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RAILROADS AND THE ENVIRONMENT: ESTIMATION OF FUEL CONSUMPTION IN RAIL TRANSPORTATION

Volume II - Freight Service Measurements

John B. Hopkins
A. T. Newfell

U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

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16. Abstract

Fuel consumption measurments have been carried out in cooperation with several railroads for a variety of types of revenue freight service. Intermodal operations have been emphasized, but this report also includes studies relating to branchline and general freight movements. The wide range of operating parameters examined includes train speed, weight, length, type, power-to-weight ratio, and terrain. In particular, this report describes the test conditions, operating parameters and fuel usage indices for 80 separate line-haul movements on six different railroads, covering 53,000 train miles. Trailer-On-Flatcar (TOFC) service predominates, but several manifest freights, two unit coal trains, and two COFC trains are included. Branchline service is also reported and analysed for six 174-mile round trips. In spite of considerable variation in relevant parameters and inherent imprecision in the data, the results are found to exhibit a basic consistency both internally and with past estimates.

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PREFACE

The research described in this report was carried out in the context of an overall project at the Federal Railroad Administration (FRA) to provide a technical basis for the improvement of rail transportation service, efficiency, and productivity. This project was sponsored and directed by the Office of Research and Development, Office of Freight Systems.

Volume I in this series (Report No. FRA-OR&D-75-74.I) applied a simplified physical model to a variety of rail transportation services, with the primary objectives of estimating sensitivity of fuel consumption to operating and equipment parameters. This document, Volume II, reports measured fuel usage for a wide range of freight trains. Volume III will present a comparison of these experimental measurements to computer simulations based upon the model of Volume I.

A. T. Newfell of the Transportation Systems Center (TSC) has had full responsibility for arranging and coordinating all railroad fuel measurements, and participated in many of the tests. J. Hopkins, also of TSC, had overall responsibility for direction of the project and for analysis and documentation of the results. Computer simulation work related to this project has been the responsibility of M. Hazel (TSC). The cooperation of several railroads, and particularly the effort of numerous individuals, is greatly appreciated. A partial listing of some of those people and railroads who have been especially helpful includes: C. A. Mennell, T. Wall, and T. Schmidt of the Missouri Pacific Railroad Company; J. Hillard, A. Schuck, and D. Propp of the Burlington Northern; W. O'Neill, R. Austill, and A. G. Newell of the Southern Pacific; J. Angold and D. Long of the Santa Fe Railway Company; D. Catalan, H. Patterson, and E. Rhine of the Union Pacific; W. Bolla and J. Lehman of the Illinois Central Gulf Railroad; and S. Culliford, A. McAdam, and D. Taylor of the Boston & Maine Corporation.

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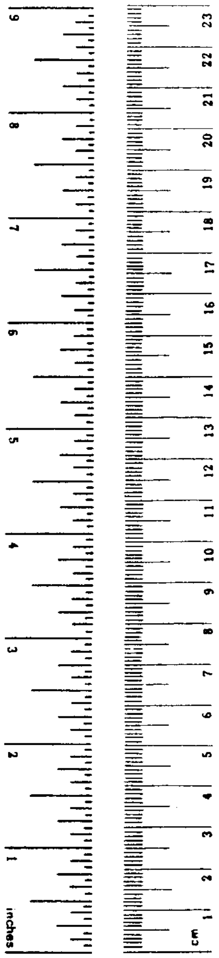
METRIC CONVERSION FACTORS

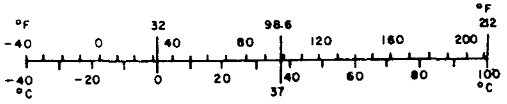
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

1.1 OBJECTIVE

In recent years, the subject of fuel consumption in rail transportation of freight has received considerable attention. As fuel oil has changed from a relatively minor cost of train operation to an expensive and limited resource, railroads and Government alike have become increasingly interested in the characterization and improvement of railroad fuel efficiency. In the other major general freight mode, namely the highways, there is a basic consistency to operations - roads, vehicles, and speeds vary sufficiently little that it can be meaningful for many purposes to characterize energy efficiency of the mode by a single number. However, different railroad operations may be carried out at running speeds from less than 20 to greater than 70 mph, with power-to-weight ratios ranging from less than one HP/ton to five or more. The rolling stock - gondolas, box cars, auto-rack cars, Trailer-On-Flatcar (TOFC), Container-On-Flatcar (COFC), tank cars, hopper cars (covered or uncovered), etc., can vary greatly in aerodynamic drag and net/tare weight ratios.

Thus, it can be both futile and erroneous to attempt to develop a single number to characterize the fuel or energy intensiveness of railroad transportation of freight. An average value, no matter how achieved, can be highly misleading if applied to a specific case differing in some crucial factor. Even for relatively general policy purposes it is necessary to have fuel efficiency values for each of several "typical" and extreme cases. Indeed, this need alone warrants a meaningful effort to determine fuel consumption under various circumstances, and represents one major objective of the research described here.

