon minimal calculation must be left for a future date, but it is possible on the basis of wind tunnel tests to estimate (as shown in Table I) that a crosswind could easily be responsible for 5 percent of the original 20 percent. Train stretching might be estimated at a slightly lower figure of 3 percent.

In addition, there are factors which may be contributing but both the magnitude of which and the certainty of which are unknown. Among these are such uncertainties as the failure to model the deterioration of engine efficiencies with time, the fact that for a particular operation the conversion factor used to convert work done to fuel consumption may not be completely applicable, and the fact that information on idling rates of different locomotives has not always been readily available and has been estimated in certain instances. The lack of speed limit information on the unit coal train operation undoubtedly affected the velocity profile for the trip, even though the input to the program was adjusted so that the average trip velocity was approximately equal to the reported one. Both the difference in the velocity profile and the absolute difference in the average velocity contribute on a small scale to the discrepancy. An assignment of another 20 percent of the total budget does not seem unreasonable.

An examination of the figures above reveals that the sum is 50 percent higher than the average discrepancy of 20 percent. The reason is that some of the estimates above are uncertainties rather than necessarily shortfalls. The figures therefore have each been reduced approximately and proportionally so that the sum reflects the 20 percent discrepancy. Table II illustrates the final apportionment of the discrepancy.

TABLE II

BUDGET OF 20% DISCREPANCY

Percent	Contributing Factor
5.1	Underestimate of curve resistance
1.8	Grade averaging
2.7	Program sensitivity
2.1	Underestimate of mechanical resistance
3.4	Effect of probable cross wind
2.1	Effect of probable train stretching
1.4	Inaccurate modelling of specific fuel consumption
1.4	Lack of speed limit information and variations in velocity profile
20.0	

It can be seen from the table that there are listed eight general categories which are likely contributors to the average shortfall, and estimates of all are reasonably close to each other, with the possible exception of the contribution of curve resistance.

Since the first category appears to be more significant than the others, it is clear that some care should be taken to ensure reasonable accuracy of curvature data. Probably there will always be some contribution to inaccuracy and particularly a shortfall from each of the remaining seven, regardless of the care taken, unless a new apporach is taken in the modelling. It seems likely then that the present approach will consistently underestimate the actual consumption by approximately ten percent. This consistency, however, is to be preferred to erring on both sides of the true value.

2.4 Summary

The results of further computer simulations of freight train operations for which measured fuel consumption figures were available, made after final adjustments of the program in order to incorporate the latest aerodynamic drag data, were reported. Specifically, simulations were made of an intermodal operation (TOFC) on a western track and a unit coal train operation on an eastern track. Simulation was made in both directions of operation; in the case of the unit coal train, it returned empty. The simulation of the intermodal operation predicted a figure in close agreement with the reported consumption; in the reverse direction, however, there was a disparity of almost thirteen percent. It is suspected that a directional bias attributable to wind, either headwind or crosswind or both, was largely responsible for the discrepancy.

For the case of the unit coal train, agreement between reported figures and predictions were not as good, and discrepancies of 13 percent and 22.6 percent were found. As these discrepancies and all previous ones have consistently been on the low side, it is suspected that contributory factors not taken into consideration are responsible. A discussion of the relative impact of some of the possible contributory factors and a possible budget for them have been given. Further examination of these factors and considerations of modifications to the program to improve accuracy should be the subject for future research.

3.0 AN ECONOMIC ANALYSIS

3.1 Introduction

The technical aspects of this effort have been directed towards determination of the fuel savings resulting from equipment modifications, design improvements, or changes of an operational nature. Of greater interest to railroad personnel are the dollar savings and in particular whether or not these savings make the investments in the newer equipment, as an example, worthwhile. A variety of economic methods exists by which such investment decisions can be made. An explanation of the various methods in current vogue and a discussion of advantages and disadvantages associated with each type are given in Appendix A. In this section a particular type of economic analysis is utilized to evaluate the impact of fuel savings resulting from the use of lightweight hopper cars in unit coal train service.

3.2 Application of the Net Present Value (NPV) Method to Railcar Investment Evaluation

This example illustrates an application of the net present value (discounting) method to the evaluation of alternative freight car investments.

The NPV methodology is used rather than the IRR approach primarily because it facilitates comparison of mutually-exclusive projects, i.e, those which compete for a company's fixed investment funds in such a way that only one project can be selected. Furthermore, the limited scope of this effort precluded the implementation of the more extensive, iterative Internal Rate of Return (IRR) procedure.

The operational example used to illustrate the economic analysis approach is a (rather simple) unit coal train operation simulated on existing Western U.S. track. The example is simplified in that the payload demand (coal) is assumed constant throughout the expected service life of the proposed investment. On the other hand, technical, operational and economic input data reflect actual data or estimates drawn from a variety of sources.

Essentially the objective of the analysis is to assist a decision-maker in determining which investment in freight cars for the unit coal train operation is the most beneficial to the railroad. The three investment options to be compared are the acquisition of:

1. standard triple hopper steel cars,
2. lightweight steel gondolas, and
3. lightweight aluminum gondolas.

The investment decision to be made is the selection of only one car fleet (mixes are not considered) which meets service demand at least total cost to the railroad.

For the economic comparison to be valid, however, the following conditions must be met:

1. The annual payload delivered at the generating station (electric utility) must be equal for each option.
2. Over the fixed route, equal train speeds must be assumed.
3. Freight car utilization rates and the times available for car maintenance operations should be the same (or virtually equal) for each option.
4. Maximum load limits on rail are the same for all options.

Given these conditions, the following input data and assumptions are used in the analysis.

3.2.1 Input Data and Assumptions

Operational, equipment, and economic input parameters and related assumptions are summarized in Tables III, IV, and V.

3.2.2 Meeting the Payload Demand

3.2.2.1 Option 1 - Purchase Fleet of Standard Triple Hopper Steel Cars

Operating conditions determine the number of train trips required per year. For example, each round trip time—considering loading, transit, and unloading (switching, inspection, and miscellaneous times are included herein)—amounts to 28 hours or 1.2 days per trip. At this rate, 305 trips/year are required per train under fully utilized operations.

To deliver an annual payload of 2M tons of coal at the generating facility, 65 steel hopper cars (101 ton payload) are needed per train trip. To allow for equipment outages, a car utilization rate of 85 percent has been assumed based on Reference 13. To guarantee coal delivery throughout the year requires that 10 additional cars be purchased as spares. Thus, 75 standard triple hopper steel cars must be acquired for this operation. Such a fleet size and an 85 percent utilization rate allows 1176 hours per car for maintenance operations annually.

A train with 65 standard triple hopper cars can deliver 6565 tons of coal per trip or slightly more than the 2M ton requirements each year (2,002,325 tons/year).

TABLE III

OPERATIONAL PARAMETERS

Payload Type Demand	Coal, average density of 50 lbs. per foot^3, 2,000,000 tons per year at generating station.	
Route/Track	Typical Western U.S. track; relatively high speed operation; small percentage of grades and curvature; distance, 221 miles; (Reference 2, Table III, p. 37)	
Train Speed		
Delivery Mode	25 mph	Average Speeds (Ref. 2)
Backhaul Mode	45 mph	
Transit Time		
Delivery	9 hours	
Backhaul	5 hours	
Round Trip	14 hours	
Load/Unload Time		
Load	2 hours	Assumption based on Ref. 13
Unload	12 hours	
Fuel Type	Diesel #2	
Consumption	Delivery: 0.78 gals/1000 TTM Ref. 2 Backhaul: 1.50 gals/1000 TTM	
Locomotive		
Maintenance	$0.294 per 1000 GTM (Ref. 14)	
Lubrication	$0.039 per 1000 GTM	
ROW Maintenance	$0.708 per 1000 GTM (Ref. 14)	
Car Utilization Rate	85% (Assumed for each investment)	
Other Operating Costs	Dispatching, crew wages/benefits assumed independent of investment alternative.	

TABLE IV

EQUIPMENT PARAMETERS FOR EACH INVESTMENT

INVESTMENT OPTIONS	1	2	3
Type	std. triple hopper	53' gondola	53' gondola
Lt. wt.	61,000# (30T)	50,400# (25T)	46,800# (23T)
Gross wt. on rails	263,000#	263,000#	263,000#
Payload	202,000# (101T)	212,6000# (106T)	216,200# (108T)
Capacity (level)	4000 cu ft	4240 cu ft	4320 cu ft
Service life	25 years	25 years	25 years
Annual Maintenance (ref. 14)	←	$0.04 per car-mile	→
Price per car (1979$)	$37,000	$33,200	$38,500

TABLE V

ECONOMIC FACTORS

Fleet Purchase	100% cash, no financing assumed
Investment Tax Credit	10%
Depreciation	Average Rate over 12 year period
Corporate Tax Rate	50%
Inflation Rate	6%/year
Scrap Value	Steel cars $0.035/lb (Ref. 14) Aluminum cars $0.34/lb
Rebuilding Costs*	Steel cars $6000/car (Ref. 14) Aluminum cars none
Fuel Costs	$0.63/gal (Ref. 15)
Discount Rate	10% (Assumed after tax cost of capital to the railroad industry; Ref. 16)
State/Local Taxes	Not considered

*Based on frequency of once per 25 years and assumed expensed during 15th year.

3.2.2.2 Option 2 - Purchase Fleet of Lightweight Steel Gondolas

Assuming that 305 train trips will be made annually, 62 lightweight steel gondolas (106 ton payload) will be needed under fully utilized operations. Given the 85 percent car utilization rate, 9 additional cars will be required as spares, thus fixing the fleet size at 71 cars. Under these conditions, 1111 hours per car are available for maintenance.

A train with 62 lightweight steel gondolas can deliver 6572 tons of coal per trip or 2,004,460 tons of coal per year, thus more than meeting the required demand.

3.2.2.3 Option 3 - Purchase Fleet of Lightweight Aluminum Gondolas

Under the same 305 train trip per year assumption, 61 aluminum gondolas of 108 ton payload are needed per trip. With an 85 percent car utilization rate, 9 additional cars will be needed as spares. Therefore, a fleet size of 70 aluminum gondolas will satisfy the operational conditions and still allow for 1125 hours per car for maintenance each year.

A train consisting of 61 aluminum gondolas can deliver 6588 tons of coal per trip or 2,009,340 tons per year.

3.2.3 Estimating Annual Operating Costs

Five basic cost categories are considered: fuel consumption, car maintenance, locomotive maintenance, locomotive lubrication, and ROW maintenance. As noted earlier, personnel costs such as for crews and dispatching were assumed invariant with each investment option; therefore, these are not included.

Two other cost categories included in subsequent cash flow analyses are car rebuilding costs which are assumed to occur during the 15th year of service for the steel cars and tax on salvage income which occurs at the end of the 25th year--the assumed service life of the car fleet. Due to their one-time occurrence, they are not considered here as annual costs.

3.2.3.1 Fuel Consumption Costs

Annual fuel consumption costs were based on the fuel consumption rates noted in Table IV and a 1979 price of $0.63 per gallon of diesel(15) subject to an inflation rate of 6 percent per year. No other cost trends were considered.*

Option 1

Fuel consumption varies with the type of train operation (i.e., either loaded or empty), among other factors. The standard triple hopper steel train (65 cars in length) has a gross trailing weight of 8515 tons loaded and 1950 tons in its backhaul mode. Fuel consumed during each delivery run is 1468 gallons and 690 gallons per backhaul trip for a round trip fuel consumption of 2158 gallons. At this rate, 658,190 gallons of diesel fuel will be needed each year. At the 1979 price of $0.63/gallon this amounts to $414,660.

Option 2

A lightweight steel gondola train 62 cars long has a gross trailing weight of 8122 tons loaded and 1550 tons in its backhaul mode. Gallons consumed per delivery and return haul are 1400 gallons and 548 gallons, respectively or 1948 gallons per round trip. Annually, some 594,140 gallons of diesel fuel will be required amounting to $346,308 at current prices.

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* The combined 1979 price per gallon and assumed 6 percent inflation factor produce a price forecast similar to that given in Reference 17.

Option 3

If the train is composed entirely of lightweight aluminum gondolas (61 cars/train) the gross trailing weight will be 7991 tons (loaded) and 1403 tons (empty). Gallons consumed per each delivery and backhaul trip are therefore 1366 gallons and 496 gallons, respectively. On an annual basis this amounts to 571,265 gallons or $359,897 at current prices. Table VI summarizes the fuel consumption estimates for each investment alternative.

TABLE VI

COMPARATIVE FUEL CONSUMPTION ESTIMATES

(Gallons)

Gallons Consumed	Investment Option 1	2	3
Per round trip	2158	1948	1873
Delivery	1468	1400	1377
Backhaul	690	548	496
Per Year	658,190	594,140	571,265
$,@ 69¢/gallon	$414,151	$409,957	$394,173
Average Train Length (cars)	65	62	61

The benefits of the lightweight and higher payload equipment in terms of reduced fuel requirements are obvious—especially in backhaul trips where approximately 150-200 gallons can be saved per trip relative to the heavier equipment (Option 1). Such savings imply that the lightweight steel car train will use about 64,000 fewer gallons per year or approximately 1.6 million gallons less than the heavier steel train during the 25 year service period. Similarly, annual and 25 year total fuel savings for the lightweight aluminum train relative to the heavier steel train amounts to nearly 87,000 gallons and 2.2 million gallons, respectively.

3.2.3.2 Car Maintenance Costs

Routine car maintenance expenses are a function of the number of cars in the fleet and their annual mileage. Since average car miles traveled are essentially the same for each investment option (note, car utilization rates are equal), the only way that car maintenance costs can vary between investment types is via the lower number of cars requiring maintenance in either the lightweight steel or aluminum car fleets. We have implicitly assumed that maintenance functions (including labor and material costs) do not depend upon car type.

Using the assumed car maintenance cost rate of $0.04 per car-mile(14) and an average of 114,589 miles per car per year, annual car maintenance costs for each investment alternative amount to:

Option 1 - $343,767
Option 2 - 325,433
Option 3 - 320,849

These costs are subject to inflation and are treated as such throughout the 25 year service life in subsequent cash flow analyses.

Considering savings relative to the standard steel car investment, the lightweight steel car fleet will save about $18,000 per year while the aluminum car fleet will save approximately $23,000 annually in car maintenance costs.

Car rebuilding or overhaul costs are expected to be incurred only for the two steel car investments.[14] For these, a major rebuilding program (in which both the car sides and bottom will be replaced) is expected during the 15th year of service. Current rebuilding costs are estimated at $6,000 per steel car, also subject to inflation.

3.2.3.3 Locomotive Maintenance and Lubrication Costs

These costs vary directly with annual ton-miles. Using the rates estimated in Section 3.1.1, 134,810 train miles traveled per year* and total gross trailing weight per train, annual maintenance and lubrication costs are estimated as follows:

	Maintenance	Lubrication
Option 1	$ 207,564	$ 27,534
Option 2	191,688	25,428
Option 3	185,808	24,648

The lower annual maintenance and lubrication costs of the lightweight equipment translate into savings of nearly $18,000/yr. for the lightweight steel cars compared with the standard steel car investment. Even higher relative savings are evident for the aluminum car investment option, amounting to about $25,000 annually.

As with fuel and car maintenance costs, locomotive maintenance and lubrication costs are subject to inflation through the 25 year service period.

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*Based on 442 miles per round trip and 305 round trips per year.

3.2.3.4 Right-of-Way Maintenance Costs

These costs include maintenance operations to the roadbed, rails ties, fasteners, bridges and structures, railcrossings, signal systems, and switches. Estimated to vary with gross ton miles on track at a rate of $0.708 per 1000 GTM,(14) annual costs for each investment are as follows:

Option 1 - $998,838
Option 2 - 923,148
Option 3 - 896,615

As with previous operating costs, the lower costs of Options 2 and 3 are due solely to the fewer number of cars required to haul the coal and their lighter weight. Savings per year for Options 2 and 3 relative to the standard steel hopper car fleet amount to $75,690 and $102,223, respectively.

Annual costs are subject to inflation rates throughout the 25 year service life.

3.3 Determining Total Costs and Benefits

Disregarding revenues generated by the coal delivery operation, the purchaser of the freight car fleet (also assumed to be the operator of the unit coal train) realizes benefits via annual tax savings on his operating costs (including depreciation expenses), a one-time tax credit on the investment, and salvage income at the end of the equipment's service life.

Salvage income is based on current scrap values and on estimated pounds of salvageable scrap per car. Furthermore, salvage income is subject to inflation and taxation at the end of the twenty-fifth year when cars will be scrapped.

The following rates were used to estimate the future salvage value of the aluminum and steel freight car fleets:

1. Current scrap values of \$0.34 per pound for aluminum and \$0.035 per pound for steel;(14)
2. Estimated salvageable weight of 14,000 pounds per aluminum car and 31,000 pounds for each steel hopper car.(14) For the lightweight steel gondola, it was assumed that about 50 percent of its empty weight could be salvaged for scrap or 25,000 pounds per car.

Current scrap values were considered subject to an inflation rate of 6 percent compounded annually. Table VII presents the estimated future value of salvage income for each investment option, both on a per car and per fleet basis.

TABLE VII

FUTURE VALUES OF SALVAGE INCOME FOR INVESTMENT OPTIONS

Investment Option	Estimated Current Values	Twenty-five Year Future Values	
		Per Car	Per Fleet
1 - Std. steel hopper cars	\$1,085 per car	\$ 4,657	\$ 349,200
2 - Lightweight steel gondolas	\$ 875 per car	\$ 3,755	\$ 266,600
3 - Aluminum gondolas	\$5,100 per car	\$21,889	\$1,532,200

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Based on these considerations, the future value of salvage income for each investment is:

Option 1: $ 349,262
Option 2: 266,640
Option 3: 1,532,244

The investment model used to determine and evaluate the overall benefits of the lightweight equipment alternatives uses differential cash flow analysis in which the net cash flows for the lightweight car options are compared with those of the standard steel hopper car fleet over the twenty-five year life cycle. Total costs and benefits are then compared with the investment outlay using present value procedures. Tables VIII, IX, and X illustrate the cash flow statements for each of the investment alternatives.

3.3.1 Life Cycle Costs and Benefits

Considering the 25 year service period, the lightweight aluminum car fleet appears to offer the highest benefits to the investor--a net cash outflow of approximately $49 million. However, the lightweight steel car fleet investment option is highly competitive, accounting for a net cash outflow of nearly $52 million; Table XI summarizes these for the overall service period. Comparing the cost and benefit categories for these two options indicates that the relative advantage of the aluminum car fleet depends primarily on two factors: (1) its higher salvage income and (2) the avoidance of car rebuilding expenses during the 25 year service life. Should the second assumption be incorrect, the lightweight steel car fleet investment could become extremely competitive with the aluminum fleet option.

TABLE VIII

CASH FLOW DATA SHEET-INVESTMENT OPTION 1
PURCHASE OF 75 STANDARD TRIPLE HOPPER STEEL CARS

YEARS

Cash Flow Out	0	1	2	3	4	5	6	7	8	9	10	11	12
Cash downpayment (I_o)	$ 2775	0	0	0	0	0	0	0	0	0	0	0	0
Fuel costs	0	414.7	439.6	466.0	493.9	523.5	554.9	588.2	623.5	660.9	700.5	742.6	787.1
Locomotive maintenance	0	207.6	220.1	233.3	247.2	262.1	277.8	294.5	312.2	330.9	350.7	371.8	394.1
Locomotive lubrication	0	27.5	29.2	30.9	32.8	34.7	36.8	39.0	41.3	43.8	46.5	49.2	52.2
Car maintenance	0	343.8	364.4	386.3	409.5	434.0	460.1	487.7	516.9	548.0	580.8	615.7	652.6
Car rebuilding cost	0	0	0	0	0	0	0	0	0	0	0	0	0
Right-of-way maintenance	0	998.9	1058.8	1122.4	1189.7	1261.1	1336.8	1417.0	1502.0	1592.1	1687.6	1788.9	1896.2
Salvage tax	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW OUT(-)	2775	1992.5	2112.1	2238.9	2373.1	2515.4	2666.4	2826.4	2995.9	3175.7	3366.1	3568.2	3782.2
Cash Flow In (Tax Savings)													
Depreciation (12 yrs. SL)	0	115.6	115.9	115.6	115.6	115.6	115.6	115.6	115.6	115.6	115.6	115.6	115.6
Fuel costs	0	207.4	219.8	233.0	247.0	261.8	277.5	294.2	311.8	330.5	350.4	371.4	393.7
Locomotive maintenance	0	103.8	110.0	116.6	123.6	131.0	138.9	147.2	156.1	165.4	175.3	185.8	197.0
Locomotive lubrication	0	13.8	14.6	15.5	16.4	17.4	18.5	19.6	20.8	22.0	23.3	24.7	26.2
Car maintenance	0	171.9	182.2	193.1	204.7	217.0	230.0	243.8	258.4	273.9	290.3	307.8	326.3
Car rebuilding	0	0	0	0	0	0	0	0	0	0	0	0	0
Right-of-way maintenance	0	499.4	529.4	561.1	594.8	630.4	668.2	708.3	750.8	795.8	843.5	894.2	947.8
Investment tax credit	0	277.5	0	0	0	0	0	0	0	0	0	0	0
Salvage value	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW IN (+)	0	1389.4	1171.9	1234.9	1302.1	1373.2	1448.7	1528.7	1613.5	1703.2	1798.4	1899.5	2006.6
NET CASH FLOW	- 2775	-603.1	-940.2	-1004.0	-1071.0	-1142.2	-1217.7	-1297.7	-1382.4	-1472.5	-1567.7	-1668.7	-1775.6

*Present value based on a 10% discount rate reflecting the railroad's after tax cost of capital.

All figures in thousands of dollars.

13	14	15	16	17	18	19
0	0	0	0	0	0	0
834.4	884.4	937.5	993.7	1043.4	1116.5	1183.5
417.7	442.8	469.4	497.5	527.4	559.0	592.5
55.3	58.6	62.2	65.9	69.9	74.0	78.5
691.8	733.3	777.3	823.9	873.4	925.8	981.3
0	0	1078.6	0	0	0	0
2010.0	2130.6	2258.4	2393.9	2537.5	2689.8	2851.2
0	0	0	0	0	0	0
4009.2	4249.7	5583.4	4774.9	5061.6	5365.1	5687.0
0	0	0	0	0	0	0
417.3	442.4	468.9	497.0	526.9	558.5	592.0
208.8	221.3	234.6	248.7	263.6	279.4	296.2
27.8	29.5	31.2	33.1	35.1	37.2	39.4
345.8	366.5	388.5	411.8	436.5	462.7	490.5
0	0	539.3	0	0	0	0
1004.7	1065.0	1128.9	1196.6	1268.4	1344.5	1425.2
0	0	0	0	0	0	0
0	0	0	0	0	0	0
2004.4	2124.7	2791.4	2387.2	2530.5	2682.3	2843.3
-2004.8	-2125.0	-2792.0	-2387.7	-2531.1	-2682.8	-2843.7

YEARS							
20	21	22	23	24	25	TOTAL	PV*
0	0	0	0	0	0	$ 2,775.0	$ 2,775.0
1254.6	1329.8	1409.6	1494.2	1583.9	1678.9	22,749.8	2,093.0
628.1	665.8	705.7	748.1	793.0	840.5	11,389.8	1,047.9
83.2	88.2	93.5	99.1	105.0	111.3	1,508.6	138.8
1040.2	1102.6	1168.8	1238.9	1313.2	1392.0	18,862.3	1,735.3
0	0	0	0	0	0	1,078.6	257.8
3022.3	3203.6	3395.8	3599.6	3815.5	4044.5	54,804.2	5,042.0
0	0	0	0	0	194.6	174.6	0
6028.4	6390.0	6773.4	7179.9	7610.6	8241.8	113,342.9	13,089.8
0	0	0	0	0	0	1,387.5	442.6
627.5	665.2	705.1	747.4	792.2	839.8	11,378.7	1,046.8
314.0	332.8	352.8	374.0	396.4	420.2	5,693.5	523.8
41.8	44.3	47.0	49.8	52.8	56.0	757.8	69.7
520.0	551.1	584.2	619.2	656.4	695.8	9,428.4	867.4
0	0	0	0	0	0	539.3	128.9
1510.7	1601.3	1697.4	1799.2	1907.2	2021.6	27,394.4	2,520.3
0	0	0	0	0	0	277.5	252.2
0	0	0	0	0	349.3	349.3	0
3014.0	3194.7	3386.5	3589.6	3805.0	4382.7	57,206.4	5,851.7
-3014.4	-3195.3	-3386.9	-3590.3	-3805.6	-3859.1	-56,136.5	-7,238.1

TABLE IX

CASH FLOW DATA SHEET-INVESTMENT OPTION 2
PURCHASE OF 71 LIGHTWEIGHT STEEL CARS

	YEARS												
Cash Flow Out	0	1	2	3	4	5	6	7	8	9	10	11	12
Cash downpayment	$ 2357.2	0	0	0	0	0	0	0	0	0	0	0	0
Fuel costs	0	374.3	396.8	420.5	445.8	472.5	500.9	531.0	562.8	596.6	632.4	670.3	710.5
Locomotive maintenance	0	191.7	203.2	215.4	228.3	242.0	256.5	271.9	288.2	305.5	323.9	343.3	363.9
Locomotive lubrication	0	25.4	26.9	28.5	30.2	32.1	34.0	36.0	38.2	40.5	42.9	45.5	48.2
Car maintenance	0	325.4	344.9	365.6	387.5	410.8	435.4	461.6	489.3	518.6	549.8	582.7	617.7
Car rebuilding cost	0	0	0	0	0	0	0	0	0	0	0	0	0
Right-of-way maintenance	0	923.1	978.5	1037.2	1099.4	1165.4	1235.3	1309.4	1388.0	1471.3	1559.6	1653.2	1752.3
Salvage tax	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW OUT(-1)	$ 2357.2	1838.8	1950.3	2067.2	2191.2	2322.8	2462.1	2609.9	2766.5	2932.5	3108.6	3295.0	3492.6
Cash Flow In (Tax Savings)													
Depreciation (12 yrs. SL)	0	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2
Fuel	0	187.1	198.3	210.2	222.8	236.2	250.4	265.4	281.3	298.2	316.1	335.0	355.2
Locomotive maintenance	0	95.8	101.5	107.6	114.1	120.9	128.2	136.9	144.0	152.7	161.8	171.5	181.8
Locomotive lubrication	0	12.7	13.5	14.3	15.1	16.0	17.0	18.0	19.1	20.2	21.4	22.7	24.1
Car maintenance	0	162.7	172.5	182.8	193.8	205.4	217.7	230.8	244.6	259.3	274.9	291.4	308.8
Car rebuilding	0	0	0	0	0	0	0	0	0	0	0	0	0
Right-of-way maintenance	0	461.6	489.3	518.6	549.9	582.8	617.7	654.8	694.0	735.7	779.9	826.6	876.2
Investment tax credit	0	235.7	0	0	0	0	0	0	0	0	0	0	0
Salvage value	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH FLOW IN (+)	0	1253.8	1073.3	1131.7	1193.8	1259.5	1329.2	1403.1	1481.2	1564.3	1652.3	1745.4	1844.3
NET CASH FLOW	-$ 2357.2	-586.1	-877.0	-935.5	-997.4	-1063.3	-1132.9	-1206.8	-1285.3	-1368.2	-1456.3	-1549.6	-1648.3

*Present value (PV) based on a 10% discount rate which reflects the railroad's after tax cost of capital.

All figures in thousands of dollars.

13	14	15	16	17	18	19
0	0	0	0	0	0	0
753.1	798.3	846.2	897.0	950.8	1007.8	1068.3
385.7	408.9	433.4	459.4	487.0	516.2	547.2
51.1	54.2	57.4	60.9	64.5	68.4	72.5
654.8	694.0	735.7	779.8	826.6	876.2	928.8
0	0	1021.1	0	0	0	0
1857.5	1968.9	2087.0	2212.3	2345.0	2485.7	2634.9
0	0	0	0	0	0	0
3702.2	3924.3	5180.8	4409.4	4673.9	4954.3	5251.7
0	0	0	0	0	0	0
376.5	399.0	423.0	448.4	475.3	503.8	534.0
192.8	204.3	216.6	229.6	243.4	258.0	273.4
25.5	27.1	28.7	30.4	32.3	34.2	36.2
327.4	347.0	367.8	389.9	413.3	438.1	464.4
0	0	510.6	0	0	0	0
928.8	948.6	1043.6	1106.2	1172.6	1243.0	1317.5
0	0	0	0	0	0	0
0	0	0	0	0	0	0
1851.0	1962.0	2590.3	2204.5	2336.9	2477.1	2625.5
-1851.2	-1962.3	-2590.5	-2204.9	-2337.0	-2477.2	-2626.2

YEARS							
20	21	22	23	24	25	TOTAL	PV*
0	0	0	0	0	0	$2357.2	$2357.2
1132.4	1200.4	1272.4	1348.7	1429.7	1515.4	20,534.9	1889.2
580.0	614.8	651.7	690.8	732.2	776.2	10,517.3	967.6
76.8	81.5	86.3	91.5	97.0	102.8	1,393.3	128.2
984.5	1043.6	1106.2	1172.6	1242.9	1317.3	17,852.5	1642.4
0	0	0	0	0	0	1,021.1	244.0
2793.0	2960.5	3138.2	3326.5	3526.0	3737.6	50,645.8	4659.4
0	0	0	0	0	133.3	133.3	0
5566.7	5900.8	6254.8	6630.1	7027.8	7582.8	104,455.4	11,888.0
0	0	0	0	0	0	1178.6	376.0
566.1	600.0	636.0	674.2	714.7	757.5	10,264.7	944.4
289.8	307.2	325.7	345.2	365.9	387.9	5,255.6	483.5
38.4	40.7	43.2	45.8	48.5	51.4	696.5	64.1
492.3	521.8	553.1	586.3	621.5	658.8	8,926.4	821.2
0	0	0	0	0	0	510.6	122.0
1396.6	1480.4	1569.2	1663.4	1763.2	1869.0	25,325.1	2329.9
0	0	0	0	0	0	235.7	214.2
0	0	0	0	0	266.6	266.6	0
2783.2	2950.1	3127.2	3314.9	3513.8	3991.2	52,659.8	5,355.3
-2783.5	-2950.7	-3127.6	-3315.2	-3514.0	-3591.6	-51,795.6	-6,532.7

Cash Flow Out	0	1	2
Cash downpayment (I_o)	$ 2695.0	0	0
Fuel Costs	0	359.9	381.5
Locomotive maintenance	0	185.8	196.9
Locomotive lubrication	0	24.6	26.1
Car maintenance	0	320.8	340.0
Car rebuilding cost	0	0	0
Right-of-way maintenance	0	896.6	950.4
Salvage tax	0	0	0
TOTAL CASH FLOW OUT(-1)	$ 2695.0	1787.7	1894.9
Cash Flow in (Tax Savings)			
Depreciation (12 Yrs. SL)	0	112.3	112.3
Fuel	0	180.0	190.8
Locomotive maintenance	0	92.9	98.5
Locmotive lubrication	0	12.3	13.0
Car maintenance	0	160.5	170.0
Car rebuilding	0	0	0
Right-of-way maintenance	0	448.3	475.2
Investment tax credit	0	269.5	0
Salvage value	0	0	0
TOTAL CASH FLOW IN (+)	0	1275.7	1059.8
NET CASH FLOW	-$ 2695.0	-512.0	-835.1

*Present value (PV) based on 10% discount rate reflecting the railroad's

All figures in thousands of dollars.

TABLE X

CASH FLOW DATA SHEET-INVESTMENT OPTION 3
PURCHASE OF 70 LIGHTWEIGHT ALUMINUM CARS

YEARS									
3	4	5	6	7	8	9	10	11	12
0	0	0	0	0	0	0	0	0	0
404.4	428.6	454.4	481.6	510.5	541.2	573.6	608.0	644.5	683.2
208.8	221.3	234.5	248.6	263.5	278.4	296.1	313.9	332.7	352.7
27.6	29.3	31.0	32.9	34.9	37.0	39.2	41.5	44.2	46.7
360.4	382.1	405.0	429.3	455.1	482.4	511.3	542.0	574.5	609.0
0	0	0	0	0	0	0	0	0	0
1007.4	1067.9	1131.9	1199.8	1271.8	1348.2	1429.0	1514.8	1605.7	1702.0
0	0	0	0	0	0	0	0	0	0
2008.6	2129.2	2256.8	2392.2	2535.8	2688.2	2849.2	3020.2	3201.4	3393.6
112.3	112.3	112.3	112.3	112.3	112.3	112.3	112.3	112.3	112.2
202.2	214.4	227.2	240.9	255.4	270.6	286.9	304.1	322.4	341.7
104.4	110.6	117.3	124.3	131.8	139.7	148.1	157.0	166.4	176.6
13.8	14.6	15.5	16.5	17.4	18.5	19.6	20.8	22.0	23.3
180.2	191.0	202.5	214.6	227.5	241.2	255.6	271.0	287.2	304.5
0	0	0	0	0	0	0	0	0	0
503.7	533.9	566.0	599.9	635.9	674.0	714.5	757.4	802.8	851.0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1166.6	1176.8	1240.8	1308.2	1380.2	1456.3	1537.0	1622.6	1713.1	1809.1
-842.0	-952.4	-1016.0	-1083.7	-1155.6	-1231.9	-1312.2	-1397.6	-1488.3	-1584.5

after tax cost of capital.

13	14	15	16	17	18	19
0	0	0	0	0	0	0
724.2	767.6	813.7	862.5	914.3	969.1	1027.3
373.9	396.3	420.1	445.3	472.0	500.3	530.3
49.5	52.5	55.6	59.0	62.5	66.2	70.2
645.5	684.2	725.3	768.8	814.9	863.8	915.7
0	0	0	0	0	0	0
1804.1	1912.4	2027.1	2148.8	2277.7	2414.3	2559.2
0	0	0	0	0	0	0
3597.2	3813.0	4041.8	4284.4	4541.4	4813.7	5102.7
0	0	0	0	0	0	0
362.2	383.9	407.0	431.4	457.3	484.7	513.8
186.9	198.1	210.0	222.6	236.0	250.2	265.2
24.8	26.2	27.8	29.5	31.2	33.1	35.1
322.8	342.1	362.6	384.4	407.5	431.9	457.8
0	0	0	0	0	0	0
902.1	956.2	1013.6	1074.4	1138.8	1207.2	1279.6
0	0	0	0	0	0	0
0	0	0	0	0	0	0
1798.8	1906.5	2021.0	2142.3	2270.8	2407.1	2551.5
-1798.4	-1906.5	-2020.8	-2142.1	-2270.6	-2406.6	-2551.2

YEARS							
20	21	22	23	24	25	TOTAL	PV*
0	0	0	0	0	0	$ 2695.0	$ 2695.0
1088.9	1154.3	1223.5	1296.9	1374.7	1457.2	19,745.6	1816.6
562.1	595.9	631.6	669.5	709.7	752.3	10,193.5	937.8
74.4	78.9	83.6	88.6	94.0	99.6	1,349.4	124.1
970.6	1028.8	1090.6	1156.0	1225.4	1298.9	17,600.4	1619.2
0	0	0	0	0	0	0	0
2712.8	2875.5	3048.0	3230.9	3424.8	3630.3	49,191.4	4525.6
0	0	0	0	0	766.1	766.1	0
5408.8	5733.4	6077.3	6441.9	6828.6	8004.4	101,541.4	11,718.3
0	0	0	0	0	0	1347.5	429.8
544.6	577.3	611.9	648.6	687.6	728.8	9875.6	908.5
281.1	297.9	315.8	334.8	354.8	376.1	5096.9	468.9
37.2	39.4	41.8	44.3	47.0	49.8	674.6	62.0
485.3	514.4	545.3	578.0	612.7	649.4	8799.9	809.6
0	0	0	0	0	0	0	0
1356.4	1437.8	1524.0	1615.5	1712.4	1815.3	24,595.9	2262.8
0	0	0	0	0	0	269.5	245.0
0	0	0	0	0	1532.2	1532.2	0
2704.6	2866.8	3038.8	3221.2	3414.5	5151.6	52,242.0	5186.6
-2704.2	-2866.6	-3038.5	-3220.7	-3414.1	-2852.8	-49,299.4	-6531.7

TABLE XI

LIFE CYCLE CASH FLOW COMPARISON OF FREIGHT CAR FLEET INVESTMENTS
(All data in $K)

Cost Category	Investment Option 1	Investment Option 2	Investment Option 3
Outflow			
Investment	2,775.0	2,357.2	2,695.0
Fuel	22,749.8	20,534.9	19,745.6
Car Maintenance	18,862.3	17,852.5	17,600.4
Locomotive Maintenance	11,389.8	10,517.3	17,600.4
Locomotive Lubrication	1,508.6	1,393.3	1,349.4
Car Rebuilding	1,078.6	1,021.1	0.0
ROW Maintenance	54,804.2	50,645.8	49,191.4
Salvage Tax	174.6	133.3	766.1
Total Outflow	113,342.9	104,455.4	101,541.4
Inflow			
Depreciation Allowance	1,387.5	1,178.6	1,347.5
Fuel	11,378.7	10,264.7	9,875.6
Car Maintenance	9,428.4	8,926.4	8,799.9
Locomotive Maintenance	5,693.5	5,255.6	5,096.9
Locomotive Lubrication	757.8	696.5	674.5
Car Rebuilding	539.3	510.6	0
ROW Maintenance	27,394.4	25,325.1	24,595.9
ITC	277.5	235.7	269.5
Salvage Income	349.3	266.6	1,532.2
Total Inflow	57,206.4	52,659.8	52,242.0
Net (Outflow)	56,136.5	51,795.6	49,299.4

In terms of fuel consumption, investment option 3 clearly offers the highest life cycle benefits. Relative benefits (after taxes) of the lightweight freight car fleets are shown in Table XII. This table suggests overall savings in fuel costs of $1.1 million to $1.5 million for the lightweight equipment compared with the standard steel hopper car fleet in the assumed operation. Translated into current fuel prices (for illustrative purposes only) such savings approximate between 1.7 and 2.4 million gallons throughout the equipment's service period.

3.3.2 Present Value of Future Costs and Benefits

In addition to total life cycle cash flows, the competing investments are evaluated using present value tables. The comparisons are presented in Table XIII assuming a cost of capital (after taxes) of 10 percent. As in the previous analysis (Section 3.3.1) the aluminum car fleet suggests the highest benefits in net present value terms; however, the net present value of the lightweight steel car fleet investment is virtually identical to that of the aluminum car fleet, indicating that either lightweight car investment would appear equally attractive to the investor. Note, however, that salvage incomes which are not part of the NPV calculations* must also be taken into account in the decision process.

A differential net present value comparison is illustrated in Table XIV. Here the present value of differences in net purchasing and operating expenses of the lightweight equipment are compared with the heavier steel car fleet in the first two columns. Column three compares the two lightweight equipment options and indicates

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*We consider that salvage income is not assumed to be realized until the last day of the 25th year of the fleet's service life; thus its present value is virtually 0.

TABLE XII

RELATIVE SAVINGS* IN FUEL CONSUMPTION OF LIGHTWEIGHT FREIGHT CAR FLEETS

(25 year life cycle)

Investments Compared	Relative Savings ($'s in thousands)	Advantages to:
Option 1 vs. Option 2	$1,100	Lightweight Steel Car Fleet
Option 1 vs. Option 3	$1,500	Lightweight Aluminum Car Fleet
Option 2 vs. Option 3	$ 400	Lightweight Aluminum Car Fleet

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*Net Basis (after taxes).

TABLE XIII

NPV COMPARISON OF INVESTMENT OPTIONS*

(After Taxes)
(All figures are thousands of dollars)

Investment	Option 1	Option 2	Option 3
<u>Net Investment Expenses</u>			
Investment	- 2,775.0	- 2,357.2	- 2,695.0
Depreciation Tax Savings	442.6	376.0	429.8
ITC	252.2	214.2	245.0
Salvage	0	0	0
Subtotal	- 2,080.2	- 1,767.0	- 2,020.2
<u>Net Operating Expenses</u>			
Fuel Costs	- 1,046.2	- 944.8	- 908.1
Car Maintenance Cost	- 867.9	- 821.2	- 809.6
Car Rebuilding Cost	- 128.9	- 122.0	0
Locomotive Maintenance and Lubrication Cost	- 593.2	- 548.2	- 531.0
ROW Maintenance Cost	- 2,521.7	- 2,329.5	- 2,262.8
Subtotal	- 5,157.9	- 4,765.7	- 4,511.5
NPV	- 7,238.1	- 6,532.7	- 6,531.7

*Present values based on a 10% discount rate reflecting the railroads after tax cost of capital.

TABLE XIV

DIFFERENTIAL NPV COMPARISON
(All figures are thousands of dollars)

Investment Options	1 vs 2	1 vs 3	2 vs 3
Investment	417.8	80.0	337.8
Depreciation Tax Savings	- 66.6	- 12.8	53.8
ITC	- 38.0	- 7.2	30.8
Salvage	0	0	0
Subtotal	313.2	60.0	-253.2
Fuel Costs	101.4	138.1	36.7
Car Maintenance Cost	46.7	58.3	11.6
Car Rebuilding Cost	6.9	128.9	122.0
Locomotive Maintenance and Lubrication Cost	45.0	62.2	17.2
ROW Maintenance Cost	192.2	258.9	66.7
Subtotal	392.2	646.4	254.2
NPV Difference (All expense categories)	705.4	706.4	1.0

NOTE: A + implies an advantage for the lightweight equipment.

equivalency between lightweight car investments. Note that the higher purchasing cost of the aluminum car fleet is balanced out by its lower operating costs compared with the lightweight steel car fleet. Either of the lightweight car fleet investments has about the same NPV advantage over the heavier steel hopper car alternative.

3.4 Conclusions

The NPV method was applied to illustrate the benefits of lightweight freight cars in a unit coal train operation. The example used to illustrate the methodology, though simplified, presents the incremental benefits of the lightweight (steel and aluminum) equipment relative to the standard heavier steel cars. Essentially, the life-cycle benefits reflect the greater payload delivery capability of the lightweight car and a smaller fleet and train size requirement due to the larger payload, lower maintenance, and fuel consumption expenses. Usually,* these lower life cycle costs are traded off against a higher investment expense per fleet.

The payload delivery requirement can be met as follows:

Option 1 - Standard Triple Hopper Cars

- Train Length - 65 cars
- Fleet Size - 75 cars

Option 2 - Lightweight Steel Gondolas

- Train Length - 62 cars
- Fleet Size - 71 cars

Option 3 - Lightweight Aluminum Gondolas

- Train Length - 61 cars
- Fleet Size - 70 cars

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*The lower purchase price per freight car for the lightweight steel car is an exception.

Thus, three to four cars per train and four to five cars per fleet can be saved through the use of lightweight equipment.

Of considerable interest currently are the fuel consumption savings due to a lightweight fleet operation. Table XV summarizes the annual and 25 year life cycle savings for the lightweight equipment relative to the standard steel car fleet. These savings* have a net present value (after taxes) to the lightweight freight car investor of approximately $101,000 for lightweight steel cars and about $138,000 for the aluminum car fleet (See Table XIV).

TABLE XV

RELATIVE FUEL CONSUMPTION SAVINGS OF LIGHTWEIGHT GONDOLAS
(Gallons)

	Option 2	Option 3
Annual Savings	64,000	87,000
25 Year Life-Cycle Savings	1.6 million	2.2 million

Similarily for the remaining operating expense categories, the after tax net present values of the lightweight equipment options imply maintenance savings as indicated in Table XVI.

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*Savings are based on 1979 diesel fuel prices and an annual inflation rate of 6%.

When considered in the more complete NPV context (i.e., investment costs, depreciation and tax credits), the two types of lightweight car fleets become more competitive, each suggesting approximately similar savings relative to the standard steel hopper car fleet in present value terms (see Table XIV).