Often, however, it is desirable to be able to make relatively specific decisions concerning policy, operating procedure, or even mode choice. Such questions can arise for transportation companies, shippers, and governmental bodies. In these cases, it becomes important to have available the capability to estimate fuel usage with reasonable accuracy for a variety of scenarios. The development of appropriate computer models and "Train Performance Calculators" (TPC's) has been a common solution to this type of situation. These simulations can be relatively elaborate and are inherently based upon a small number of rather old measurements of train resistance (the force required to pull a train under given circumstances) and normally include a number of important simplifying assumptions. Typical railroad uses of TPC's include examination of the sensitivity to various operational changes of train running time and fuel necessary in cases where high precision in absolute numbers is usually not required. Although users generally indicate that the results are satisfactory for their purposes, few attempts have been made or published which actually establish the accuracy of current TPC's. For this reason, it has been judged appropriate that the U.S. Department of Transportation undertake to obtain actual fuel consumption data under sufficiently realistic and well-defined circumstances to permit calibration and validation of Government (and other) computer simulations. Only then can a wide variety of questions be answered readily and simply without recourse to large specific studies or dependence upon educated guesses. This, then, has been a second major goal of the work to be described here.

The third objective of this research has been a better characterization of fuel efficiency in TOFC and COFC operations. This has been an area in which there has been considerable controversy, and which bears upon significant policy decisions. In particular, an attempt has been made to supply the basic information required to support FRA intermodal systems engineering efforts.

1.2 APPROACH

In order that these objectives be met, accurate and well documented measurements of locomotive fuel consumption are necessary under a variety of circumstances. For this information to be valid and credible, it must be obtained during actual revenue operations of railroads. Since the business of a railroad is moving freight, rather than conducting fuel measurements, this activity has required securing the active cooperation of railroads and developing test plans which were compatible with their normal practices and operations. Given the number of parameters which must be known or controlled, this has been a complex undertaking, and in different cases has been achieved in a variety of ways, at several different levels of detail. In essence, it has been necessary to depend to a large degree upon "targets of opportunity" operations in which consists, routes, fueling procedures, speeds, test equipment, and interest on the part of the railroad have been suitable to the generation of data meeting the stated needs.

Ideally, for meaningful generalization as well as for calibration and validation of simulations, detailed data is required. This falls into three categories: train, route, and operating scenario. Information concerning the train includes number and type of locomotives (weight, power, etc.), and number, type, and weight of cars. Route information is basically track data: curvature and grade. Necessary details of the operation include speed, time, and fuel consumed (all recorded frequently), and information on stops, wind, etc. Collection of this much data is complex and expensive, and requires in-motion scales for weighing the train, fuel meters on the locomotives, and a well-instrumented test car, with a cooperative and interested crew, as part of the train consist.

In practice, this degree of precision is quite expensive and often not attainable. However, much can be learned from less comprehensive data. For example, a standard and readily attainable computer-generated consist list, the actual operating schedule, and the total fuel pumped into the locomotive can provide meaningful, if imprecise, estimates of the overall fuel efficiency in various operations. Since this approach is relatively inexpensive, it may be possible to make numerous runs of this type, thereby developing averages in which one can have confidence.

A variety of cases occurred in the measurement project in which the detail, accuracy, and quantity of the data collected lie between these extremes. Although the special need in this project was for TOFC/COFC data, it has also proven feasible to obtain data for several other categories of general freight, unit coal trains, and light-traffic branchline operations. Tests that have been carried out incorporate considerable variety in terrain, speeds, consists and power-to-weight ratios.

1.3 CONSTRAINTS

The experimental findings and analysis to be described below must be viewed from a realistic perspective. In general, it is seldom possible to collect data sufficient in quantity and accuracy to generate truly precise characterization of rail-freight transportation energy intensiveness in a specific situation. Weighing of cars is time-consuming and often not possible. Determination of net weights requires detailed examination of a large number of bills of lading. Changes in consist, whether planned or the result of mechanical problems, can also be difficult to record precisely in normal operations and very tedious to analyse. (This is particularly true of TOFC/COFC operations, in which one must also obtain records concerning the weight and contents of the trailer or container.)

A variety of practical factors make high accuracy in fuel measurement attainable only through installation of flow meters on each locomotive, and it is normally difficult and expensive to keep a group of metered locomotives together for a sequence of tests. Further, diesel engines are designed such that a fuel pump supplies fuel to the engine at a constant rate, regardless of throttle setting, and all fuel not consumed is returned to the tank. Thus, measurement of fuel consumption requires installation of meters in both the supply and the return lines, with data recorded for each. At low throttle settings, one is faced with measuring a small difference between two relatively large numbers, so that meter inaccuracies can have disproportionate effect. One possible source of errors of this type is the heating of the oil as it passes through the engine, changing its volume.

Fuel can vary significantly in energy content, which can be determined accurately only through laboratory analysis. Changes in barometric pressure and temperature can also affect the efficiency of combustion. Accurate recording of speed variations, including all stops and slowdowns, is labor-intensive in collection and/or analysis, but necessary to any attempt to associate fuel consumption with velocity (large variations in speed are characteristic of most rail operations). At higher speeds, for which aerodynamic forces become particularly significant, winds can be especially important, but are difficult to monitor, and may vary markedly over the length of a train or a particular run.