Finally, the impact of salvage must be considered in the investment evaluation process. The future values of salvage income (after taxes) for each investment are:

Option 1 - $175,000
Option 2 - $133,000
Option 3 - $766,000

The net cash flow effects of salvage income can be seen in Table XI.

Overall, when life cycle cash flows are considered, the aluminum car fleet offers the higher benefits to the investor given the assumptions and input data specified in Section 3.2.1. Disregarding salvage, however, the lower purchasing costs associated with the lightweight steel car fleet essentially offsets the lower operating costs of the alunimum car fleet; consequently both lightweight freight car investments can be considered equivalent, using present value cash flow comparisons.

In Section 4, a study is made of the effect of terrain upon certain freight operations and feasible modifications thereto. A sensitivity of predicted fuel savings attributable to the use of lightweight equipment to assumptions concerning the operations is noted. Consideration should therefore be given to the conclusions of Section 4 before financial decisions based upon economic analyses such as this example are made.

TABLE XVI

PV OF MAINTENANCE SAVINGS* FOR LIGHTWEIGHT RAIL FREIGHT CARS FOR 25 YEAR SERVICE CYCLE

Fleet Type	Car Maintenance	Car Rebuilding	Locomotive Maintenance & Lubrication	ROW Maintenance	TOTAL
Lightweight Steel	$47,000	$7,000	$45,000	$192,000	$291,000
Lightweight Aluminum	$58,000	$129,000	$62,000	$259,000	$508,000

*Savings relative to standard steel hopper car fleet.

4.0 FREIGHT TRAIN FUEL CONSUMPTION OVER UNDULATING TERRAIN

4.1 Purpose and Background

The purpose of this section is to present the results of an effort to substantiate several heuristic curves concerning fuel consumption of freight trains which were published in an earlier report(2). The computer program developed during the earlier study of freight train fuel consumption, the results of which were described in the above mentioned report, was utilized to substantiate the curves. While the correspondence between the expected values and the results of the computer runs was not perfect because of relatively uncontrollable variations in the velocity profile of the train, nevertheless the results confirm the accuracy of the assumptions underlying the previously published curves. The curves themselves demonstrate the relative dependence of fuel savings attributable to the use of light weight equipment upon the particular type of operation and the nature of the terrain over which the train is being operated.

It is interesting to note that since this material was originally prepared, directly after the publication of Volume II(2) the author's attention was called to an earlier paper by Morlock(3) which espouses essentially the same approach. Figures very similar to those herein are presented in his paper. Morlock's conclusion that "route profile, and hence topography in general, has a considerable effect upon the propulsive work required" to move freight is certainly in consonance with the contentions of this section. The same basic point is made that for small grades, in normal operation work expended against gravitational forces is recovered. The effort reported in this section was directed towards demonstrating the correctness of these postulates or intuitive feelings by means of a computer simulation of the operation, and also towards demonstrating that the possible recovery of this energy is quite sensitive to other parameters besides the average grade level, notably the average speed of the operation and the type of operation.

4.2 Theory and Calculation

Figure 7 shows the previously published(2) curves, the substantiation of which is sought. Briefly, the curves suggest that for the simple up-down operation illustrated in Figure 8, the fuel consumption for a given consist as a function of grade will remain constant up to a certain grade, beyond which the fuel consumption will rise (upper curve); for a lighter consist (lower curve) the grade up to which fuel consumption remains constant is somewhat larger, and the rise in fuel consumption beyond this grade is less rapid, so that the difference between the curves, or the potential fuel savings, always increases. The curves presuppose a speed restriction on the operation in the form of a maximum speed limitation. The reader is referred to the previous report for details of the underlying assumptions.

It was decided to substantiate these curves by simulating an operation of a standard unit coal train over a track which generally resembled such an up-down operation. To make the track more realistic, stretches of level track were interspersed among the up and down grades of three hills in a symmetrical pattern, so that the elevation profile of the track used was as shown in Figure 9. Thirteen segments, each of a length of five miles, constituted the complete track for an overall length of sixty-five miles. The grade on the up-grade was made the same as the grade on the down-grade and was represented in the calculation by the parameter "α". Initially, "α" was made equal to zero, to equate the simulated operation to level tangent track operation. Subsequently, "α" was varied in increments up to a value of a grade of .75; this value appeared to be sufficiently large to establish the trend. The fuel consumption as a function of the grade "α" was then plotted and compared with the predicted straight-line curve.

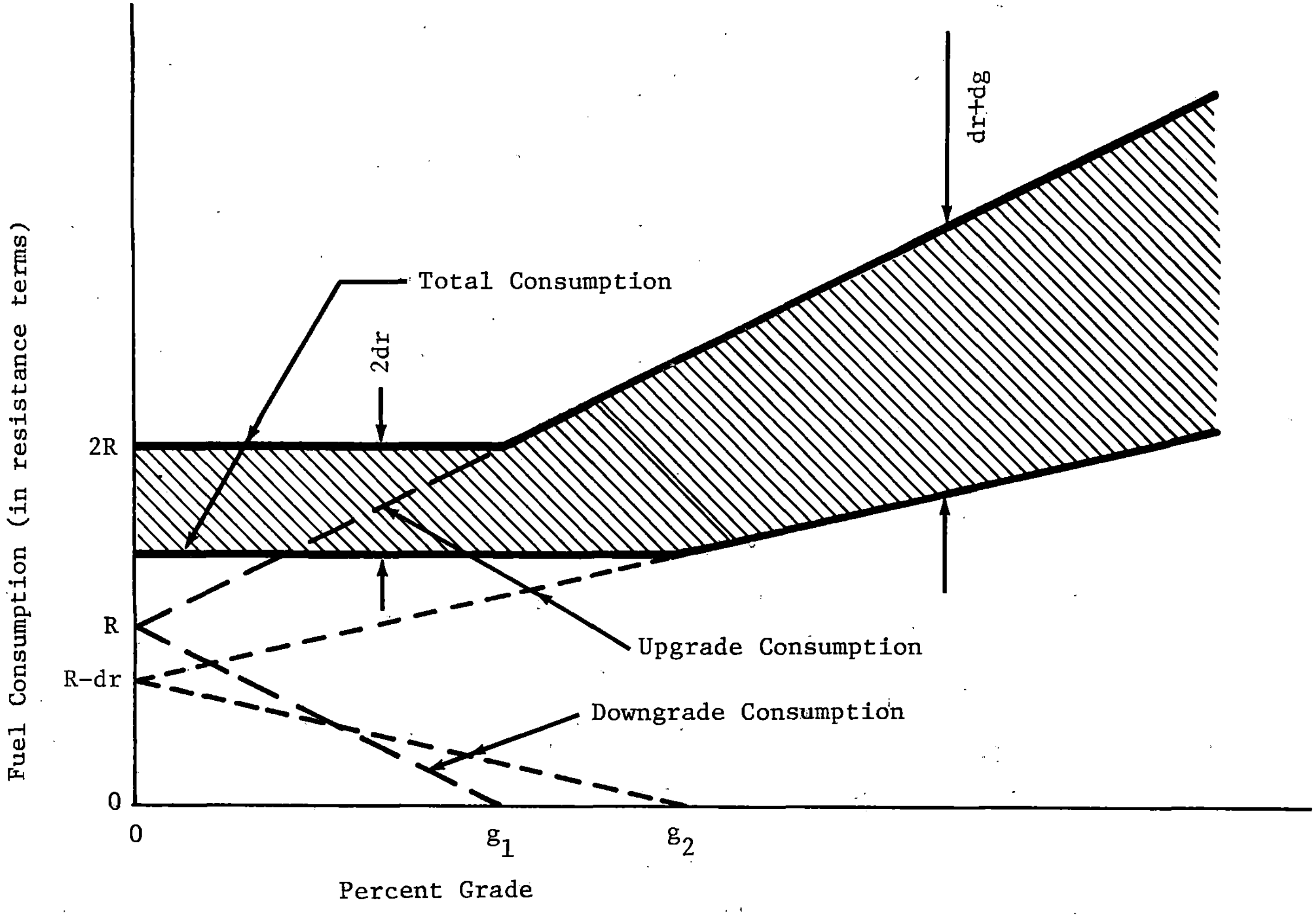

FIGURE 7
FUEL SAVINGS FOR LIGHT WEIGHT EQUIPMENT

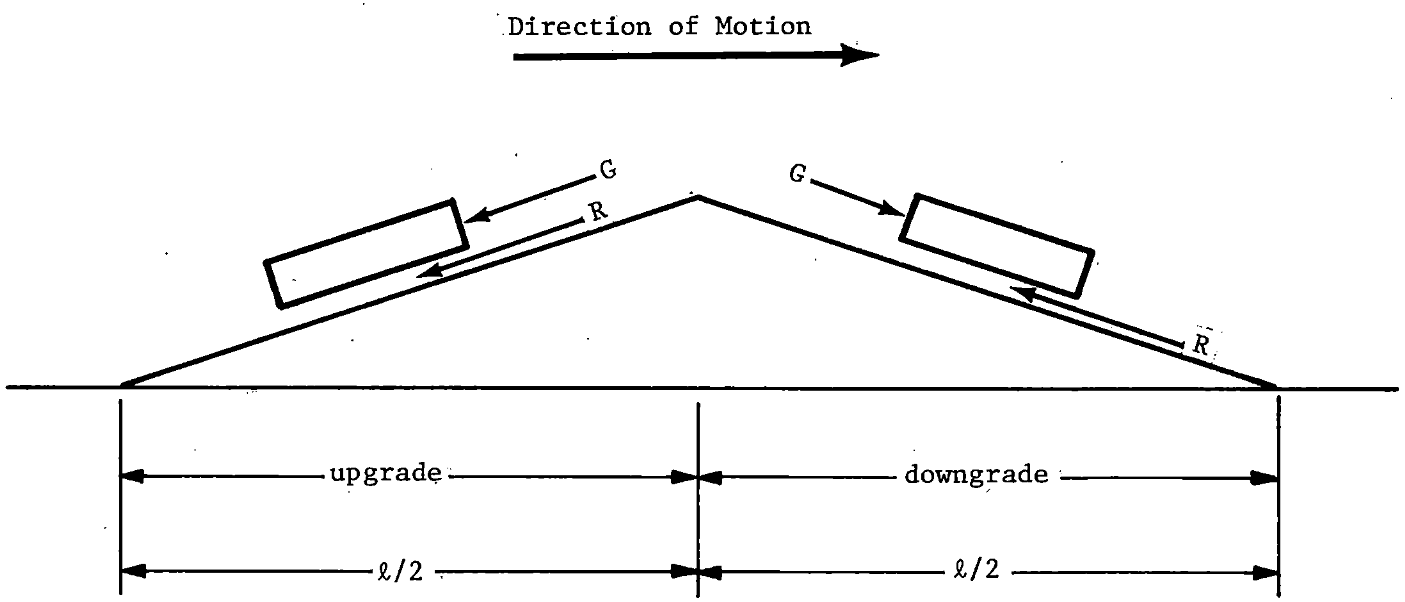

FIGURE 8
SIMPLE UP AND DOWN OPERATION

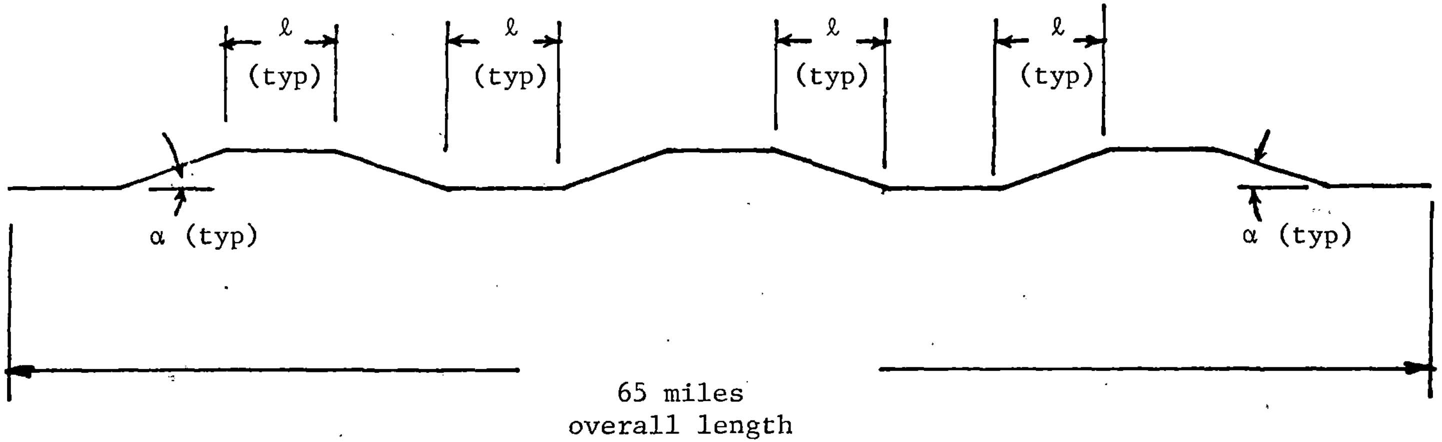

FIGURE 9
ELEVATION PROFILE OF TRACK USED

The trains used in the trial runs were artificially contrived but were deemed to be sufficiently representative that the results would not be biased. The same unit coal trains which were used over difficult terrain in the earlier study were used again$^{(2)}$. Both a high-speed operation with a 60 mph speed limit and a low-speed operation with a 25 mph speed limit were simulated. The trains were run first in the loaded condition, then in the empty condition. The number of locomotives was not changed, although for the empty return run this naturally represented a change in the power-to-gross-trailing-ton ratio. The train using standard weight cars was used to obtain the points for the upper curve, and the train using light-weight cars was used to obtain the points for the lower curve.

Figure 10 shows the theoretical fuel consumption curve and the several other curves of which it is composed. For the particular track in question, the total expected consumption is composed of the fuel consumed over the 35 miles of level tangent track and the 30 miles of up- and down-grade tracks. The latter is similarly composed of the fuel consumed over the 15 miles of up-grade and the fuel consumed over the 15 miles of down-grade. The component curves are simply added to form the top curve.

Only three parameters need to be determined to plot the expected curve. The first of these is the consumption over the 35 miles of level tangent tracks (point a). The second is the consumption over the remaining 30 miles if the grade were zero (point b). The third is the slope of the up-grade consumption curve. The slope for the down-grade curve is the negative of the other. Once these values are set, the entire curve is established.

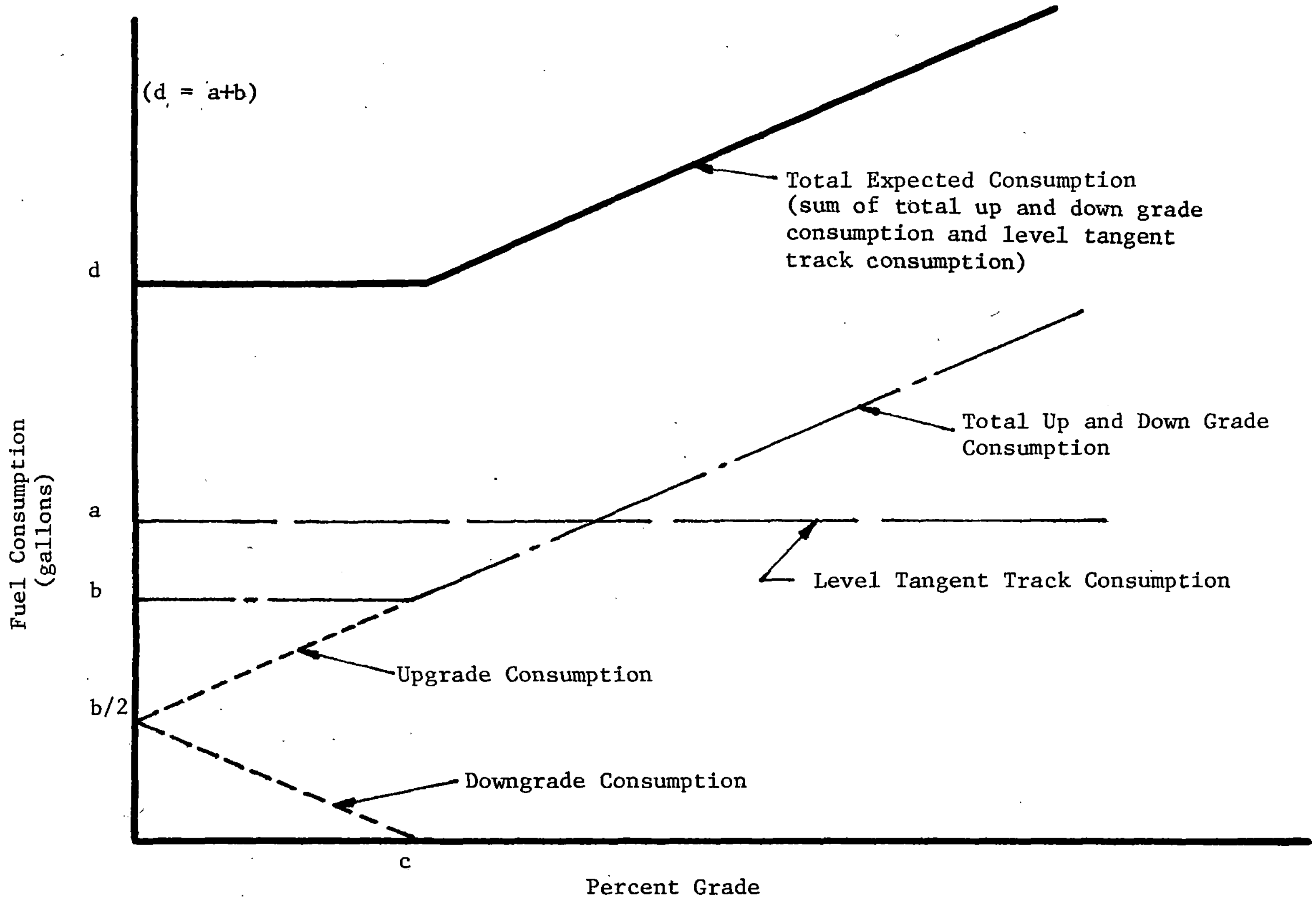

FIGURE 10
THEORETICAL FUEL CONSUMPTION

The two ordinates are determined from consideration of train resistance at the average trip velocity. The fuel consumed is divided in proportion to the 35 mile level tangent track and the 30 mile up- and down-grade portion. The figure for each portion, using the same conversion factor from Poole(18) of .0644 gallons/brake HP-hr used in the previous work,(1) is then

$$.0644 \cdot R \cdot \ell \cdot 5280 \cdot 5.05E\text{-}7$$

in which ℓ is the length of the portion in question and R is the resistance at the average velocity, and the last figure is a conversion factor from ft-lbs to HP-hrs.

The expected slope of the curve representing upgrade consumption can be calculated theoretically and precisely for a train whose weight is known. If the same figure for specific fuel consumption is used, the expression for the rise of the curve for a particular grade, for a train of weight W_o tons is then

$$\ell \cdot 5280 \cdot \%\ \text{grade} \cdot W_o \cdot 2000 \cdot .0644 \cdot 5.05E\text{-}7$$

in which ℓ is the length of the upgrade in miles and the last number is the conversion factor used in the earlier expression. The percent grade must be divided by 100, i.e., for a .1 percent grade the figure to be used is .001.

Given the ordinate previously determined and the slope determined above, the abscissa of the break point of the curves is determined by geometrical considerations.

Unfortunately, the level tangent track consumption* cannot be predicted as precisely as the slope, since the fuel consumption will vary with the train resistance, and the train resistance is a function of the non-constant velocity. A considerable discrepancy was found

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* point "a"

to exist between the fuel consumption predicted by using the average velocity in the calculation and the fuel consumption determined from the computer program. Since the computer program takes into consideration these changes in velocity in computing fuel consumption, the results from the program are deemed to be a more accurate representation than a number calculated from average velocity considerations.

The rationale adopted was therefore that the curves would first be calculated by using the resistance of the train at the average velocity, and the excess consumption predicted by the computer program would be added after the break point of the curve had been determined according to the preceding rationale. While this approach is somewhat heuristic, it produced satisfactory results. A numerical example is given in the next section.

4.3 Results

The results from the 44 computer runs are given in Table XVII along with other pertinent information about the simulated journeys. The fuel consumptions for the runs are plotted in Figures 11 through 16. The straight line segments are the expected results predicted by means of the rationale discussed in the preceding section.

Although some of the deviation from the predicted values is attributable to inherent inaccuracies in the calculation, most of the deviation is attributable to the fact that average velocities for the trips were not identical. Variations in average velocities for otherwise identical trips can cause considerable variation in fuel consumption. It was beyond the scope of the effort reported herein to ensure that the average velocities for the trips were

TABLE XVII

SUMMARY OF FUEL CONSUMPTION RUNS

RUN NO.	TRAIN NO.	ORDER NO.	TRACK NO.	GRADE	CAR WEIGHT	NO. OF LOCOMOTIVES	NO. OF CARS	OPERATIONAL SPEED LIMIT	NET TRAIN LOAD (TONS)	GROSS TRAIN WEIGHT (TONS)	HP/GTT	AVERAGE VELOCITY FOR TRIP	TOTAL FUEL CONSUMPTION	ROUND TRIP FUEL CONSUMPTION
1	23	65	70	.00	Std	4	65	60	6102	8654	1.5	49.00	415.25	697.94
2	24	65	70	.00	Std	4	65	60	0	2552	6.6	50.09	286.69	
3	23	65	71	.05	Std	4	65	60	6102	8654	1.5	48.59	402.96	685.75
4	24	65	71	.05	Std	4	65	60	0	2552	6.6	50.31	282.79	
5	23	65	72	.10	Std	4	65	60	6102	8654	1.5	49.19	407.58	690.21
6	24	65	72	.10	Std	4	65	60	0	2552	6.6	50.23	282.63	
7	23	65	73	.15	Std	4	65	60	6102	8654	1.5	48.83	417.27	696.78
8	24	65	73	.15	Std	4	65	60	0	2552	6.6	49.83	279.51	
9	23	65	74	.20	Std	4	65	60	6102	8654	1.5	48.77	429.68	714.43
10	24	65	74	.20	Std	4	65	60	0	2552	6.6	50.32	284.75	

TABLE XVII (Continued)

RUN NO.	TRAIN NO.	ORDER NO.	TRACK NO.	GRADE	CAR WEIGHT	NO. OF LOCOMOTIVES	NO. OF CARS	OPERATIONAL SPEED LIMIT	NET TRAIN LOAD (TONS)	GROSS TRAIN WEIGHT (TONS)	HP/GTT	AVERAGE VELOCITY FOR TRIP	TOTAL FUEL CONSUMPTION	ROUND TRIP FUEL CONSUMPTION
11	23	65	75	.25	Std	4	65	60	6102	8654	1.5	48.37	448.28	731.95
12	24	65	75	.25	Std	4	65	60	0	2552	6.6	50.06	283.67	
13	23	65	76	.30	Std	4	65	60	6102	8654	1.5	47.93	477.04	760.99
14	24	65	76	.30	Std	4	65	60	0	2552	6.6	50.30	283.95	
15	23	65	78	.40	Std	4	65	60	6102	8654	1.5	46.96	523.40	809.28
16	24	65	78	.40	Std	4	65	60	0	2552	6.6	49.59	285.88	
17	23	65	80	.50	Std	4	65	60	6102	8654	1.5	45.63	578.61	871.88
18	24	65	80	.50	Std	4	65	60	0	2552	6.6	49.65	293.27	
19	23	65	82	.60	Std	4	65	60	6102	8654	1.5	44.37	614.42	928.88
20	24	65	82	.60	Std	4	65	60	0	2552	6.6	49.78	314.46	

TABLE XVII (Continued)

RUN NO.	TRAIN NO.	ORDER NO.	TRACK NO.	GRADE	CAR WEIGHT	NO. OF LOCOMOTIVES	NO. OF CARS	OPERATIONAL SPEED LIMIT	NET TRAIN LOAD (TONS)	GROSS TRAIN WEIGHT (TONS)	HP/GTT	AVERAGE VELOCITY FOR TRIP	TOTAL FUEL CONSUMPTION	ROUND TRIP FUEL CONSUMPTION
21	23	65	85	.75	Std	4	65	60	6102	8654	1.5	42.38	672.19	1007.43
22	24	65	85	.75	Std	4	65	60	0	2552	6.6	49.14	335.24	
23	25	62	70	.00	Lt.Wt.	4	62	60	6156	8260	1.6	49.12	391.13	639.41
24	26	62	70	.00	Lt.Wt.	4	62	60	0	2104	8.8	51.82	248.28	
25	25	62	71	.05	Lt.Wt.	4	62	60	6156	8260	1.6	49.08	391.55	649.98
26	26	62	71	.05	Lt.Wt.	4	62	60	0	2104	8.8	49.64	258.43	
27	25	62	72	.10	Lt.Wt.	4	62	60	6156	8260	1.6	49.69	393.66	654.09
28	26	62	72	.10	Lt.Wt.	4	62	60	0	2104	8.8	49.81	260.43	
29	25	62	73	.15	Lt.Wt.	4	62	60	6156	8260	1.6	48.82	400.09	658.19
30	26	62	73	.15	Lt.Wt	4	62	60	0	2104	8.8	49.66	258.10	

TABLE XVII (Continued)

RUN NO.	TRAIN NO.	ORDER NO.	TRACK NO.	GRADE	CAR WEIGHT	NO. OF LOCOMOTIVES	NO. OF CARS	OPERATIONAL SPEED LIMIT	NET TRAIN LOAD (TONS)	GROSS TRAIN WEIGHT (TONS)	HP/GTT	AVERAGE VELOCITY FOR TRIP	TOTAL FUEL CONSUMPTION	ROUND TRIP FUEL CONSUMPTION
31	25	62	74	.20	Lt.Wt.	4	62	60	6156	8260	1.6	49.03	423.62	686.79
32	26	62	74	.20	Lt.Wt.	4	62	60	0	2104	8.8	50.33	263.17	
33	25	62	75	.25	Lt.Wt.	4	62	60	6156	8260	1.6	48.72	436.12	694.53
34	26	62	75	.25	Lt.Wt.	4	62	60	0	2104	8.8	49.72	258.41	
35	25	62	76	.30	Lt.Wt.	4	62	60	6156	8260	1.6	48.50	445.61	707.84
36	26	62	76	.30	Lt.Wt.	4	62	60	0	2104	8.8	49.76	262.23	
37	25	62	78	.40	Lt.Wt.	4	62	60	6156	8260	1.6	46.99	492.50	756.07
38	26	62	78	.40	Lt.Wt.	4	62	60	0	2104	8.8	49.60	263.57	
39	25	62	80	.50	Lt.Wt.	4	62	60	6156	8260	1.6	46.37	534.42	796.98
40	26	62	80	.50	Lt.Wt.	4	62	60	0	2104	8.8	49.85	262.56	

TABLE XVII (Concluded)

RUN NO.	TRAIN NO.	ORDER NO.	TRACK NO.	GRADE	CAR WEIGHT	NO. OF LOCOMOTIVES	NO. OF CARS	OPERATIONAL SPEED LIMIT	NET TRAIN LOAD (TONS)	GROSS TRAIN WEIGHT (TONS)	HP/GTT	AVERAGE VELOCITY FOR TRIP	TOTAL FUEL CONSUMPTION	ROUND TRIP FUEL CONSUMPTION
41	25	62	82	.60	Lt.Wt.	4	62	60	6156	8260	1.6	44.82	583.02	859.53
42	26	62	82	.60	Lt.Wt.	4	62	60	0	2104	8.8	49.35	276.51	
43	25	62	85	.75	Lt.Wt.	4	62	60	6156	8260	1.6	42.98	628.72	922.24
44	26	62	85	.75	Lt.Wt.	4	62	60	0	2104	8.8	49.75	293.52	