Even if all these and several other parameters can be determined with high precision, and one succeeds in the exact characterization of a specific train movement, there remains the problem of generalization. Some scheduled trains vary little from day to day, such as in expedited TOFC or unit train service, but the more common case includes substantial differences in weather, delays, switching, track conditions, power-to-weight ratio, etc., as well as the effects of the train-handling practices of different engineers.

2. MEASUREMENTS AND RESULTS

2.1 BRANCHLINE OPERATIONS (MISSOURI PACIFIC)

During November, 1974, measurements were carried out by the Missouri Pacific Railroad on a branch line between Mcgehee, Arkansas and Delhi, Louisiana, a distance of 87 miles. Speeds over different portions of the basically level run were generally eigher 10 MPH or 25 MPH, with consists ranging from 0 to 38 cars, and a single locomotive. Fuel metering devices were installed in the input and return fuel lines of the EMD GP-7 normally assigned to this run. For a period of two weeks (six round trips), the train crew was accompanied by a Missouri Pacific (MoPac) staff engineer, who periodically noted fuel meter readings, time of day, consist, and type of movement. The consist list for the runs, track charts, and speed recorder tapes provided additional information.

The consist lists were examined to determine average weights (estimated by MoPac) for empty and loaded cars for each day. Empty and loaded car miles could then be converted to gross and net ton miles for three segments of the routes, comprised of sections for which speeds and train make-up were relatively constant. With fuel consumption and ton-miles known, it is a simple matter to calculate various indices of efficiency. Results of this test series are shown in Table 1, based upon data corrected as described below. Only fuel consumed in running and switching is considered in that table; idling is excluded. For the six round trips in this test, approximately 40 percent of the fuel consumed was associated with idling and 15 percent with switching activities; only 45 percent was required for moving the train between stopping points.

The fuel rate at idle as measured was found to be rather high (approximately 10 gallons/hour for a 1600 HP locomotive), suggesting that meter inaccuracies could be contributors (as mentioned in the previous section) to overstated fuel usage. Thus, "adjusted" calculations were also made, under the assumption of a +1 percent

TABLE 1. MISSOURI PACIFIC FUEL MEASUREMENTS (BRANCHLINE SERVICE)

RUN CODE	HP	NR OF CARS			NR OF TRLRS	WEIGHT		HP/ TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL		CONSIST TYPE
		BOX	TTX	TOTAL		GR TR	NET					GR TR	NET	
MOP 1-1	1600	37	0	38	0	1777	645	0.9	39	27.0	132	524	190	BOX
MOP 1-2	1600	7	0	8	0	299	72	5.4	19	24.0	12	470	113	BOX
MOP 1-3	1600	3	0	4	0	120	0	13.3	29	10.0	31	112	0	BOX
MOP 1-4	1600	20	0	21	0	1430	788	1.1	39	27.0	131	423	233	BOX
MOP 1-5	1600	0	0	1	0	30	0	53.3	19	23.0	19	30	0	BOX
MOP 1-6	1600	2	0	3	0	91	0	17.6	29	10.0	29	90	0	BOX
MOP 2-1	1600	3	0	4	0	159	42	10.1	39	27.0	32	191	51	BOX
MOP 2-2	1600	2	0	3	0	131	33	12.2	19	24.0	18	135	34	BOX
MOP 2-3	1600	4	0	5	0	165	0	9.7	29	10.0	33	143	0	BOX
MOP 2-4	1600	26	0	27	0	830	72	1.9	39	27.0	93	345	30	BOX
MOP 2-5	1600	10	0	11	0	351	44	4.6	19	23.0	29	222	28	BOX
MOP 2-6	1600	6	0	7	0	216	23	7.4	29	10.0	41	153	16	BOX
MOP 3-1	1600	4	0	5	0	340	165	4.7	39	27.0	38	347	168	BOX
MOP 3-2	1600	3	0	4	0	266	137	6.0	19	24.0	17	296	153	BOX
MOP 3-3	1600	3	0	4	0	335	206	4.8	29	10.0	47	203	125	BOX
MOP 3-4	1600	22	0	23	0	1158	546	1.4	39	27.0	118	382	180	BOX
MOP 3-5	1600	3	0	4	0	203	92	7.9	19	23.0	18	214	97	BOX
MOP 3-6	1600	3	0	4	0	183	81	8.7	29	10.0	39	136	60	BOX
MOP 4-1	1600	19	0	20	0	758	139	2.1	39	27.0	96	306	56	BOX
MOP 4-2	1600	3	0	4	0	124	0	12.9	19	24.0	16	146	0	BOX
MOP 4-3	1600	1	0	2	0	61	0	26.2	29	10.0	32	55	0	BOX
MOP 4-4	1600	6	0	7	0	346	157	4.6	39	27.0	59	229	104	BOX
MOP 4-5	1600	2	0	3	0	153	65	10.5	19	23.0	20	139	59	BOX
MOP 4-6	1600	1	0	2	0	110	41	14.5	29	10.0	28	111	42	BOX
MOP 5-1	1600	14	0	15	0	1139	621	1.4	39	27.0	114	387	211	BOX
MOP 5-2	1600	4	0	5	0	219	49	7.3	19	24.0	22	184	41	BOX
MOP 5-3	1600	2	0	3	0	110	0	14.5	29	10.0	44	72	0	BOX
MOP 5-4	1600	20	0	21	0	828	184	1.9	39	27.0	123	261	58	BOX
MOP 5-5	1600	6	0	7	0	381	158	4.2	19	23.0	28	257	107	BOX
MOP 5-6	1600	3	0	4	0	166	39	9.6	29	10.0	44	110	26	BOX
MOP 6-1	1600	11	0	12	0	482	92	3.3	39	27.0	74	253	48	BOX
MOP 6-2	1600	6	0	7	0	297	73	5.4	19	24.0	27	205	50	BOX
MOP 6-3	1600	5	0	6	0	467	276	3.4	29	10.0	67	200	118	BOX
MOP 6-4	1600	17	0	18	0	694	175	2.3	39	27.0	92	293	74	BOX
MOP 6-5	1600	4	0	5	0	217	75	7.4	19	23.0	23	174	60	BOX
MOP 6-6	1600	4	0	5	0	217	74	7.4	29	10.0	52	120	41	BOX
AVG	1600	0	0	9	0	413	143	8.6	29	20.2	51	272	96	

error on the input meter and -1 percent for the return line. This correction reduced the measured fuel rate at idle to a more reasonable 5 gal/hour. Results are plotted in Figures 1 and 2 for both "raw" and "adjusted" data respectively. These graphs are based on running fuel only. Differences become small for the larger trains since the assumed error mechanism is important only at low fuel rates. Although a number of uncertainties existed in the test situation which lead to considerable scatter in the data, a basic consistancy is observed in shape of the curves. It is to be noted that it is only in the range below 400-500 gross tons that there is significant variation from the general linehaul situation. This is quite reasonable theoretically; for the longer trains the weight of the caboose and locomotive(s) becomes a less significant portion of total weight, and the power consumed by locomotive accessories (about 100 HP) becomes small in comparison with that required to overcome train resistance.

2.2 LONG-DISTANCE TOFC (BURLINGTON NORTHERN)

In June 1975, the Burlington Northern Railroad collected a variety of information relating to fuel usage on a scheduled TOFC train operating daily between Chicago and Seattle. This train normally carried a number of cars the full distance, with other cars being set out and picked up at St. Paul, Fargo, Minot, Havre, and Spokane. Its scheduled running time was 49 hours, 15 minutes, for the 2200 mile trip. With the exception of an occasional mail car, it was purely TOFC, with almost all trailers loaded. No empty cars were hauled.

The data obtained included computer-generated consist lists (including estimated car weights) for departure from each major terminal area; the conductor's log sheet, showing arrival and departure times, consist, and delay reports; tapes from on-board speed recorders; and total fuel added at Minot and Seattle. The trains left Chicago with full tanks, and fuel was added only at those two points, at which accurate metering was available. Condensed track profiles were provided for the entire route. On several occasions, power changes or other circumstances limited the test to the Chicago-Minot portion.