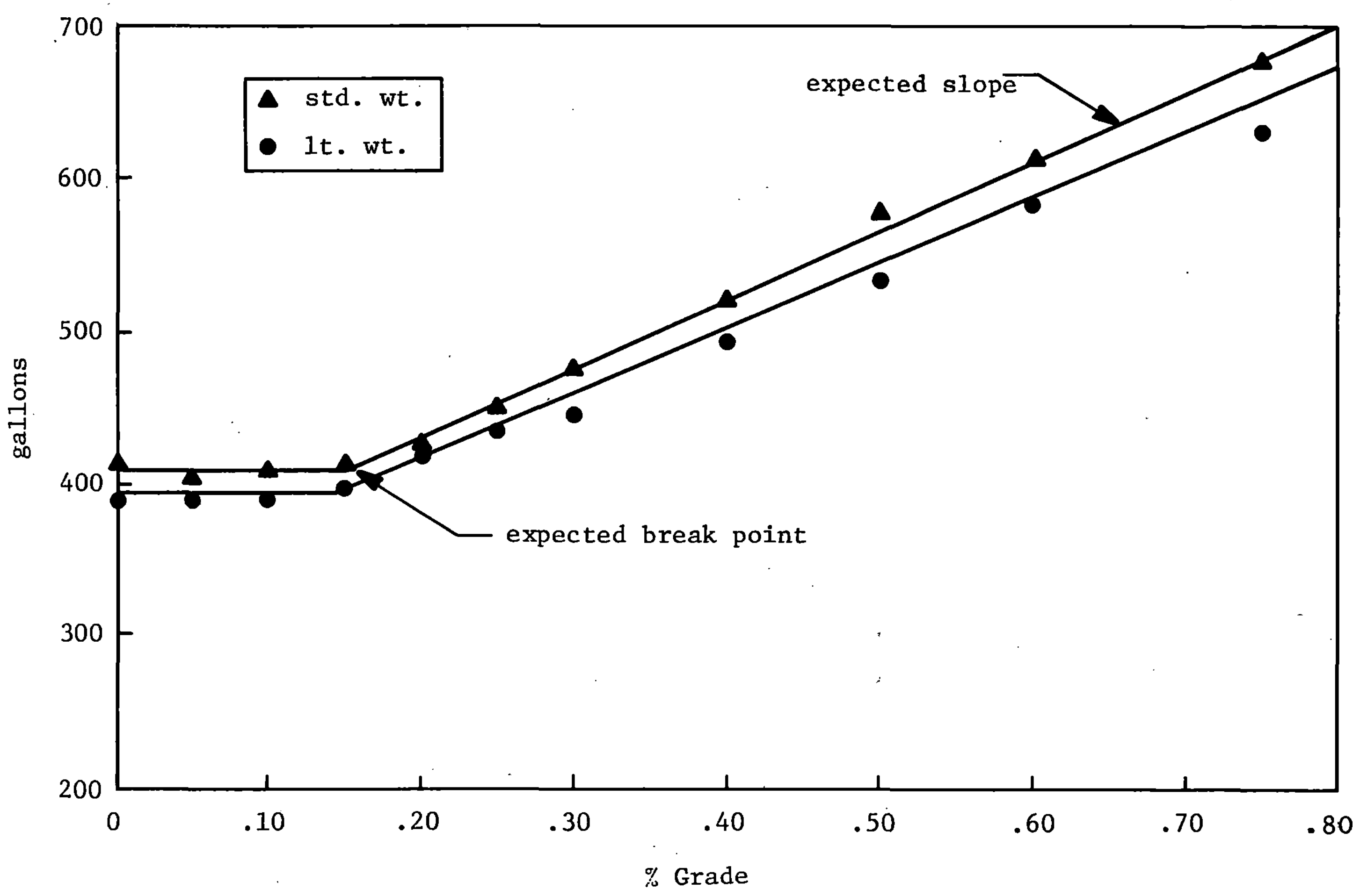

FIGURE 11
ONE-WAY, LOADED, 60 MPH OPERATION

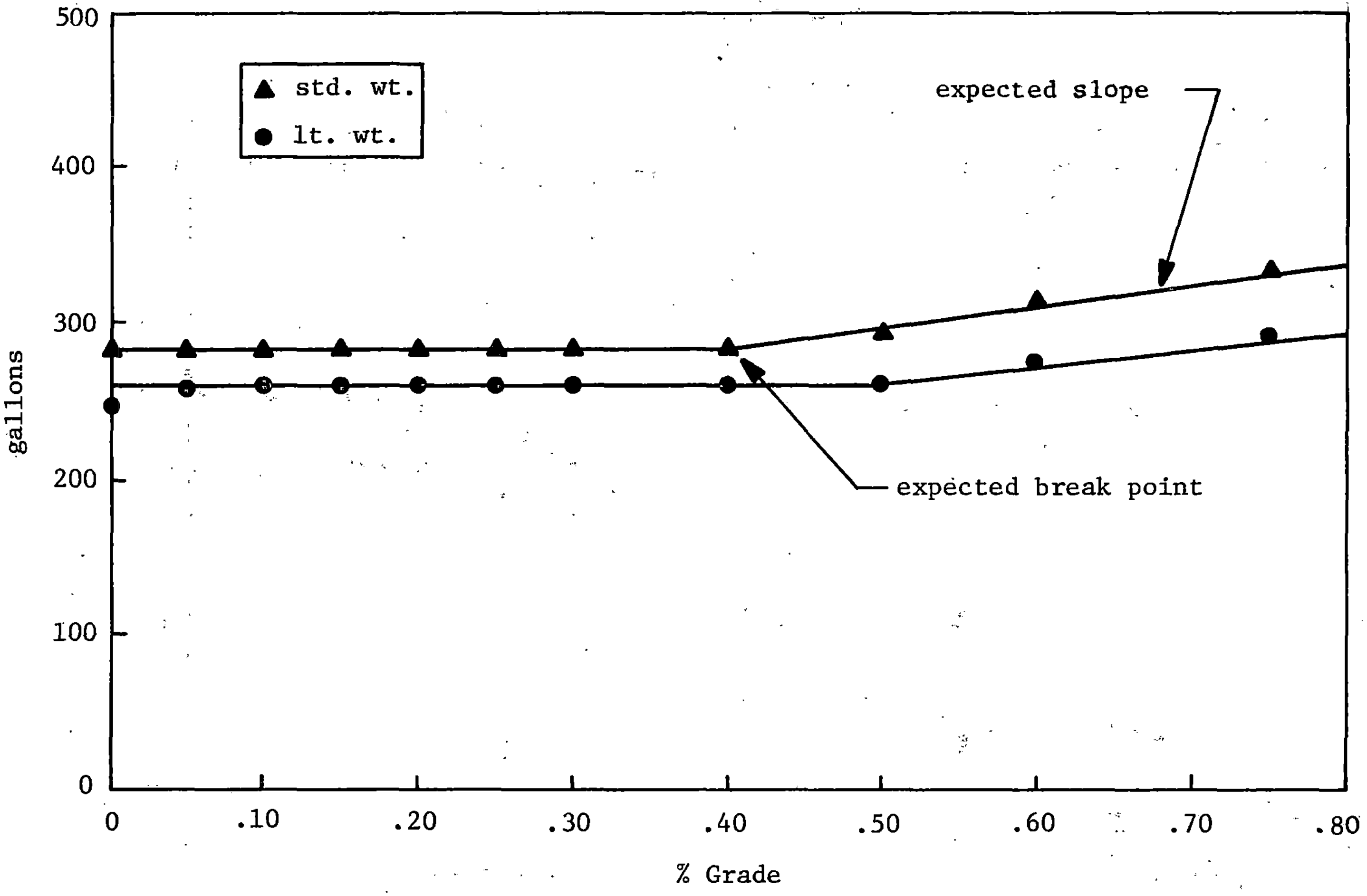

FIGURE 12
ONE-WAY, EMPTY, 60 MPH OPERATION

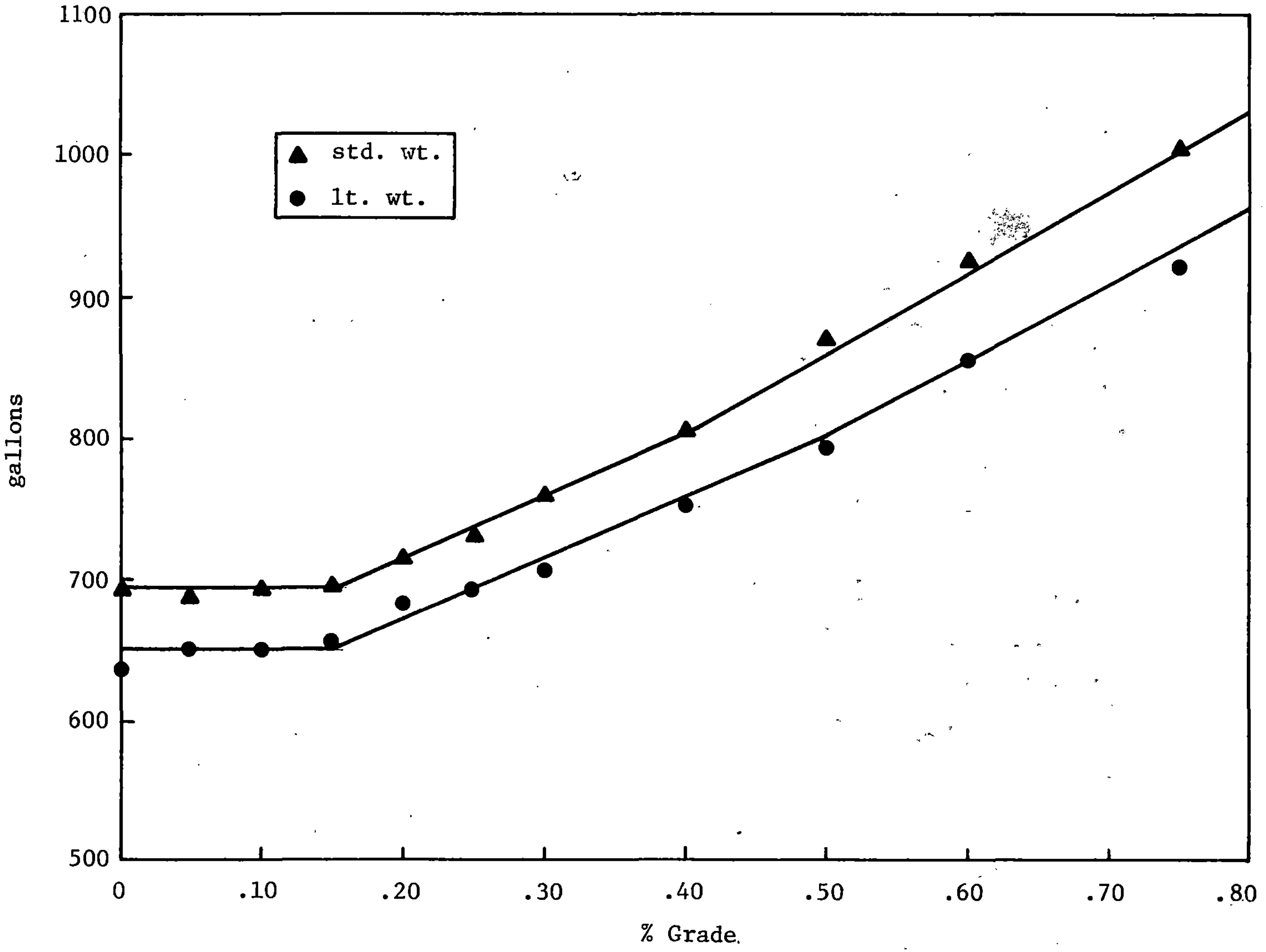

FIGURE 13
ROUND TRIP, 60 MPH OPERATION

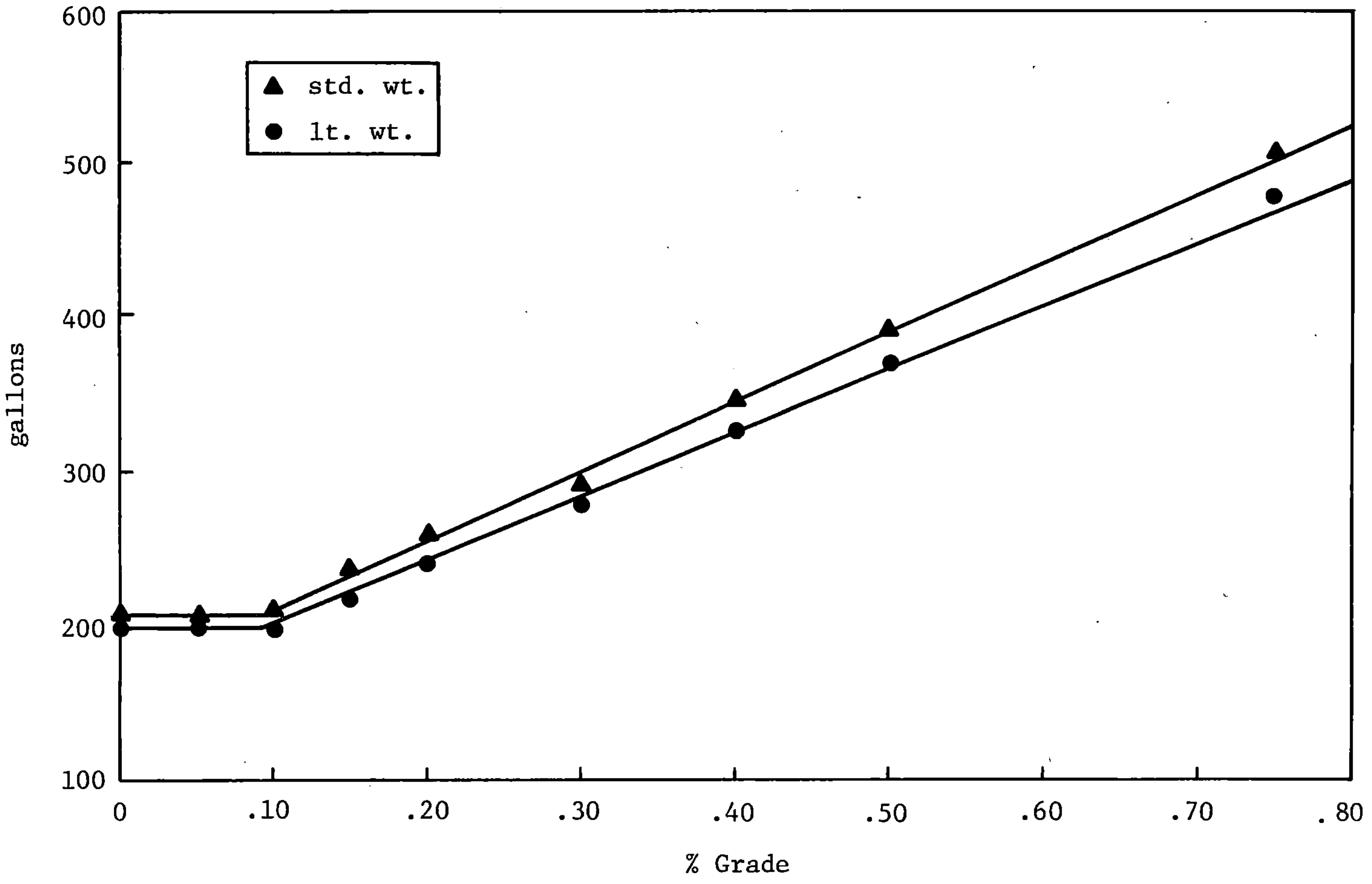

FIGURE 14
ONE-WAY LOADED 25 MPH OPERATION

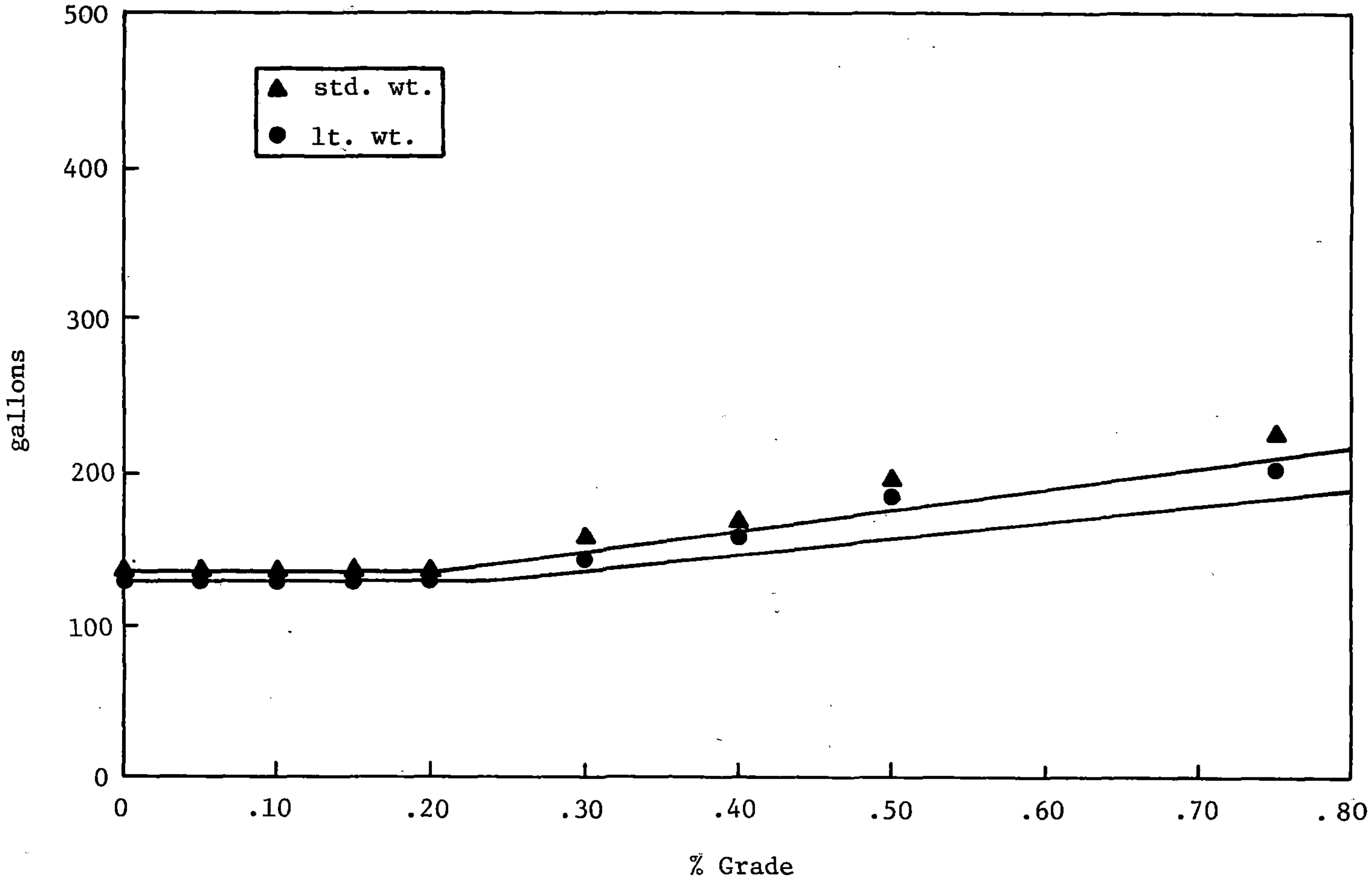

FIGURE 15
ONE-WAY, EMPTY, 25 MPH OPERATION

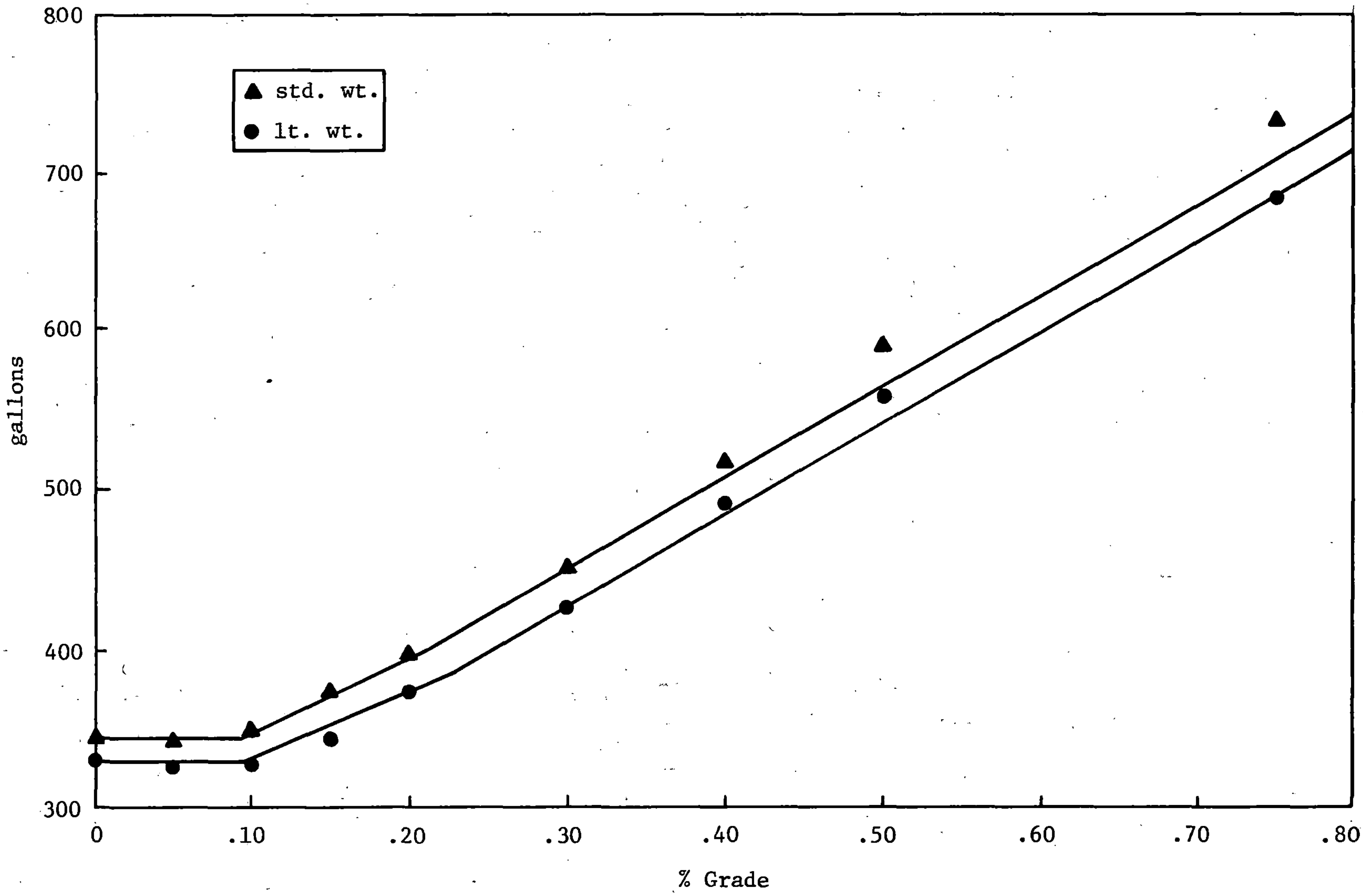

FIGURE 16
ROUND TRIP, 25 MPH OPERATION

identical. The deviation of certain points from the predicted curves is on the order of 2 percent. This is felt to be sufficiently small that the premises underlying the predicted curves have been confirmed.

The numerical example given below corresponds to establishing the predicted curve for the standard weight train in a unidirectional 60 mph operation (Figure 11, upper curve). The rationale for determining all the other curves for unidirectional operation is the same. The composite curves for a complete round trip, reflecting a fully loaded condition upon departure and an empty condition for the return trip, were created by adding the expected curves together. Similarly, the computed points for the round trips were generated by summing the complete fuel consumption for two separate trips, one in the loaded condition and one empty.

The resistance of the train at the average velocity of 49 mph is first determined, either by interpolation from the full computer printout, by plotting a curve from the same data, or by manual calculation. R was determined to be 25,500 lbs. The expected fuel consumption for the entire 65 mile trip with $\alpha = 0$ is then

$$.0644 \cdot 25{,}500 \cdot 65 \cdot 5280 \cdot 5.05\text{E}{-7}$$

or 284.61 gallons. This is divided proportionally between the 35 miles of always level track and the 30 miles of up and down grade where α would not normally be zero, 153.25 gallons and 131.35 gallons, respectively. The latter is divided by two to yield 65.67 gallons for the 15 miles of up-grade and the same for the 15 miles of down-grade. This establishes point b and b/2 (see Figure 10).

The slope is calculated to be

$$15 \cdot 5280 \cdot .001 \cdot 8654.16 \cdot 2000 \cdot .0644 \cdot 5.05E{-7}$$

or 44.58 gallons for a .1% grade. The break point (point c), from geometrical considerations, is simply

$$65.67 \cdot .1 / 44.58$$

or .147.

The slope and the break point having been established, the actual consumption at grades near zero (from runs 1, 3, 5, 7) is averaged and used as the ordinate for the horizontal portion of the predicted curve (point d), 410.76 gallons, instead of the calculated value of 284.61 gallons determined by using the average velocity, for reasons previously explained. This calculation completes the determination of the three parameters necessary to plot the predicted curve in Figure 11. The other curves are similarly constructed.

4.4 Conclusions

Within the limitations of the study, agreement has been established between fuel consumption calculated by a computer program and predicted curves for fuel consumption of freight trains operating over artificial tracks with a particular degree of undulation. The predicted curves had been postulated in a previous report. The curves confirm the contention that even if the track is over undulating terrain, fuel savings from the use of light weight equipment are limited to the modest savings effected in level tangent track operation unless the degree of undulation exceeds a certain amount. Beyond this amount, fuel savings are larger, the larger the degree of undulation. It is also demonstrated that the curves for fuel consumption over such terrain and the fuel savings (the difference between the curves) are heavily dependent upon the type of operation being conducted; for instance, the operational speed limit is a significant parameter.

It should be noted in this regard that the results of the economic analysis in Section 3 were predicted upon certain average trip velocities the values of which, although judged to be reasonable, were selected arbitrarily. Time unfortunately did not permit a complete determination of the sensitivity of the economics of the operations to such assumptions, but it appears likely from the foregoing analysis that selection of different average velocities would have modified to a certain extent the financial figures resulting from the predicted fuel savings and the conclusions drawn therefrom. As a consequence it is recommended that some examination of the sensitivity of the economic analysis to such assumptions be made before losing financial decisions upon such analyses.

The track over which the simulated trips were made is admittedly contrived, and the conclusions reached herein would be affected to a certain extent if curved sections were included, if the lengths of the sections were not identical or were different from the 5-mile length used herein, and if the grades were not identical, conditions that would prevail in real tracks. Nevertheless, it is thought that these curves add some degree of rationality to the area of interest.

5.0 RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

During the course of this extended investigation of the train resistance phenomenon and its effect upon fuel consumption, several avenues of investigation have been left relatively untouched. Each of these is worth mentioning either as an area for future investigation, or as one in which research is presently under contract. Each of these is discussed below.

5.1 Improved Truck Design

Examination of the dynamic behaviour of improved trucks has been proceeding for some time in connection with the FRA-sponsored Truck Design Optimization Project (TDOP). As a part of Phase II of this project, particular emphasis is being placed upon the economics of improved truck design, and the MITRE program is being utilized to simulate runs to determine the better fuel consumption characteristics of improved trucks.

It has been pointed out that the previous MITRE simulation of improved trucks(2) possibly underestimated the advantages to be derived from improved trucks in the form of lowered train resistance by merely eliminating velocity-dependent resistance, which is normally ascribed to the flanges impacting the rail. One of the putative advantages of certain models of improved truck design is that the curving ability is enhanced. Since the MITRE simulation originally was intended to embody the characteristics of all improved trucks, it did not simulate improved curving ability. In retrospect a separate assessment should have been made in order to determine the cost advantages of such a truck accruing from reduced fuel consumption through reduction of curving resistance.

Fortunately, it is to be expected that one of the byproducts of the TDOP Program will be an analysis of the impact of reduced curving resistance of improved trucks upon fuel consumption. The results should be of considerable interest to the railroad industry.

5.2 Increased Flange Resistance Due to Crosswind

Extensive wind tunnel tests have recently been completed(11) on models of ordinary rolling stock which determined, with reasonable accuracy, the aerodynamic drag of conventional railroad vehicles as a function of yaw angle. Theoretically, as the relative yaw angle approaches 90°, the drag should diminish to zero and curves confirming such diminution have been previously published(7) (19).

Nevertheless, crosswinds appear to have an additional effect, which has generally been ignored in practice, although the magnitude of its effect may be substantial. This is the additional friction created by the rubbing of the flanges on the far rail caused by the crosswind. Its existence was acknowledged early (1927) by Sanders(20) and its magnitude was made the subject of a theoretical investigation by AREA.(21) A representative magnitude for this effect is .65 lbs/ton, being the approximate additional drag for a train moving at 20 mph with a 10 mph wind at 90° to the track.

The above figures constitute what might be expected on the unit coal train run (Section 2.2.2) in the way of additional resistance if a side wind of such magnitude had in fact been encountered. For that loaded train of 13,026.83 gross tons, the additional resistance would be no less than 8,467 lbs., or no less than 38 percent of the total resistance at 20 mph. It is easy to speculate that this phenomenon is likely to contribute substantially to the shortfall in the prediction of fuel consumption when the journey has been made under conditions other than completely calm air, which generally prevail. The magnitude of the phenomenon must not be exaggerated, however, as undoubtedly the measurements which led to the coefficients in the empirical formula for train resistance were not made under conditions of completely calm air; nevertheless, it is believed unlikely that the coefficients were intended to represent unusually gusty conditions which might prevail under certain circumstances.

It would be of interest to confirm the theoretical value for the magnitude of the phenomenon which has been put forth. As part of a research program such as the aforementioned TDOP, the increase in resistance attributed to a carefully calibrated side thrust on the metric car would be a valuable contribution to the understanding of the train resistance phenomenon.

5.3 Open Doors on Boxcars

A casual observation of any long freight train will reveal a number of empty boxcars being backhauled with the doors open. Because of the current energy shortage, especially of gasoline, much emphasis has lately been directed towards methods by which gasoline consumption by the private automobile can be reduced. A claim has recently been brought to the writer's attention that closing the automobile's windows saves more energy than is consumed by the air-conditioner. The writer's impression is that automobile air-conditioners range upwards from five horsepower.

The connection with railroad rolling stock is obvious. Boxcar doors are far larger than automobile windows, and a saving of a possible aerodynamic drag of such a magnitude would be highly desirable, as it appears to be on the order of the bearing friction.

An estimate of what the magnitude of the additional aerodynamic drag would be, in the absence of any tests or reference in previous literature, was therefore made. The opening size was approximated to be 10' x 10'. Since the block tests (10) had indicated that little or no aerodynamic effect occurred until the gap between blocks was greater than .4 times the block width, the postulated air flow into the car was conservatively drawn as in Figure 17, to take this into consideration. It is, therefore, assumed that a prism of air whose height is that of the door and whose width is two feet will be brought to rest inside the car for each open door. The stagnation pressure for the train velocity times the cross-sectional area of the prism of air yeilds the increased force on the car.

For this hypothetical situation, and with the train travelling at 30 mph, the additional force on the boxcar is readily calculated to be 4.58 lbs., which is equivalent at that speed to 3.6 hp. For two open doors, 7.2 hp. Comparison of the results of this crude calculation with the estimated HP of an automobile air-conditioner shows that the order of magnitude is correct, although it is believed the calculation is very conservative. If half the doors are left open in a 100 car train, 360 additional HP are required even at 30 mph by this conservative estimate, a not completely insignificant portion of the horsepower likely to be assigned to such a train. In any case, it appears that the dissipated power is as significant as bearing friction and that an effort to assure that car doors are closed is worthwhile.

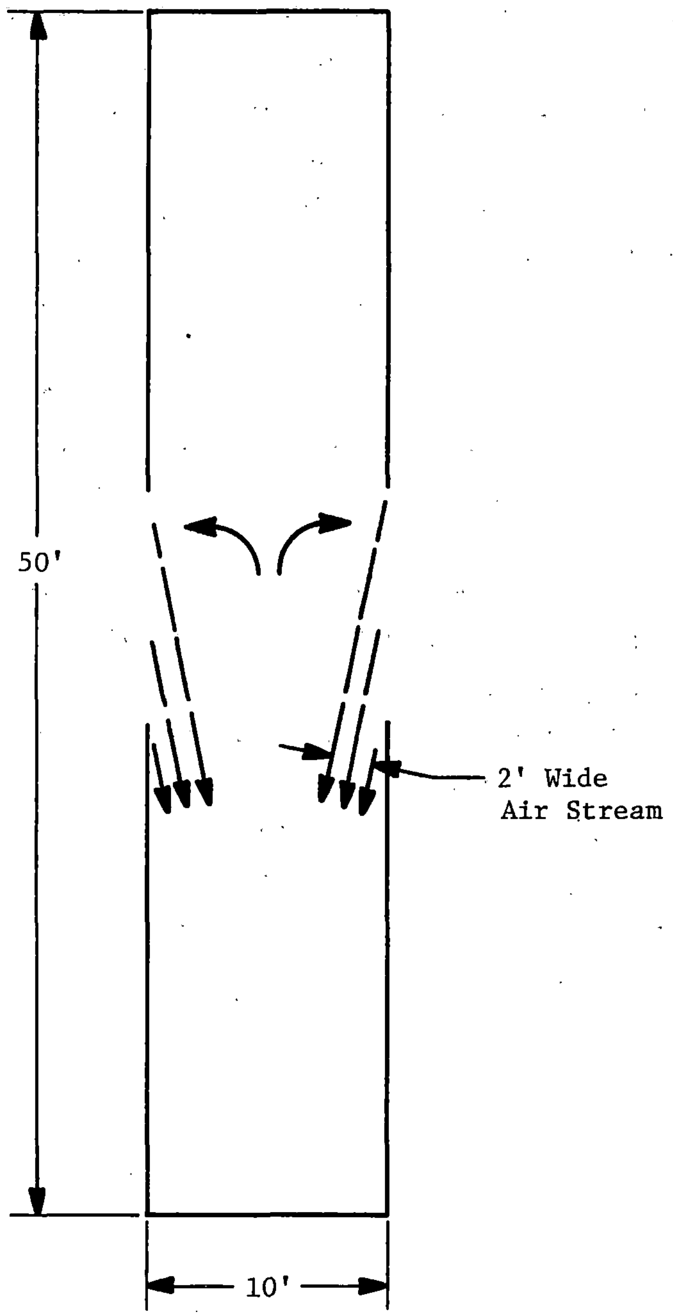

FIGURE 17
BOXCAR WITH OPEN DOORS

6.0 SUMMARY AND CONCLUSIONS OF THE STUDY

Since the effort reported herein has been directed towards three distinct areas, this section is correspondingly divided.

6.1 Correlation Efforts

In an effort to relate the predictions of the computer program with actual field measurements of fuel consumption, MITRE was supplied with data from two different sources: some intermodal runs in the midwest and some unit coal train runs on an Eastern railroad. The intermodal runs were simulated first, with the result that the prediction was approximately 20 percent less than the measured consumption.

A careful comparison of the field data with the predictions on a mile-by-mile basis revealed that at least one cause of the discrepancy was likely to be train stretching, a common practice in the industry, where the train is kept stretched on a downgrade by driving against the brakes. The rate of fuel consumption differed noticeably on the downgrade in the section of track considered. In addition it was considered possible that the coefficient of the velocity-dependent term of the modified Davis formula was not accurate, as no rationale for reducing its value from the 0.45 figure of the old Davis formula to the .01 figure has been found.

It was also suspected that the aerodynamic drag of the intermodal operation was being underestimated. As a consequence, attention was then directed to a unit coal train operation whose aerodynamic characteristics were thought to be better understood. When a simulation of that operation produced an even larger discrepancy between field data and prediction, other causes were suspected. Nevertheless, the rationale for utilizing the wind tunnel data was modified at that time to correctly reflect the drag of the intermodal equipment in both the shielded and unshielded condition. A subsequent simulation in the easterly direction was quite accurate, but the same simulation in the westerly direction predicted a value almost 13 percent below the reported consumption. It is suspected that a headwind, or a crosswind of equivalent effect, may be causing the discrepancy between the accuracies of the two runs in opposite directions.

After the simulation of the unit coal train operation was found to have an equal discrepancy, the track data were examined in detail. A manual extraction of curvature data directly from the track charts showed that a large portion of the discrepancy could be attributed in that simulation to an inadequate level of detail of the curvature data. Incorporation of the detailed curvature data led to an acceptable level of accuracy in the simulation.

The final effort was preparation of a probable budget accounting for the error. The strongest contributors to inaccurate prediction are likely to be the practice of train stretching, an underestimate of curve resistance, and headwinds or crosswind effects. There are of course certain inherent inaccuracies in the program itself. It appears likely that in the absence of modelling certain effects the discrepancy will be always, as observed in the above simulations, on the low side. This is to be preferred, however, to erring with equal probability on either side.

6.2 Economic Analysis

Although it was found that discounting procedures--those which utilize the time-value-of-money concept--are becoming more popular as decision aids in capital investment evaluation, the literature does not offer consistent recommendations as to the best methodology to employ. Economists appear to favor the NPV criterion while business executives--especially in the railroad industry--tend to prefer the IRR approach. On the other hand, the most popular of all techniques, the payback method, is also judged to be one of the most inferior for long-term investment decisions. Clearly, the controversy has not been settled, and the process of capital investment evaluation remains today more of an art than a science. A survey of the relevant methods and their various advantages and disadvantages is given in Appendix A.

The method selected in this paper, the net present value approach, was favored for two reasons:

1) The procedure develops absolute present value estimates of capital investment benefits via discounting, thus facilitating incremental comparisons of projects competing for limited investment funds; and,

2) This discounting method is computationally much simpler than the IRR technique, a consideration in efforts featuring limited resources.