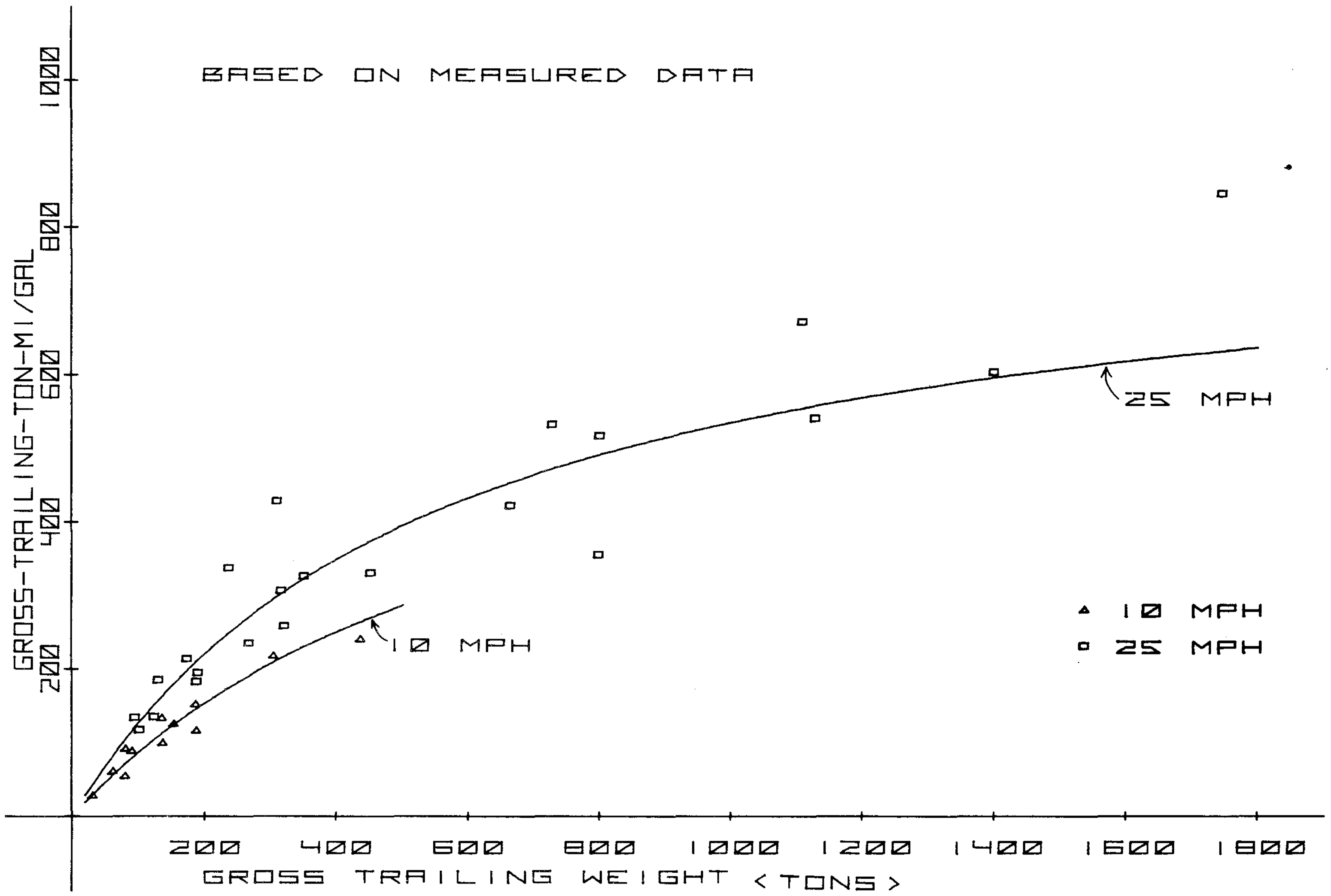

FIGURE 1. BRANCHLINE FUEL EFFICIENCY (BASED ON DATA AS MEASURED)

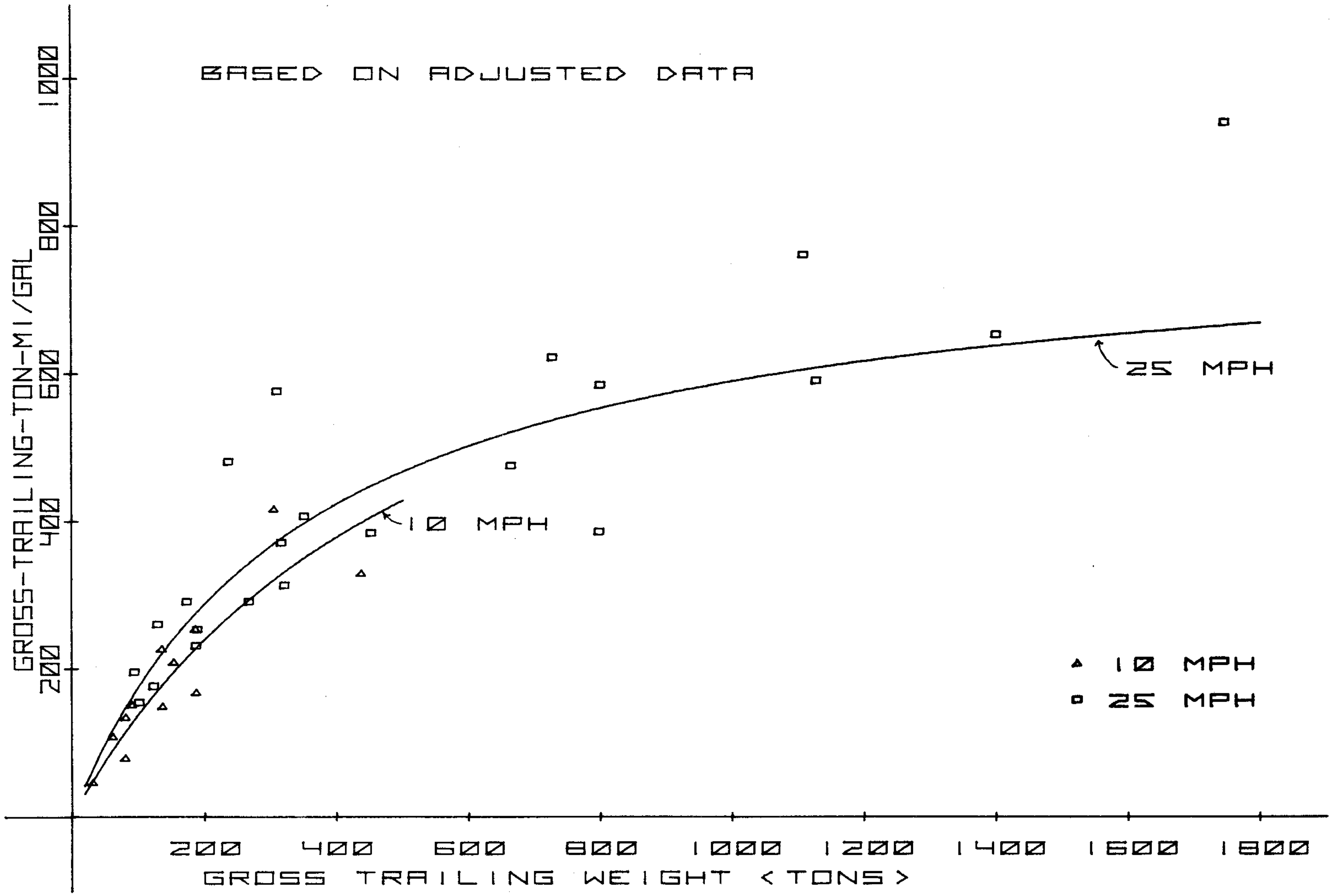

FIGURE 2. BRANCHLINE FUEL EFFICIENCY (MEASURED DATA ADJUSTED IN ACCORDANCE WITH ASSUMED METER ERRORS)

The data from these runs were analyzed by subdivision into sections chosen to accomodate all significant consist changes, with calculation of average running speeds and train weight and size for each segment. The typical consist was three locomotives (generally 3600 HP SD-45's) and 15 to 40 trailer-carrying flatcars, yielding gross trailing weights of 1100 to 2800 tons, and power-to-weight ratios of 4 to 10 HP/ton. The TTX cars normally carried either two loaded trailers or one loaded trailer. Data were provided for a total of 13 Chicago-Minot runs (922 miles), and in 6 cases for the 1257-mile continuation to Seattle. Characteristics and results of these runs are presented in Table 2. Since minor changes in consist occurred in the course of the two runs, the listed number of cars is an average (mileage-weighted) value. These trains operated at 50 to 60 MPH and delivered an overall average of 425 gross-trailing-ton-miles per gallon. The speeds indicated in Table 2 are a point-to-point average, with known stops excluded. The car weights provided were the values carried in the BN computer for each car type, since actual weighing was not possible. These figures were judged by railroad personnel to have an uncertainity of about 10 percent. Net weights are estimated based upon the assumption of 15 tons per loaded trailer, 50 tons per box car; these values are consistent with findings in other tests, but could be significantly in error in any given situation.

For pure TOFC operations, a useful index can be calculated even without accurate weights. From the consist lists it is possible to determine the number of trailers carried. Similarly, the fuel figures may be considered to be accurate to within a few percent. Thus, one can readily determine the "trailer-miles per gallon" with good accuracy. This quantity is the one appropriate to comparison with highway movement of trailers, for which it is equivalent to truck miles per gallon (for single-trailer operations). The overall average for these runs was 10.2 trailer-miles per gallon, with virtually all trailers loaded. It should be noted that the average load carried may not be the same for the rail and highway cases.

TABLE 2. BURLINGTON NORTHERN FUEL CONSUMPTION MEASUREMENTS, FIRST SERIES

MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: TOFC
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TON" = "HORSEPOWER PER GROSS TRAILING TON"

RUN CODE	HP	NR OF CARS BOX	TTX	TOTAL	NR OF TRLRS	WEIGHT GR TR	NET	HP/ TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL GR TR	NET	TR-MI /GAL
BN 1-1	10800	1	36	38	65	2670	1012	4.0	922	51.8	5498	448	170	10.9
BN 1-2	10800	0	33	34	60	2390	905	4.5	1257	50.8	4601	653	247	16.5
BN 2-1	10200	1	23	25	42	1804	658	5.6	922	56.7	3985	417	152	9.8
BN 2-2	10200	0	18	19	33	1479	501	6.9	1257	51.2	4050	459	156	10.4
BN 3-1	10500	1	33	35	63	2611	982	4.0	922	56.4	5170	466	175	11.2
BN 3-2	10500	0	27	28	49	2127	731	4.9	1257	51.4	4998	535	184	12.3
BN 4	10800	0	35	36	64	2718	957	4.0	922	55.2	4808	521	184	12.2
BN 5	10500	0	22	23	40	1513	594	6.9	922	57.3	3952	353	139	9.2
BN 6-1	10800	0	18	19	33	1221	491	8.9	922	54.1	3268	344	138	9.2
BN 6-2	10800	0	16	17	29	1038	428	10.4	1257	49.9	3115	419	173	11.5
BN 7	10200	1	24	26	40	2641	639	3.9	922	54.3	5646	431	104	6.5
BN 8-1	10200	1	30	32	53	2091	831	4.9	922	56.4	5605	344	137	8.7
BN 8-2	10200	0	25	26	41	1671	618	6.1	1257	50.2	5559	378	140	9.3
BN 9	10200	1	32	34	57	2356	897	4.3	922	54.2	5398	402	153	9.8
BN 10	13800	1	37	39	70	2675	1087	5.2	922	53.1	7124	346	141	9.0
BN 11	10500	1	35	36	65	2585	1018	4.1	922	54.8	5360	445	175	11.2
BN 12-1	9900	0	21	22	35	1425	525	6.9	922	55.5	3618	363	134	8.9
BN 12-2	9900	0	16	17	29	1283	428	7.7	1257	46.4	3674	439	146	9.8
BN 13	10800	0	15	16	26	1055	386	10.2	922	54.6	3562	273	100	6.6
AVG	10611	0	26	27	46	1966	720	6.0	1028	53.4	4684	425	155	10.1