The method was used to evaluate the life cycle cash flow of three investment options for a unit coal train operation: standard equipment, lightweight steel hoppers, and aluminum hoppers. Use of the technique and the assumptions going into the calculation showed a clear advantage to the use of the lightweight equipment. In the future, although fuel savings alone formed only a portion of the discounted savings, the differential between the various investment options will undoubtedy become larger because of the rising cost of fuel.

6.3 Operation Over Undulating Terrain

Reasonable agreement was established between predictions of fuel consumption by the computer program and theoretical results corresponding to the simulated trips. The results demonstrated that fuel savings attributable to the use of lightweight equipment are limited to the small savings achieved over level tangent track through the reduction of mechanical resistance if the average grade is below a certain figure. If, however, the average grade is higher than this figure, the savings in fuel can be substantial. It is also shown that the type of operation being conducted has a significant impact upon the conclusions.

6.4 General

The efforts at correlating the predictions from the computer program with reported fuel consumption from the field led to the conclusion that there are fundamental limits to the accuracy with which fuel consumption can be predicted for a particular journey. Unless the program is refined to take into consideration hitherto unmodeled effects such as train stretching or crosswinds, a truly accurate prediction of fuel consumption is virtually impossible. It is believed that the present program, given accurate track data, should predict fuel consumption for a trip to within 10 percent below the true value or better. At this time it seems unlikely that an overprediction will be made; the unmodelled effects which are present always ensure that the actual consumption will be larger than the prediction.

The economic methods outlined in Appendix A and the particular situation analyzed in detail in the main body of the report demonstrate that the effects of potential improvements in equipment can be carefully evaluated so that a truly rational investment decision can be made. While time did not permit such an economic analysis to be made of other potential improvements in equipment or operation, the interested party can utilize the computer program to perform his own simulation and evaluate the life cycle cost of an investment in new technology by utilizing the economic methods outlined herein.

In summary, a valuable tool has been generated which in conjunction with the economics analysis can prove useful in evaluating the impact of modifications to railroad equipment or certain railroad operations upon energy consumption and prospective fuel savings.

APPENDIX A

EVALUATING RAIL FREIGHT CAR INVESTMENTS

1.0 INTRODUCTION

Previous studies(1,2) have investigated the technical aspects of freight train resistance and provided preliminary estimates of cost savings resulting from potential modifications of the technology of freight cars and track structure. The types of technological modifications examined in these studies included:

- lightweight hopper and flat cars,
- improved roller bearing seals,
- improved truck designs, and
- greater track rigidity.

In addition, the effect of train resistance on the rearrangement of freight cars in a consist and the resultant savings in fuel consumption were also examined.

In Reference 1, a methodology was outlined by which the costs and benefits to a railroad of specific long-term technological improvements could be estimated. To illustrate the method, a unit coal train operation over an existing track route was simulated and operational requirements calculated. The performance and costs of these types of freight car investment options were examined for the given route and operation, and the results were reported in Section 3 of this report. This appendix discusses the advantages and disadvantages of several techniques which are available for the extension of the methodology to a specific case as illustrated in Section 3.

2.0 TECHNIQUES FOR EVALUATING INVESTMENT ALTERNATIVES

Capital investment evaluation techniques are used to assist the railroad executive faced with the decision to select from competing equipment the one alternative which meets the life cycle service requirements at least cost. Within the past twenty year period, there has been a gradual but consistent trend to the adoption of more quantitative techniques for evaluating investment proposals in business and industrial organizations.(22) The art of investment analysis is slowly being replaced by a more objective-oriented quantitative structure which utilizes the "time-value-of-money" concept in investment decisions. Thus, the percentage of firms using discounting methods as investment analysis tools has recently been estimated at about 66%.(23)

The methods used by the railroad industry to formally evaluate investment proposals vary widely based on a recent survey conducted for the Office of Intermodal Transportation.(24) Typically, the methods range from simplified rules-of-thumb--which are based primarily on the intuition, experience, and judgment of the evaluator--to modern quantitative techniques such as simulation, linear programming, and risk analysis. The variability is due to many different factors, including:

- the decision-maker's familiarity with the company's accounting systems and financial indicators,
- the available benefit and cost information,
- assumptions about the cost of capital, tax life, salvage value, inflation rates, productivity improvements, expected market expansion, improved lines of service, etc.

In addition, the methods employed often depend on the economic value of the investment and the financial viability of the organization. Small projects, for example, may not warrant extensive analyses;

therefore, less sophisticated rules-of-thumb are often acceptable, especially in preliminary planning or budgeting cycles.

Capital investments basically involve the expenditures of large sums of money at one point in time for facilities or equipment which are acquired to increase the future viability of the organization. The benefits of this investment are usually treated as future income expected over the life of the investment. Benefits could take the form of reduced operating costs, additional revenue due to improved operations or an expanded market, or improved profitability.

3.0 EXAMPLES

The methods used in evaluating capital investment proposals essentially fall into two groups: non-discounting and discounting* techniques. The difference between these groups is basically the consideration of the time value of money. Non-discounting techniques do not consider this aspect while discounting procedures specifically take the time value of money into account. Although many different techniques exist, two of the more well known techniques from each group were examined and selected for discussion purposes. As examples of non-discounting techniques, the payback and accounting rate of return methods were chosen. To illustrate discounting techniques, the net present value (NPV) and internal rate of return (IRR) methods were selected as representative examples.

3.1 The Payback Method

The payback method--also known as the capital recovery, cash return, or payout method--is one of several techniques for measuring the attractiveness of a capital investment project. This method is the one most commonly used for capital expenditure decisions in the U.S.(24) Its popularity results primarily from the fact that it is easy to understand and simple to use. In this method, the attractiveness of the project is determined by the payback period or the time needed to recover the amount invested via the benefit stream.** For example, suppose a capital expenditure of \$80,000 is expected to yield benefits of \$4,000 annually for 25 years. Here the payback period is simply \$80,000 ÷ \$4,000 or 20 years.

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[*] By discounting we imply that future economic benefits and costs should be less heavily weighted than current (or near term) ones. The weighting factor is the discount (or interest) rate which reflects the productivity of the next-best investment opportunity.

[**] The benefit stream is merely the income received at different time periods as a result of the investment.

The major weakness of the payback method is that it does not consider the time value of money. Thus, cash flow analyses are impeded. Also, since capital investment decisions focus on future project profitability, the payback method cannot be used directly because it only provides data on how fast a given investment can be recovered - not its profitability. A project with a five year payback period, for example, cannot be considered more profitable per se than one with a ten year payback period. In fact, the reverse is often true. Thus the payback approach should not be used by itself for major capital investment decisions.

However, the procedure can be of supplemental use for capital investment analyses such as in preliminary ranking of various investment projects especially in estimating their impact on budgets. The payback method is also justifiable in companies for which short term recovery of expenditures is critical, e.g. those with cash flow problems, or those offering high risk products or services. Under these circumstances, the shorter the payback period, the lower the investment uncertainty and therefore, the more attractive the proposed project.

3.2 Rate of Return Method

Basically, this method compares the annual expected benefits from an investment with the amount to be invested in the project and expresses this relationship as a percentage return on investment. Table A-1 illustrates the concept.

This method is quite popular in capital expenditure analyses largely due to the decision maker's familiarity with rate of return and accounting procedures. The rate of return (ROR) method has a variety of other names, among them: the accounting method, the return on investment method, and the financial statement method.

TABLE A-1

ILLUSTRATION OF TWO DIFFERENT RATES OF RETURN (ROR) FOR THE SAME INVESTMENT

Investment	\$5000
Annual benefits	\$1600 (before taxes and depreciation)
Benefit period	10 years (no salvage value)
Tax rate	50%

Straight line depreciation is assumed.

1. Average benefits before depreciation and taxes:

$$\text{ROR} = \frac{\$1600}{\$5000} \times 100 = 32\%$$

2. Average benefits <u>after</u> depreciation and taxes:

Benefits before depreciation and taxes	=	\$1600
Less depreciation $\left(\frac{\$5000}{10 \text{ yrs}}\right)$	=	500
Net benefit before taxes	=	\$1100
Less taxes (50%)		550
Net benefit after depreciation and taxes	=	\$ 550

$$\text{ROR} = \frac{\$\ 550}{\$5000} \times 100 = 11\%$$

Wide variations of each are in apparent use in business organizations. These variations are largely due to the ways benefits are determined. For example, benefits can be based on the initial year's income, annual income, or the average income throughout the life of the investment. Furthermore, income can be calculated in different ways:

- before or after depreciation
- by type of depreciation method (straight line, declining balance, sum-of-the-years-digits, etc.)
- before or after corporate taxes or
- before or after deducting the cost of capital.

In addition, the inclusion of the expected salvage value of the investment can produce different rates. Reference 25 provides a good discussion on the variety of ROR methods in use.

Is the ROR criterion better than the payback method? That depends on the decision-maker, the investment proposal and a host of other factors. However, the ROR method is considered superior to the payback method since it measures a project's profitability (return on investment) and considers the entire life cycle of the project. The ROR method, in theory, is inferior to discounted cash flow methods because the ROR approach ignores the time value of money. This is considered a serious shortcoming because all benefits regardless of when received, are treated equally. Nevertheless, the ROR method allows projects to be easily ranked and compared to a preset "hurdle rate" or minimum return on investment used by corporate management to screen future investment proposals. Its use is recommended only as a supplemental technique or for evaluating small or short-term investment alternatives for which more sophisticated methods are not justified.

3.3 Internal Rate of Return (IRR)

The internal rate of return is a time-discounted measure of investment attractiveness.* The IRR is defined as the discount rate which equates the present value of a benefit stream (e.g., cash receipts) with the initial investment. Thus,

$$I_o = \sum_{t=1}^{n} \frac{S_t}{(1+k)^t}$$

where:

I_o = original investment

S_t = net cash receipts or benefits at the end of time, t.

k = discount rate

n = duration of investment (usually, years).

Note that k = IRR only when the benefit stream equals the original investment, using present value calculations. The IRR method is also known as the discounted cash flow rate method, the discounted return method, the yield method, or the time adjusted rate of return method.

Alternatively, IRR can also be defined as that discount rate which equates the net present value (NPV) of the cash flows to zero. Symbolically, this relationship is illustrated as follows:

$$\sum_{t=1}^{n} \frac{S_t}{(1+k)^t} - I_o = 0$$

Thus, k = IRR, if NPV = 0.

---

*This measure should not be confused with the rate of return (ROR) criterion described in Section 3.2.2.

The IRR is usually determined via a trial and error process using annuity tables. Generally, the process is as follows: given the investment amount (I_o) and the cash flow (S_t), a discount rate is selected and the NPV calculated. If NPV = +, a higher discount rate (k) is chosen and the process repeated. If NPV = –, a lower discount rate is selected and the remaining calculation performed. If NPV = 0, the discount rate (k) <u>is</u> the IRR. Table A-2 illustrates this process.

The decision rules applicable to the investment proposal must consider the discount rate (k) or the minimum required rate of return on new investment. Thus,

if $IRR > k$, accept the project and,

if $IRR < k$, reject the project.

If IRR = k, total indifference to the project is implied.

3.4 Net Present Value (NPV) Method

The NPV method is another discounting cash flow method for evaluating the desirability of investment proposals. Computationally,

$$NPV = \sum_{t=1}^{n} \frac{S_t}{(1+k)^t} - I_o$$

where,

S_t = net cash inflow at the end of year (t)

I_o = original investment

k = discount rate (the required minimum rate of return on new investment)

n = project's duration (years)

Thus, a project's NPV is derived by discounting the cash receipts at a rate reflecting the value of the alternative use of these funds, summing them over the project's duration and deducting the initial

TABLE A-2

DETERMINING THE INTERNAL RATE OF RETURN (IRR)

Year (t)	Net Cash Flow (S_t)	Discount Factor $\frac{1}{(1+k)^t}$	Present value of cash flow (PV)
	First Iteration: 8% Discount Rate (k)		
1	452	0.926	418.6
2	500	0.857	428.5
3	278	0.794	220.7
		PV of Receipts	1,067.8
	Less:	Initial Outlay (I_o)	-1,000.0
		NPV	+67.8
	Second Iteration: 15% Discount Rate (k)		
1	452	0.870	393.2
2	500	0.756	378.0
3	278	0.658	182.9
		PV of Receipts	954.1
	Less:	Initial Outlay (I_o)	-1,000.0
		NPV	-45.9
	Final Iteration: 12% Discount Rate (k)		
1	452	0.893	403.6
2	500	0.797	398.5
3	278	0.712	197.9
		PV of Receipts	1,000.0
	Less:	Initial Outlay (I_o)	1,000.0
		NPV	0

Therefore, IRR = the discount rate (k) which produces a NPV of 0 or IRR = k = 12%.

outlay. Present value tables are utilized to obtain the discount factors for the assumed discount rate, k, and the time period, t. These factors--actually, $\frac{1}{(1+k)}$ t --are then multiplied by each years expected receipt (S_t) to get the present value of the cash flow. Table A-3 illustrates this process.

The decision rules implicit in the NPV method are;

if NPV = +, accept the proposed investment and,
if NPV = -, reject the proposed investment.

If NPV = 0, total indifference to the investment is implied.

TABLE A-3

ILLUSTRATION OF THE NET PRESENT VALUE METHOD

Year (t)	Net Receipt (S_t)	10% Discount Factor $\left[\frac{1}{1.10}\right]^t$	Present Value of Cash Flow (PV)
1	400	0.909	363.60
2	600	0.826	495.60
3	500	0.751	375.50
		Total =	1,234.70
		Less Initial Outlay (I_o) =	-1,000.00
		NPV =	+234.70

4.0 A COMPARISON OF THE TWO DISCOUNTING METHODS

From the previous section - particularly the formulas - it is already clear that the NPV and IRR methods are not very different. Both provide a measure of the proposed investment's "profitability" and both consider the time value of money. However, the methods do not necessarily lead to the same investment decisions for some types of projects. Factors which influence the decision outcome are: whether or not the projects to be evaluated can be considered economically independent, the degree of knowledge of the cost of capital, and the scale (or economic value) of the proposed investment.

Suppose two investment proposals are to be evaluated and only one selected. In this case, the two are considered to be economically dependent or mutually exclusive--the selection of one precludes the selection of the other. If the organization operates under a maximum profit policy, (i.e., maximizing (benefits - costs)), the selection criterion becomes one of determining which project is a better buy for the organization. Under these conditions it can be shown that the NPV and IRR methods will not rank order the two projects the same.* Consider the following two mutually exclusive one-year projects:

	I_o	$S_{t = 1}$
Project A	\$10,000	\$12,000
Project B	\$15,000	\$17,700

---

*In the situation where investment projects to be evaluated can be considered independent (that is, the acceptance of one project does not prevent the acceptance of the other), ranking is unimportant. Consequently, the ranking criterion is also not critical and the choice of the discounting method is immaterial.

Using the IRR approach:

$$I_o = \frac{S_t}{1+R} \text{ or } 1+R = \frac{S_t}{I_o}$$

$$1+R_A = \frac{\$12,000}{\$10,000} \text{ or IRR} = 20\%$$

and

$$1+R_B = \frac{\$17,700}{\$15,000} \text{ or IRR} = 18\%.$$

Thus, if IRR were the selection criterion, Project A would be chosen since it offers the highest rate of return.

Using the NPV approach for the same projects and assuming a cost of capital of 10% (discount factor at end of year 1 = 0.909):

$$NPV_A = S_t \text{ (d.f.)} - I_o$$

$$= \$12,000 \ (0.909) - \$10,000 = \$908$$

and

$$NPV_B = \$17,700 \ (0.909) - \$15,000 = \$1,089.$$

Consequently, if only one of the two projects could be selected, Project A would be chosen using the IRR method and Project B becomes the winner using the NPV approach. Which is the better investment? Project B is if we consider that the NPV approach always compares the incremental cash flows with the cost of capital to obtain an absolute dollar return. The IRR, on the other hand, is expressed in terms of percent - thus ignoring the scale (or size) of the investment and, as argued by some (8), most decision-makers prefer absolute dollar--rather than percentage--returns as a basis for selecting between competing projects.

Note that a major difference between the two approaches in terms of ranking investment proposals is that the IRR criterion is a fixed criterion while the NPV criterion varies with the discount rate. For example, the selection of dependent projects via the IRR is always determined by the highest rate (a project with a 25% return is always preferred to one with a 20% rate.) If using the NPV approach, the assumed discount rate is equal to or greater than the cost of capital, project ranking will be identical with the IRR criterion. However, if the assumed discount rate is less than the cost of capital, project ranking will differ with the method or criterion chosen. Figure A-1 illustrates the relationship between NPV and discount rate (k).

Another important difference between the IRR and NPV methods in terms of ranking dependent projects is the implicit assumption pertaining to the reinvestment of interim cash inflows. While the NPV approach assumes that such cash flows are to be reinvested at the opportunity cost of capital to the firm, the IRR method assumes that the annual cash flows will be reinvested at the project's own internal rate of return. The latter has no real economic basis since the cost of capital, (k) cannot have different values at any given time, t. However, the cost of capital can usually be assumed to vary in future years. If so, the IRR criterion is again not economically meaningful since the project's rate of return (R) is assumed to be a single-valued average rate over the project's entire life cycle. If, in this case, the cost of capital in different future periods is k_1, k_2, $k_3 \ldots k_n$ it becomes difficult to relate the average rate (R) to k_n to decide whether to accept or reject the investment proposal at t_o.

Another weakness of the IRR methodology arises in determining the rate of return (R) in non-conventional projects, i.e. those in

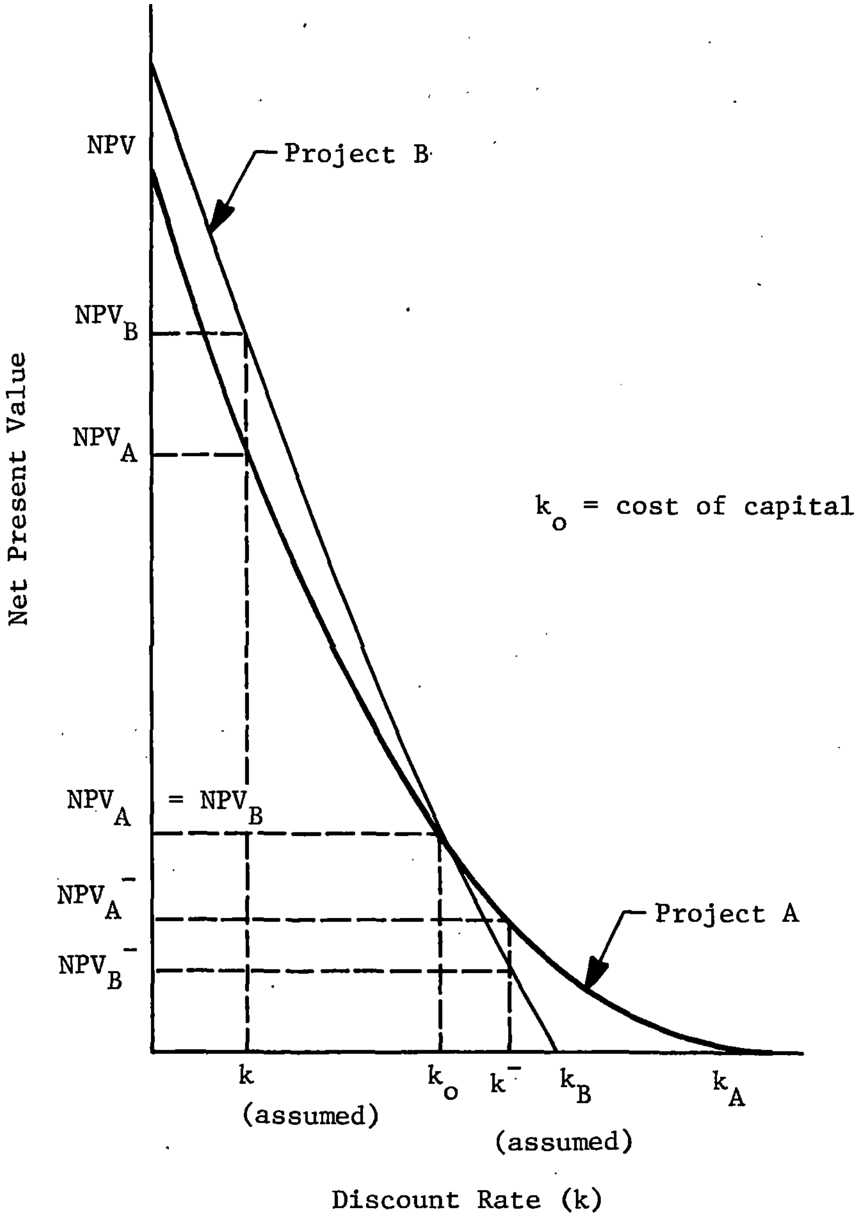

FIGURE A-1
THE RELATIONSHIP BETWEEN PROJECT RANKING AND DISCOUNT RATES USING THE NPV METHOD

which cash flows have more than one change of sign.* In such cases, it can be shown that a project's real IRR may not exist or may have multiple solutions. Reference 26 provides a detailed discussion of the multiple (and imaginary) root problem in non-conventional projects. The problem is mentioned here only to alert the evaluator choosing to use the IRR approach for investment project analysis.

---

* Examples of non-conventional cash flows are: -100, +50, -200, or +100, -200, +150. A conventional cash flow is typically as follows: -100, +20, +30, +25 .... .

APPENDIX B

MODIFICATIONS TO PROGRAM

1.0 INTRODUCTION

In an effort to obtain the highest degree of correlation between predictions from the computer program and actual field data, certain modifications to the program were made over a period of time which both enhanced its accuracy and facilitated the actual operation of the program. Some of these merely require mentioning for the record; the rationale behind others, in contrast, is worth discussing in detail. This appendix addresses both these types of changes.

2.0 PROGRAM IMPROVEMENTS

2.1 Data Files

The data file containing fundamental mechanical and aerodynamic data on all items of rolling stock which the program utilizes has been expanded and modified. Data on three different types of locomotives encountered during the correlation effort are now included. Loaded hopper cars are distinguished from empty hopper cars in the table, reflecting recent wind tunnel data, and twenty-one rather than eighteen lines of data are now utilized. The new data file is illustrated in Figure B-1 (top). Aerodynamic coefficients shown in the table have been adjusted to reflect the latest wind tunnel data. The rationale behind the adjustment of the values is given in detail in Section 4.0 of this Appendix.

A locomotive data table (Figure B-1, bottom) has been added which supplies to the program, when called upon, certain locomotive parameters necessary for the correct computation of locomotive resistance, tractive effort, or fuel consumption. Since these particular parameters are unique to locomotives, they were not made a portion of the main data table, which contains data necessary for calculating the mechanical resistance and the aerodynamic resistance for all types of rolling stock, including locomotives.

2.2 Minor Changes

The program has been modified to print out, if the data print option is selected, both the main data table and the locomotive data table, as illustrated in Figure B-1. This will prove useful for checking purposes.

Several of the input parameters at the beginning of the program were eliminated as inputs and initialized to a particular value, to simplify program operation. In particular, the random number

CAR & LOCOMOTIVE DATA TABLE

124.0	124.0	3.0	3.0	60.7	23.3	.0100	34.8	65.8	410000.0
124.0	124.0	3.0	3.0	60.7	23.3	.0100	34.8	65.7	392000.0
122.0	122.0	3.0	3.0	59.4	22.8	.0100	34.4	59.2	277500.0
110.0	110.0	2.0	2.0	31.0	10.0	.0061	32.0	50.0	60700.0
90.0	90.0	1.5	1.5	32.5	12.5	.0238	28.0	45.0	58000.0
90.0	90.0	1.5	1.5	22.8	8.7	.0166	28.0	45.0	58000.0
45.0	45.0	2.0	2.0	19.5	7.5	.0241	19.0	54.0	68900.0
10.0	10.0	2.0	2.0	0.0	0.0	.0104	12.0	60.0	79500.0
122.0	10.0	3.0	45.0	37.9	9.5	.0085	25.0	85.0	76200.0
10.0	122.0	45.0	3.0	37.9	9.5	.0085	25.0	85.0	76200.0
122.0	122.0	3.0	3.0	8.5	8.5	.0170	38.0	85.0	69000.0
78.0	10.0	3.0	45.0	34.6	8.6	.0085	20.0	85.0	76200.0
10.0	78.0	45.0	3.0	34.6	8.6	.0085	20.0	85.0	76200.0
78.0	78.0	3.0	3.0	34.6	8.6	.0085	28.0	85.0	76200.0
124.0	124.0	11.5	11.5	31.7	7.9	.0085	29.0	60.0	51500.0
150.0	150.0	2.0	2.0	137.6	34.4	.0180	40.0	85.0	76200.0
135.0	135.0	2.0	2.0	90.6	22.6	.0085	37.0	79.0	180000.0
135.0	135.0	3.0	3.0	39.0	13.0	.0051	37.0	88.0	119200.0
74.0	74.0	3.0	3.0	8.5	4.5	.0108	30.0	60.0	77600.0
110.0	130.0	5.0	5.0	73.9	18.5	.0085	32.0	40.0	60000.0
10.0	10.0	2.0	2.0	6.7	1.7	.0085	12.0	85.0	76200.0

ADDITIONAL LOCOMOTIVE PARAMETERS

3.0	75000.0	10.0	10.0	5.5	25.0
3.0	47000.0	15.0	17.5	5.5	25.0
2.0	27900.0	10.0	10.0	5.5	25.0

FIGURE B-1
CAR AND LOCOMOTIVE DATA

input was initialized, so that the probability of a random stop is now zero. The capability still remains within the program if the user cares to avail himself of the possibility of making random stops during a simulated run.

2.3 Change to Calculation

2.3.1 Dynamic Braking

The calculation has been adjusted to reflect a fuel consumption rate slightly larger than idle during the braking mode. The rate is extracted from the new locomotive parameter table referred to in Section 2.1 above. In the absence of better information, a fuel consumption rate for dynamic braking was estimated for all locomotives.

2.3.2 Headwind

Because during the correlation work the importance of both headwinds and crosswinds became evident in the computation of fuel consumption, a provision for an input of the estimated headwind was made. Crosswinds, however, despite their obvious impact, are too difficult to model rationally and their effect is still omitted.

2.3.3 Idle Rate

The fuel consumption during idle while brakes are not being applied has been adjusted so that the rate is never less than the idle rate. In certain instances, because the fuel consumption calculation is a work calculation based upon the mean velocity during the time interval and the overall specific fuel consumption, it had been possible for an anamalous condition to arise in which fuel consumption over the interval was less than that during idle. This condition has been corrected.

3.0 PROGRAMMING CHANGES

3.1 Locomotive Characteristics

Tractive effort curves for the locomotive were formerly part of the main program. These curves, for the three different types of locomotives encountered during the correlation effort, have now been appended to the program as subroutines. Additional curves can be added as needed. The set of curves utilized by the program reflects the specification of locomotive type by means of the train files.

Some special notes regarding locomotives are of interest. The program makes no provision for scattered locomotives--all locomotives must be grouped together at the front of the train. The three types of locomotives presently characterized are the General Motors EMD SD-40, SD-45 and GP-38 models. The calculation of mechanical drag reflects only type BB and CC locomotives. In addition, the fuel consumption rates during regeneration braking and idle are as shown in Figure B-1 and reflect the SD-40 locomotive; other information was not available at the time of writing.

3.2 Storage

The program as originally conceived placed heavy demands upon the system in terms of storing values of variables. The program has been rewritten from a programming standpoint to improve this aspect and to eliminate the requirements for such storage. This has the advantage of reducing computational costs. The new program is listed in Figure B-2. The reader is referred to the user's manual* for more detailed information regarding the program and its use.

---

*FRA/ORD-78/04.IV, User's Manual.

```
       DIMENSION NUM(2),N1(12),N2(12),LOCO1(3,6),TRACK(3,4)
       DIMENSION ARRAY(200),DATA(200,2),COEFF(21,10),ORDER(200)
       EQUIVALENCE (ARRAY,DATA)
       INTEGER ARRAY,CUTOFF,ORDER,OPTN1
       INTEGER P,PP,PPP,Q,U,UU,W,X,Y,Z,ZX,ZSL
       REAL MV,MF,LIMIT,N3,N4,MDFC,LOCO1,KD,KE,KF,MN,NET,OSL,MPH
C------INITIALIZATION
       CDT = 0.0
       CFC = 0.0
       CRFC = 0.0
       CIT = 0.0
       Z = 0
       ZX = 0
       ZSL = 0
       KD = .0763*88.0**2/(32.2*60.0**2*2.0)
       KE = KD
       KF = KD
       CF = 5280.0*5.05E-7*.0644
       CF2 = 88.0*.0644/(550.0*60.0*3600.0)
       DT = 10.0
       NI = 2000
       TOL = 2.5
       NC = 2
       TIME = 10.0
       MF = 5.0
       CUTOFF = 1000
       SIGMA = 300.0
       AM = 0.0
       WT = 0.0
       SUM1L = 0.0
       SUM1C = 0.0
       SUM1 = 0.0
       SUM2 = 0.0
       SUM3 = 0.0
       SUM4 = 0.0
       SUM5 = 0.0
       SUM6 = 0.0
       CFC = 0.0
       J = 1
       V1 = 0.0
       VDD = 0.0
       IX = 999999999
C------READ INPUTS AND DATA FILES:
       READ(4,50) ((COEFF(I,J),J=1,10),I=1,21)
  50   FORMAT (5X,F5.1,2X,F5.1,2X,F4.1,2X,F4.1,2X,F5.1,2X,F5.1,
     1 2X,F5.4,2X,F4.1,2X,F5.1,2X,F8.1)
       READ (10,53) ((LOCO1(K,L),L=1,6),K=1,3)
  53   FORMAT (5X,F3.1,3X,F7.1,3X,F4.1,3X,F4.1,3X,F3.1,3X,F4.1)
       WRITE(6,12)
       WRITE(7,12)
  12   FORMAT(1X,' INPUT, NO. OF LOCOMOTIVES, ENTER A 1 DIGIT NO.')
       READ(5,13)NL
       WRITE(7,13)NL
  13   FORMAT(I1)
       WRITE(6,14)
```

FIGURE B-2
PROGRAM LISTING

```
      WRITE(7,14)
 14   FORMAT(1X,' INPUT,NO. OF VEHICLES IN TRAIN, (INCL. LOCOMOTIVES),
     1 ENTER A 3 DIGIT NO.')
      READ(5,33) NV
      WRITE(7,33) NV
 33   FORMAT(I3)
      READ (1,51)  ((DATA(N,L),L=1,2),N=1,NV)
 51   FORMAT  (4X,I3,F6.1)
      READ  (2,52) (ORDER(N),N=1,NV)
 52   FORMAT  (5X,I3)
      WRITE(6,116)
      WRITE(7,116)
 116  FORMAT(1X,' INPUT, NO. OF TRACK RECORDS IN TRACK FILE,
     1 ENTER A 4 DIGIT NO.')
      READ(5,17) NTR
      WRITE(7,17) NTR
 17   FORMAT(I4)
      WRITE(6,22)
      WRITE(7,22)
 22   FORMAT(1X,' START PRINT AT I = (A 4 DIGIT NO.')
      READ(5,17) INDEX
      WRITE(7,17) INDEX
      WRITE  (6,27)
      WRITE  (7,27)
 27   FORMAT  (1X,' ENTER OPERATIONAL SPEED LIMIT,MPH')
      READ  (5,19)  OSL
      WRITE  (7,19)  OSL
 19   FORMAT  (F4.1)
      WRITE  (6,18)
      WRITE  (7,18)
 18   FORMAT  (1X,' INPUT,ESTIMATED HEADWIND, MPH')
      READ  (5,19)  HW
      WRITE  (7,19)  HW
      WRITE(6,16)
      WRITE(7,16)
 16   FORMAT(1X,'DATA PRINT OPTION, TYPE 1 FOR YES, 0 FOR NO')
      READ(5,55) OPTN1
      WRITE(7,55) OPTN1
 55   FORMAT(I1)
      WRITE(7,41)
      IF  (OPTN1.EQ.0)  GO TO 115
      WRITE(7,114)
 114  FORMAT  (12X,' CAR & LOCOMOTIVE DATA TABLE')
      WRITE  (7,41)
      WRITE  (7,50) ((COEFF(I,J),J=1,10),I=1,21)
      WRITE  (7,41)
      WRITE  (7,113)
 113  FORMAT  (12X,' ADDITIONAL LOCOMOTIVE PARAMETERS')
      WRITE  (7,41)
      WRITE  (7,53) ((LOCO1(K,L),L=1,6),K=1,3)
      WRITE  (7,41)
 115  CONTINUE
C------CALCULATE TRAIN WEIGHTS
      DO 337 K = 1,NV
      NET = NET+DATA(ORDER(K),2)
```

FIGURE B-2
PROGRAM LISTING
(CONTINUED)

```
  337 GROSS = GROSS+DATA(ORDER(K),2)+COEFF(ARRAY(ORDER(K)),10)/2000.0
      WRITE(7,338) NET
  338 FORMAT (1X,'     NET TRAIN LOAD, TONS:', F10.2)
      WRITE(7,41)
      WRITE(7,344) GROSS
  344 FORMAT (1X,'     GROSS TRAIN WEIGHT,TONS:',F10.2)
      WRITE(7,41)
C------*************************************************
C
C------CALCULATE RESISTANCES OF EACH VEHICLE AND ADD
C
C------*************************************************
      DO 24 I = 1,NV
      IF (I.GT.1) GO TO 43
      DO 25 K = 1,NV
      NET = DATA(ORDER(K),2)
      TARE = (COEFF(ARRAY(ORDER(K)),10))/2000.0
      GROSS = NET+TARE
      WT = WT+GROSS
      IF (K.LE.NL)SUM1L = SUM1L+GROSS*.6+40.0*LOCO1(ARRAY(1),1)
      IF (K.GT.NL) SUM1C = SUM1C+GROSS*.6+80.0
      SUM2 = SUM2+.01*GROSS
   25 CONTINUE
      SUM1 = SUM1L+SUM1C
      IF (OPTN1.EQ.0) GO TO 43
      WRITE (7,89) SUM1L,SUM1C
   89 FORMAT (10X,' LOCO. MECH. DRAG, LBS.:',F8.2,
     1 4X,' CAR MECH. DRAG, LBS.:',F8.2)
   43 CONTINUE
      IF (I.EQ.1) GO TO 37
      GF = COEFF(ARRAY(ORDER(I)),3)+COEFF(ARRAY(ORDER(I-1)),4)
      GO TO 38
   37 GF = 1000.0
   38 IF (I.EQ.NV) GO TO 39
      GA = COEFF(ARRAY(ORDER(I)),4)+COEFF(ARRAY(ORDER(I+1)),3)
      GO TO 42
   39 GA = 1000.0
   41 FORMAT (/)
   42 CONTINUE
      IF (I.EQ.1) CFF = 1.0
      IF (I.GT.1) CFF = .5*TANH(.5*(ALOG(GF/10.0)-1.4))+.5
      IF (I.EQ.NV) CFA = 1.0
      IF (I.LT.NV) CFA = .5*TANH(1.1*(ALOG(GA/10.0)-1.4))+.5
      IF (I.EQ.1) GO TO 160
      CAA = COEFF(ARRAY(ORDER(I)),1)
      CBB = COEFF(ARRAY(ORDER(I-1)),2)
      IF (CAA-CBB)251,252,252
  251 AFF = 0.0
      GO TO 170
  252 AFF = (CAA-CBB)/CAA
      GO TO 170
  160 AFF = 1.0
  170 IF (I.EQ.NV) GO TO 140
      CC = COEFF(ARRAY(ORDER(I)),2)
      DD = COEFF(ARRAY(ORDER(I+1)),1)
```

FIGURE B-2
PROGRAM LISTING
(CONTINUED)

```
      IF (CC-DD) 253,254,254
253   AFA = -4.0*EXP(-.173*GA)*(1.0-EXP(-.173*GA))
      GO TO 402
254   AFA = (CC-DD)/CC
      GO TO 402
140   AFA = 1.0
402   CONTINUE
      FF = 1.0-(1.0-CFF)*(1.0-AFF)
      FA = 1.0-(1.0-CFA)*(1.0-AFA)
      D = KD*COEFF(ARRAY(ORDER(I)),5)*FF
      E = KE*COEFF(ARRAY(ORDER(I)),7)*COEFF(ARRAY(ORDER(I)),8)*
     1 COEFF(ARRAY(ORDER(I)),9)
      F = KF*COEFF(ARRAY(ORDER(I)),6)*FA
      IF (ARRAY(ORDER(I)).LE.NL) CDA = 8.0*LOCO1(ARRAY(1),1)
      IF (ARRAY(ORDER(I)).GT.NL) CDA = 16.0
      UC = 2.0*.272*CDA*KD+.003*KD*COEFF(ARRAY(ORDER(I)),9)*10.0
      G = D+E+F+UC
      SUM6 = SUM6+G
 24   CONTINUE
      SUM3 = SUM6/NV
      WRITE (7,41)
      WRITE (7,458) SUM1,SUM2,SUM3
458   FORMAT (4X,' EQUATION FOR THE RESISTANCE OF THIS TRAIN IN LBS. I
     1 :',//,4X,' R = ',F10.2,'  + ',F10.4,'*V  + ',F10.4,
     1 '*NV*V**2',//,10X,' WHERE NV IS THE TOTAL NO. OF VEHICLES')
C------END OF CALCULATION OF RESISTANCE COEFFICIENTS
C------EXAMINE TRACK AND SPEED LIMIT RESTRICTIONS:
      WL = COEFF(ARRAY(ORDER(1)),10)/2000.0
      LIMIT = .23*NL*WL*2000.0
      READ (3,10) ((TRACK(M,N),N=1,4),M=2,3)
 10   FORMAT (4X,3F9.2,F9.1)
      IF (TRACK(2,4).GT.OSL) TRACK(2,4) = OSL
      IF (TRACK(3,4).GT.OSL) TRACK(3,4) = OSL
      DO 79 M = 1,4
      TRACK(1,M) = TRACK(2,M)
 79   CONTINUE
      DTO = DT
      WRITE(7,41)
      CALL RANDU(IX,IY,RN)
      IF(OPTN1.EQ.1) WRITE(7,66)RN
 66   FORMAT(3X,' RN = ',F8.6,/)
C------***************************************************
C
C------START SIMULATION OF TRIP -- MAIN LOOP
C
C------***************************************************
      DO 90 I = 1,NI
      DT = DTO
 49   FORMAT (F10.2)
      P = 0
      PP = 0
      PPP = 0
      IF (I.NE.1) GO TO 110
C------INITIAL STEP OF MAIN LOOP
      TE = NL*LOCO1(ARRAY(1),2)
```

FIGURE B-2
PROGRAM LISTING
(CONTINUED)

```
      IF (TE.GT.LIMIT) TE = LIMIT
      S = 0.0
      S1 = 0.0
      L = 13
      U = L
      J = 1
      K = 2
      CALL TRCKRD (S1,NTR,OSL,J,TRACK)
      VDD=(TE-(SUM1+20.0*WT*(TRACK(2,3)+TRACK(2,2))))/(100.0*WT)
      DV = VDD*DT
      V = DV
      MV = V/2.0
      DS = V*DT/(2.0*3600.0)
      S = DS
      RFC = TE*MV*CF2*60.0
      CRFC = RFC
      IF ((V.GT.90.0).AND.(VDD.GT.0.0)) GO TO 620
      GO TO 130
C------ALL SUBSEQUENT STEPS OF MAIN LOOP
  110 Q = K-1
      IF (Z.NE.0) GO TO 726
      DO 725 W = 1,2
      CALL RANDU(IY,IY,RN)
      BASE = 1000.0*RN
      NUM(W) = BASE+1.0
  725 CONTINUE
      IF (I.GE.INDEX.AND.OPTN1.EQ.1) WRITE(7,67)NUM(1),NUM(2)
  67  FORMAT(2X,2(3X,I4))
  726 CONTINUE
      CALL TRCKRD (S1,NTR,OSL,J,TRACK)
      IF (I.GT.1.AND.J.NE.NTR.AND.V1.EQ.0.0.AND.TRACK(2,4).EQ.0.0)
     1 TRACK(2,4) = TRACK(3,4)
      IF (ZSL.EQ.1) GO TO 700
      IF (TRACK(2,4).EQ.0.0.AND.Z.NE.2) ZSL = 1
      IF (TRACK(2,4).EQ.0.0.AND.Z.NE.2) GO TO 700
      DIF = (V1-TRACK(2,4))
      IF(ABS(ABS(DIF)-TOL).LE.1.0E-3) DIF=TOL
      IF (ABS(DIF).LT.TOL.AND.J.EQ.NTR) GO TO 95
      IF (NUM(1).GT.CUTOFF.AND.Z.NE.2) GO TO 700
      IF (Z.EQ.2) GO TO 750
      IF (ABS(DIF).LT.TOL) GO TO 300
      IF (ABS(DIF).GE.TOL) GO TO 400
  300 IF (I.EQ.2) GO TO 302
      GO TO 304
  302 DIF2 = -TRACK(2,4)
      GO TO 301
  304 IF (ABS(VDD1).LE.TOL/(MF*DT)) GO TO 351
      GO TO 303
  351 IF (TRACK(1,2).EQ.TRACK(2,2).AND.TRACK(1,3).EQ.TRACK(2,3)
     1 .AND.TRACK(1,4).EQ.TRACK(2,4)) GO TO 352
  303 DIF2 = V2-TRACK(2,4)
  301 IF (VDD1.GT.0.0.AND.ABS(DIF2).GT.TOL) P = 3
      IF (VDD1.GT.0.0.AND.ABS(DIF2).LE.TOL) P = 2
      IF (VDD1.EQ.0.0) GO TO 305
      IF (VDD1.LT.0.0.AND.ABS(DIF2).LE.TOL) P = 4
```

FIGURE B-2
PROGRAM LISTING
(CONTINUED)

```
      IF (VDD1.LT.0.0.AND.ABS(DIF2).GT.TOL) P = 5
      GO TO 900
400   IF (V1-TRACK(2,4)) 600,600,500
600   IF(VDD1.GE.0.0) P = 1
      PPP = 1
      IF (VDD1.LT.0.0) P = 5
      GO TO 900
500   IF (VDD1 .GE.0.0) P = 3
      IF (VDD1.LT.0.0) P = 1
      PPP = 2
900   IF (P.EQ.2) L = L-1
      IF (P.EQ.3) L = L-NC
      IF (P.EQ.4) L = L+1
      IF (P.EQ.5) L = L+NC
      PP = 1
      GO TO 930
910   IF (PPP.EQ.1.AND.VDD.GE.0.0.AND.ABS(DIF/VDD).LT.TIME)
     1GO TO 120
      IF (PPP.EQ.2.AND.VDD.LT.0.0.AND.ABS(DIF/VDD).LT.TIME)
     1GO TO 120
920   IF (PPP.EQ.1) L = L+1
      IF (PPP.EQ.2) L = L-1
305   PP = 2
930   U = L
      IF (U.LE.0) GO TO 320
      IF (U.GT.17) GO TO 330
      GO TO 310
320   IF(OPTN1.EQ.1) WRITE(7,322)
322   FORMAT(1X,' INADEQUATE BRAKES')
      U = 1
      L = 1
      PPP = 3
      GO TO 310
330   IF (I.LT.INDEX) GO TO 367
      IF(OPTN1.EQ.1) WRITE(7,340)
340   FORMAT(1X,' MORE TRACTIVE EFFORT NEEDED')
367   U = 17
      L = 17
      PPP = 3
      GO TO 310
700   Z = 1
      L = L-NC
      IF (L.LE.0) L = 1
      U = L
310   BETA = (30.0-V1)/20.0
      FRF = .06*(EXP(BETA)-EXP(-BETA))/(EXP(BETA)+EXP(-BETA))+.18
      BFC = (NV-NL)*.60*66000.0*FRF
      BFL = NL*.90*WL*2000.0*FRF
      FB = BFC+BFL
313   IF (U.LE.9) GO TO 314
      LT = ARRAY(ORDER(1))
      VP = V1
      CALL LOCO2 (U,NL,LT,VP,TEH,TEL)
      GO TO 218
314   GO TO (201,202,203,204,205,206,207,208,209),U
```