TOTALS: 19 RUN SEGMENTS, 19528 MILES

AVG. TON-MI/GAL = TOTAL TON-MI/TOTAL GALLONS; SAME FOR TR-MI/GAL
OTHER AVERAGES NOT WEIGHTED

Information concerning eight further runs was provided in early 1976. At this time, operations had changed so that only Chicago-Minot data could be reported, and the train typically consisted of 5 to 15 box cars in addition to the TTX cars. These results are also presented in Table 3; the overall fuel usage was close to that for the previous case, 442 gross-trailing-ton-miles per gallon.

2.3 DETAILED MEASUREMENTS FOR VARIOUS CONSISTS (SOUTHERN PACIFIC)

During July 1975, the Southern Pacific Transportation Company collected detailed data concerning operational and fuel consumption characteristics for eight trains (four in each direction) running between Roseville and Bakersfield, California, a distance of 287 miles. The terrain - the Great Central Valley of California - is relatively flat. On most trips, several stops occurred at which minor changes in consist were carried out. All trains were weighed at Stockton, California, on in-motion scales, and the weights recorded. The power consist was unchanged for the eight runs, and comprised two SD-45 locomotives and a dynamometer test-car housing the test crew and measurement apparatus. Fuel consumption was determined with calibrated meters connected from the test car to each of the diesel units. Prior to testing, both locomotives were checked thoroughly to insure that they were in proper operating condition, and the meters were calibrated.

The basic test procedure consisted of recording distance traveled, milepost, fuel consumed, speed, time, and other factors at 10-mile intervals, as well as at stops or otherwise noteworthy points. The measured gross weights of the cars were subsequently added manually to computer-generated consist lists, and equipment-register car empty weights were subtracted to obtain net weights. All consist changes were carefully noted.

Three types of trains were involved. Two runs consisted of TOFC only (from 29 to 47 cars), carrying loaded trailers predominantly. These relatively light trains (2200 to 3600 tons) operated at power-to-weight ratios of 2 to 3 HP per gross trailing

TABLE 3. BURLINGTON NORTHERN FUEL CONSUMPTION MEASUREMENTS, SECOND SERIES

MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: ALL
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TON" = "HORSEPOWER PER GROSS TRAILING TON"

RUN CODE	HP	NR OF CARS BOX	TTX	TOTAL	NR OF TRLRS	WEIGHT GR TR	NET	HP/ TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL GR TR	NET	CONSIST TYPE
BN 22	10800	10	44	55	84	4291	1694	2.5	922	48.1	6311	627	247	MIXED
BN 23	9600	6	19	26	33	1861	795	5.2	922	50.4	3300	520	222	MIXED
BN 24	10200	8	9	18	16	1128	636	9.0	922	51.7	3240	321	181	MIXED
BN 25	10200	6	38	45	70	3177	1313	3.2	922	51.7	6631	442	183	MIXED
BN 26	10200	13	39	53	73	2775	1622	3.7	922	53.1	7958	322	188	MIXED
BN 27	10200	16	34	51	63	1958	1631	5.2	922	47.6	6320	286	238	MIXED
BN 29	10200	6	45	52	85	3744	1544	2.7	922	50.2	6307	547	226	TOFC
BN 30	9600	20	22	43	40	2813	1580	3.4	922	49.7	5394	481	270	MIXED
BN 31	9600	11	24	36	42	2284	940	4.2	922	51.7	4430	475	196	MIXED
BN 33	9600	10	46	57	82	3556	1625	2.7	922	48.5	7622	430	197	MIXED
AVG	10020	0	32	44	58	2759	1338	4.2	922	50.3	5751	442	214	

TOTALS: 10 RUN SEGMENTS, 9220 MILES

AVG. TON-MI/GAL = TOTAL TON-MI/TOTAL GALLONS
OTHER AVERAGES NOT WEIGHTED

NOT REPRODUCIBLE

ton, with speed often in the range of 50 to 60 MPH or higher. Four other runs involved heavy mixed-freight trains - two of over 10,000 tons, and two of 5000 - 6000 tons, operating at .7 to 1.4 HP per gross trailing ton, and moving at relatively low speeds. The remaining two runs were intermediate cases - about 30 TTX cars, mostly loaded, combined with 34 to 48 loaded freight cars. For analysis the four round trips were divided into the 13 segments listed in Table 4, based on uniformity of consists. Results are presented in Table 5.