FIGURE B-2
PROGRAM LISTING
(CONTINUED)

```
201   TE = -1.0*FB
      GO TO 225
202   TE = -.875*FB
      GO TO 225
203   TE = -.750*FB
      GO TO 225
204   TE = -.625*FB
      GO TO 225
205   TE = -.500*FB
      GO TO 225
206   TE = -.375*FB
      GO TO 225
207   TE = -.250*FB
      GO TO 225
208   TE = -.125*FB
      GO TO 225
209   TE = 0.0
      GO TO 225
218   MPH = LOCO1(ARRAY(1),3)
      IF (U.EQ.17.OR.U.EQ.16) MPH = LOCO1(ARRAY(1),4)
      IF (V1-MPH) 219,219,220
219   TE = TEL
      GO TO 221
220   TE = TEH
221   IF (TE) 225,225,224
224   IF (TE.GT.LIMIT) GO TO 230
      GO TO 225
230   IF (I.LT.INDEX) GO TO 368
      IF(OPTN1.EQ.1) WRITE(7,68)
68    FORMAT(1X,' ADHESION LIMITED')
368   U = U-1
      L = U
      PP = 2
      IF (U.LT.1) U = 1
      GO TO 313
225   IF(ZX.EQ.1)GO TO 805
237   CR = 0.0
      CR = SUM1+SUM2*V1+SUM6*(V1+HW)**2
      R = CR
      TR = R+20.0*WT*TRACK(2,3)+20.0*WT*TRACK(2,2)
      VDD = (TE-TR)/(100.0*WT)
      IF(ABS(VDD)-1.0E-3) 790,791,791
790   IF (VDD) 792,793,793
792   VDD = -1.0E-3
      GO TO 791
793   VDD = 1.0E-3
      GO TO 791
791   IF((P.EQ.1).AND.(PP.EQ.1)) GO TO 910
      IF (ABS(VDD).LE.1.0E-2.AND.U.EQ.17) GO TO 799
120   IF ((P.EQ.3.OR.P.EQ.5).AND.PPP.NE.3) DT = DT/2.0
      IF (Z.EQ.1) DT = DT/2.0
      DV = VDD*DT
      V = V1+DV
      IF (V.LT.0.0) V = 0.0
      IF (Z.EQ.1.AND.V.EQ.0) GO TO 730
```

FIGURE B-2
PROGRAM LISTING
(CONTINUED)

```
      GO TO 800
730   DT = -V1/VDD1
      Z = 2
      IF (ZSL.EQ.1) ZSL = 2
      GO TO 800
352   VDD = VDD1
      DST = TRACK(3,1)-S1
      DSC = V1**2+2.0*VDD*DST*3600.0
      IF(VDD) 353,354,355
353   DT1 = -(TOL+DIF)/VDD
      IF (DSC) 356,357,357
356   DT = DT1
      GO TO 804
357   DT2 = (-V1+SQRT(DSC))/VDD
      GO TO 358
355   DT1 = (TOL-DIF)/VDD
      DT2 = (-V1+SQRT(DSC))/VDD
      GO TO 358
354   TE = TE1
      V = V1
      DS = TRACK(3,1)-S1
      DT = (DS/V)*3600.0
      MV = V
      GO TO 810
358   IF (DT1-DT2) 359,361,361
359   DT = DT1
      GO TO 804
361   DT = DT2
      GO TO 804
804   ZX=1
      GO TO 313
805   DV = VDD*DT
      ZX=0
      V = V1+DV
      GO TO 800
750   IF (ZSL.EQ.2) GO TO 756
      N3 = 0.0
      N4 = 0.0
      DO 751 X = 1,12
      CALL RANDU(IY,IY,RN)
      BASE1 = 100.0*RN
      N1(X) = BASE1+1.0
751   CONTINUE
      IF (I.GE.INDEX) WRITE(7,69)X,N1(X)
      DO 752 Y = 1,12
      CALL RANDU(IY,IY,RN)
      BASE2 = 100.0*RN
      N2(Y) = BASE2+1.0
752   CONTINUE
      IF(I.GE.INDEX) WRITE (6,770)Y,N2(Y)
      DO 753 Z = 1,12
      N3 = N3+.01*N1(Z)
753   N4 = N4+.01*N2(Z)
      WRITE(7,69)N3,N4
69    FORMAT(6X,'N3 = ',F6.3,5X,'N4 = ',F6.3,/)
```

FIGURE B-2
PROGRAM LISTING
(CONTINUED)

```
770    FORMAT (  1H ,2X,I2,5X,I3)
       G1 = (N3-6.0)*SIGMA+AM
       G2 = (N4-6.0)*SIGMA+AM
       DT = SQRT(G1**2+G2**2)
756    IF (ZSL.EQ.2) DT = SIGMA
       CIT = CIT+DT
       WRITE(7,71)I,G1,G2,DT,CIT
 71    FORMAT (2X,I4,4(3X,F6.1))
       DFC = NL*DT*LOCO1(ARRAY(1),5)/3600.0
       Z = 0
       ZSL = 0
       TE = 0.0
       TR = 0.0
       VDD = 0.0
       DS = 0.0
       L = 13
       S = S1
       GO TO 754
799    V = V1
       DT = 3600.0*(TRACK(3,1)-S1)/V1
       DV = VDD*DT
800    MV = (V+V1)/2.0
       DS = MV*DT/3600.0
810    S = S1+DS
       IF (TRACK(3,1)-S.LE.1.0E-3.AND.J.NE.NTR)
     1 S = TRACK(3,1)
       IF ((V.GT.90.0).AND.(VDD.GT.0.0)) GO TO 620
       IF (I.GT.3.AND.V.EQ.0.0.AND.V1.EQ.0.0
     1 .AND.V2.EQ.0.0) GO TO 95
130    CR = 0.0
       CR = SUM1+SUM2*MV+SUM6*(MV+HW)**2
       R = CR
       TR = R+20.0*WT*TRACK(2,3)+20.0*WT*TRACK(2,2)
       RR = TR+100.0*WT*VDD
       DFC = CF*RR*DS
       MDFC = NL*DT*LOCO1(ARRAY(1),5)/3600.0
       IF (DFC.LT.MDFC) DFC = MDFC
       IF (U.LE.8.AND.V1.GE.15.0) DFC = NL*
     1 DT*LOCO1(ARRAY(1),6)/3600.0
754    CONTINUE
       CFC = CFC+DFC
       CDT = CDT+DT
       IF (I.EQ.1) GO TO 98
       RFC = 60.0*DFC/DT
       CRFC = 60.0*CFC/CDT
98     IF (I.GE.INDEX.OR.NUM(1).GT.CUTOFF) GO TO 97
       IF (J.EQ.NTR) GO TO 97
       GO TO 90
97     WRITE(8,58)CDT,V,RFC
58     FORMAT(F7.0,2(5X,F5.2))
       IF(OPTN1.EQ.1) WRITE(7,190)I,TE,U,TR,
     1 VDD,V,J,DS,DT,S,DFC,CFC,CDT,RFC,CRFC
       V2 = V1
       V1 = V
       TE1 = TE
```

FIGURE B-2
PROGRAM LISTING
(CONTINUED)

```
      VDD1 = VDD
      S1 = S
 90   CONTINUE
C------END OF MAIN LOOP
190   FORMAT (  1H ,I4,2PE11.2,I3,3(2PE11.2),2X,I3,2PE11.2,2PE11.2,
     1 /,5X,2PE11.2,3X,2(2PE11.2),27X,2PE11.2,/,19X,2(2PE11.2),//)
      GO TO 95
  620 WRITE(7,622)
  622 FORMAT(1X,' RUNAWAY')
      WRITE(7,621) I,L,P,VDD,V
  621 FORMAT (  1H ,1X,I3,2X,I2,2X,I2,2X,2(2PE11.2))
      GO TO 625
   95 CONTINUE
      WRITE(9,81)I
  81  FORMAT(I4)
      IF(OPTN1.EQ.0) WRITE(7,94)III,J,S1,CDT
  94  FORMAT(  1H ,2X,I4,2X,I3,4X,F8.1,3X,F8.1)
      WRITE(7,92)I,CFC
  92  FORMAT (  1H ,I4,2X,' TOTAL TRAIN FUEL CONSUMPTION',
     1 F8.2,' GALLONS')
      WRITE(7,154) CRFC
  154 FORMAT ('        AVERAGE RATE OF FUEL CONSUMPTION FOR TRIP = ',
     1 F8.2,' GAL./MIN')
      AV=S1*3600.0/CDT
      WRITE(7,99)AV
  99  FORMAT(  1H ,6X,' AVERAGE VELOCITY FOR TRIP  =  ',
     1 F8.2,' MPH')
  625 STOP
      END
      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*65539
      IF(IY)5,6,6
  5   IY=IY+2147483647+1
  6   YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

FIGURE B-2
PROGRAM LISTING
(CONCLUDED)

4.0 INCORPORATION OF WIND TUNNEL DATA

4.1 Introduction

The purpose of this section is to document the incorporation of the results of recent wind tunnel testing of various items of conventional rolling stock into the MITRE computer program. The adjustment of the coefficients used in the calculation of the aerodynamic drag by the program so that the effective drag equates with the wind tunnel values in all configurations (shielded, unshielded, and in-between cases) is also reported.

4.2 Previous Rationale for Calculation of Aerodynamic Drag

A methodology was developed in an earlier work (1) which permitted the evaluation of the aerodynamic drag of a freight car when preceded and followed by another freight car of arbitrary type. The methodology divided the aerodynamic drag of a single freight car in a train of other cars into five components: front pressure drag, skin friction on the sides and top, rear pressure drag, drag of the underneath side of the car, and truck drag. The methodology was based upon reports in the literature, theoretical considerations, wind tunnel tests of certain items of intermodal equipment, and recognition of the effect of gaps between freight cars as measured in the wind tunnel on wooden blocks representing them. Since information on the appropriate division of pressure effect between front and rear was available only for streamlined passenger trains, the pressure effect was arbitrarily divided evenly between front and rear, and a functional relationship between change in pressure drag and change in gap spacing was arbitrarily adopted which attempted to reflect the wind tunnel tests.

In a second report (2) the calculation was modified slightly to adjust the previously adopted functional relationship between change in pressure drag and change in gap spacing, reflecting further wind tunnel tests on wooden blocks, and to adjust the ratio of front and rear pressure drags on the basis of the same tests. While the calculation was believed to be as accurate as information would permit, nevertheless the fuel consumption per gross-trailing-ton-mile predicted by the program was consistently below the measured consumption by approximately twenty or thirty percent (see Table II, Reference (2)). While it was not believed that this discrepancy would contribute adversely in a significant fashion to the accuracy of predictions of changes in fuel consumption attributable to equipment modifications, nevertheless the discrepancy was disturbing. Subsequent comparisons utilizing the same methodology and calculations demonstrated comparable discrepancies and attempted to analyze the reasons for them.

4.3 Revised Methodology

The computation of the air resistance of the train by calculating it for each car and summing the results and the division of the air resistance of each individual car into five separately calculated components have not been modified. It is still felt that this approach will offer the most accuracy in the result, as it is well known that the uncertainty in the sum of a large number of independent quantities with individual uncertainties is less than the sum of the individual uncertainties.

Therefore, in order to be consistent with the information from the wind tunnel, the following rationale will be followed.

Let

D_s = drag in the shielded position

D_u = drag in the unshielded position

F = pressure drag on front of car affected by proximity considerations

R = pressure drag on rear of car affected by proximity considerations

U = skin friction drag in underside of car

T = drag of two trucks

S = skin friction drag of roof and two sides of car plus residual pressure drag not affected by proximity considerations

Then we will say that

$$D_u = F + R + S + U + T$$

and

$$D_s = S + U + T$$

Then the difference between the drags is given by

$$D_u - D_s = F + R$$

Therefore, this is the value of drag area which will be affected by proximity considerations. Since D_u and D_s have been determined for most types of rolling stock with which the computer program is concerned, a value for F and R is available. Furthermore, the ratio between F and R will be determined by the results of additional wind tunnel tests.

As an example, consider Figure B-3, which compiles the results of four boxcar configurations recently tested in the wind tunnel. The resulting drag areas in ft^2 for the metric (center) car are shown in each case for 0^o yaw angle as determined by tests reported in Reference (5), Figure 37. As a result of these tests, the difference between the drag areas of (a) and (d) of 41 will be the drag area affected by proximity conditions. The smallest drag area of 20 will be used to compute the effective skin friction coefficient.

Some redundancy was deliberately introduced into the wind tunnel testing to serve as a check on the hypothesis that a simple rationale for treating the drag of freight cars in a train of vehicles can be used; as a result, there are certain inconsistencies among the results, partly attributable to the uncertainty of the value of the figure and partly attributable to the lack of validity of such a simple rationale. Nevertheless the block tests (11) demonstrated that the rationale was acceptably correct and that the effects of the

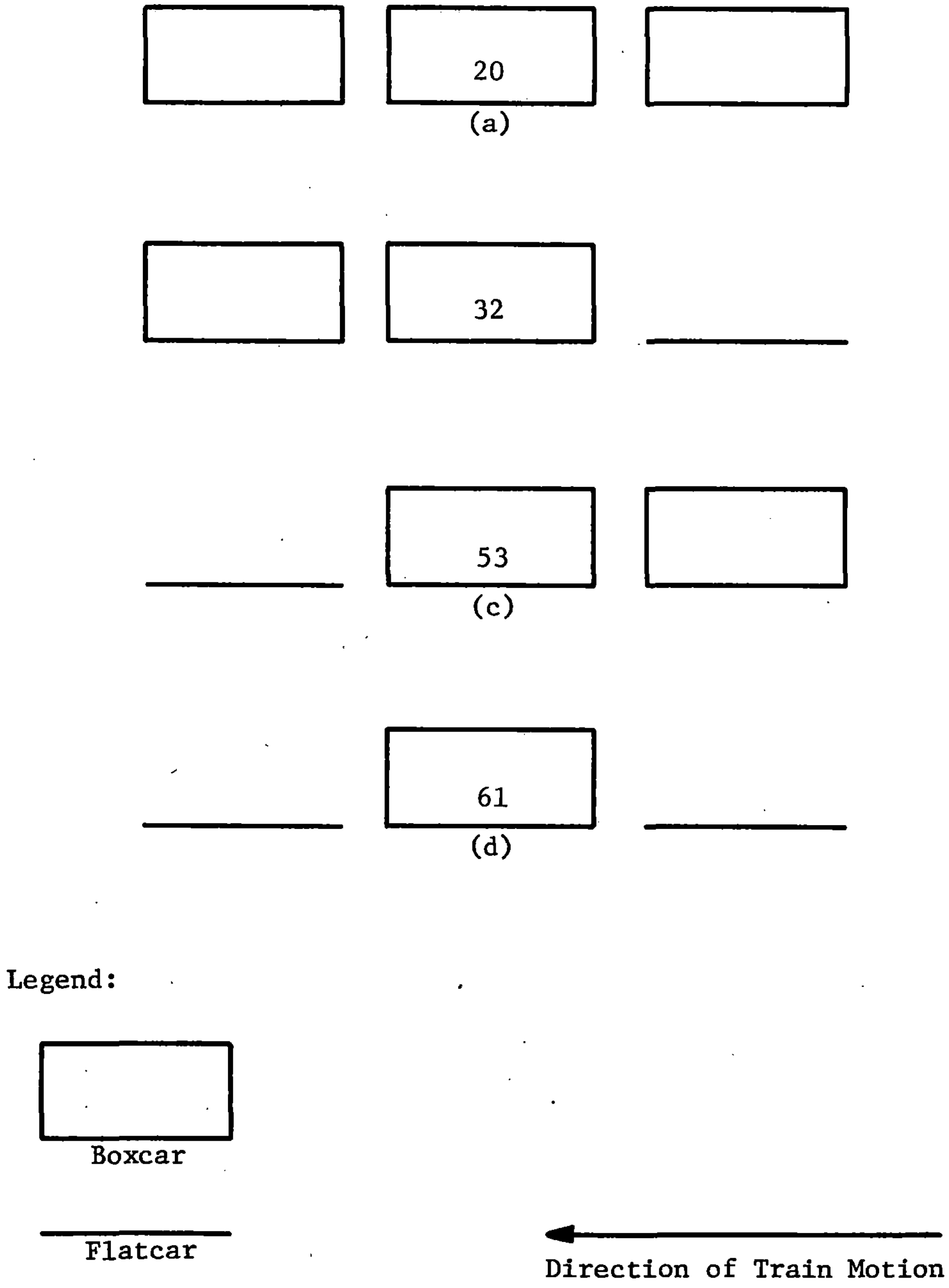

FIGURE B-3
DRAG AREAS FOR VARIOUS BOXCAR CONFIGURATIONS

leading and trailing blocks were reasonably independent. It may be noted from the data in Table B-I that there might be a slight dependence: the effect of the presence or absence of one shielding block is consistently greater (or at least equal) when the other shielding block is present. Whether this is a true effect or whether it is due to anomalies in the data is not known at this point. To avoid the dilemma posed by this slight inconsistency, an average value for the front and rear pressure effects will be taken. In all instances this results in an error on the value of this drag area for the intermediate configurations (those shielded or one end only) of less than ten percent difference from the reported value. In a train of vehicles, this should result in an error in the calculation of aerodynamic drag well below the expected uncertainty in the data from the wind tunnel itself.

If the calculation is now adjusted so that D_s, or the sum of $S + U + T$, is made equal to the drag area in the shielded position, the drag area in the unshielded position will also be correct, as 100 percent of the difference between them will be added by the calculation to D_s when the configuration approaches the unshielded one (infinite gap). A portion of the difference will be added at intermediate gaps; the functional relationship of the portion to the gap is as determined by other wind tunnel tests on wooden blocks and has been described by a smooth curve approximating the wind tunnel tests.

The drag area for two trucks has been determined to be, based on previous sources, 8.7 ft^2 (1). Similarly, a skin friction coefficient of .003 has been used for the underside of the vehicle, (1) so that the underside skin friction is then $.003 \cdot 10 \cdot \ell$, where 10 is the width of the vehicle in feet and ℓ is the length. (All vehicles have arbitrarily been assumed to be 10 feet wide.) The skin friction S will be given by $C_s \cdot s \cdot \ell$, where C_s is the skin friction coefficient, "s" is the effective sum of the height of two sides of

TABLE B-I

AERODYNAMIC DRAG PARAMETERS FOR VARIOUS TYPES OF ROLLING STOCK[1]

	Fig. No.	Drag Area, Ft² for Configuration				F + R (d - a)	Front Car Effect F		Rear Car Effect R		Average F(ft²)	Average R(ft²)	C_s
		a	b	c	d		Rear Car Present (c - a)	Rear Car Missing (d - b)	Front Car Present (b - a)	Front Car Missing (d - c)			
Boxcar	37	20	32	53	61	41	33	29	12	8	31	10	.0061
Hopper Car	47	40	55	75	85	45	35	30	15	10	32.5	12.5	.0238
Gondola	42	35	43	55	62	27	20	19	8	7	19.5	7.5	.0241
Flat Car	*[2]	19	19	19	19	0	0	0	0	0	0	0	.0104
Tank Car	46	30	35	39	43	13	9	8	5	4	8.5	4.5	.0108
Hi Cube Car	41	28	41[3]	67[3]	80	52	39	39	13	13	39	13	.0051
Twin TOFC	*[4]	66	78	78	83	17	12	5	12	5	8.5	8.5	.0170

[1] Figure numbers refer to Reference (5).

[2] Reference 6, Figure 52, Test 6. See Text for Comment.

[3] These data were computed from other tests of similar configuration.

[4] Values reflect the full scale tests rather than the wind tunnel tests.

the vehicle plus the width of the roof, and ℓ is the length. Given the drag area of the vehicle, we are then left with the following equation:

$$D_s = C_s \cdot s \cdot \ell + .003 \cdot 10 \cdot \ell + 8.7$$

Now since "ℓ" is listed as the vehicle length, it was not deemed advisable to adjust its value in order to satisfy the equation. Since "s" corresponds also with a physical dimension it seemed more reasonable to adjust the effective value of the skin friction coefficient C_s in order to make D_s equal the wind tunnel value.

Hence for each car, the actual lengths and values for "s" were inserted into this equation, together with the value for D_s in ft^2 from the wind tunnel tests, and a new effective value of skin friction coefficient was computed. Note that this technique is merely an artifice for making the residual drag (that not affected by shielding) equal to the results of the wind tunnel tests. It is not suggested that the value of the skin friction coefficient is actually different for each car; the coefficient merely represents something slightly more encompassing than simple skin friction over a smooth plate.

Table B-I displays the parameters of interest for each car for which the data were available. The data file for the computer program has been modified to reflect the values for these seven vehicles. The program data file presently is now set up to handle twenty-one different vehicles. Coefficients for other vehicles can be incorporated as the information becomes available.

4.4 Summary and Conclusions

The new aerodynamic drag data on conventional items of rolling stock have been incorporated for the vehicles of interest into the MITRE program for computing the fuel consumption of freight trains. The data have been incorporated in a manner designed to make the calculations reflect the actual drags as determined from the wind tunnel tests except in the case of the TOFC equipment, for which data from full scale measurements were used. From examination of the new data, it is likely that the magnitude of the discrepancy between measurements and predictions of fuel consumption will be reduced to a level where the remaining discrepancy can be attributed to the factors over which no control is possible and the impact of which cannot be accurately predicted.

APPENDIX C

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