The TOFC-only service, with an average of 37.5 TTX cars carrying 53.7 loaded trailers, delivered 13.2 trailer-miles per gallon, with most of the trailers loaded. The figure for net-ton-miles per gallon was 181, with a gross figure of 599, substantially higher than that for the Burlington Northern tests. (The BN runs were partially on mountainous terrain, and involved significantly higher ratios of power-to-weight.) The heavy general-freight trains moved at an average of 449 net-ton-miles per gallon (956 gross-trailing- ton-miles per gallon), and the mixed-consist trains showed 206 net, 672 gross.

2.4 LONG-DISTANCE DETAILED MEASUREMENTS (SANTA FE)

In the first half of 1976, the Santa Fe Railway Company carried out detailed measurements during three round-trips between Kansas City, Kansas and Los Angeles or Barstow, California. These tests, included two TOFC trains and one consisting primarily of box cars, hauled by either 3 or 4 SD-45 locomotives. Average speeds overall were in the range of 45 - 50 MPH, with running speeds for the TOFC trains reaching 70 MPH. A test car, located behind the power consist, was always used, equipped with a variety of instruments and data processing and recording equipment. (See Figures 3, 4 and 5.) Speed, distance, throttle setting (notch), and fuel consumption for each locomotive were recorded on magnetic tape, as were wind velocity and direction (relative to the test car). Consist changes were few, typically involving removal of bad-order cars. The first TOFC train was allowed 70 MPH whenever speed limits permitted; the second was allowed to "drift" to 70

TABLE 4. SOUTHERN PACIFIC TEST RUNS

SUMMARY OF FUEL CONSUMPTION RUNS

RUN CODE	CARS L	CARS E	CONSIST TYPE	GR TR TONS	HP/ TON	DIST (MI)	ROUTE (ORIGIN - DEST.)
SP 1-1	26	5	TOFC	2233	3.2	60	ROSEVILLE - STOCKTON
SP 1-2	27	5	TOFC	2347	3.1	115	STOCKTON - FRESNO
SP 1-3	28	5	TOFC	2298	3.1	112	FRESNO - BAKERSFIELD
SP 2-1	74	2	MIXED	4681	1.5	112	BAKERSFFIELD - FRESNO
SP 2-2	76	2	MIXED	4838	1.5	175	FRESNO - ROSEVILLE
SP 3-1	118	22	BOX	10399	0.7	287	ROSEVILLE - BAKERSFIELD
SP 4-1	35	83	BOX	5876	1.2	157	BAKERSFIELD - LINGARD
SP 4-2	34	83	BOX	5744	1.3	130	LINGARD - ROSEVILLE
SP 5-1	98	30	BOX	8960	0.8	19	ROSEVILLE - FLORIN
SP 5-2	99	37	BOX	9227	0.8	268	FLORIN - BAKERSFIELD
SP 6-1	40	69	BOX	5291	1.4	287	BAKERSFIELD - ROSEVILLE
SP 7-1	36	3	TOFC	2787	2.6	60	ROSEVILLE - STOCKTON
SP 7-2	45	3	TOFC	3584	2.0	227	STOCKTON - BAKERSFIELD
SP 8-1	74	2	MIXED	4643	1.5	227	BAKERSFIELD - STOCKTON
SP 8-2	64	2	MIXED	4161	1.7	60	STOCKTON - ROSEVILLE

TABLE 5. SOUTHERN PACIFIC FUEL CONSUMPTION MEASUREMENTS

MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: ALL
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TON" = "HORSEPOWER PER GROSS TRAILING TON"

RUN CODE	HP	NR OF CARS BOX	TTX	TOTAL	NR OF TRLRS	WEIGHT GR TR	NET	HP/ TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL GR TR	NET	CONSIST TYPE
SP 1-1	7200	0	29	31	49	2233	618	3.2	60	55.5	314	426	118	TOFC
SP 1-2	7200	0	30	32	50	2347	685	3.1	115	53.1	477	566	165	TOFC
SP 1-3	7200	0	31	33	50	2298	596	3.1	112	42.0	430	599	155	TOFC
SP 2-1	7200	48	26	76	50	4681	1605	1.5	112	48.0	727	721	247	MIXED
SP 2-2	7200	48	28	78	53	4838	1674	1.5	175	38.2	1194	709	245	MIXED
SP 3-1	7200	138	0	140	0	10399	5760	0.7	287	32.2	2680	1114	617	BOX
SP 4-1	7200	116	0	118	0	5876	2135	1.2	157	37.7	1042	885	322	BOX
SP 4-2	7200	115	0	117	0	5744	2102	1.3	130	30.6	937	797	292	BOX
SP 5-1	7200	126	0	128	0	8960	4787	0.8	19	25.3	192	888	474	BOX
SP 5-2	7200	134	0	136	0	9227	4833	0.8	268	32.1	2385	1037	543	BOX
SP 6-1	7200	107	0	109	0	5291	1708	1.4	287	28.2	1957	776	250	BOX
SP 7-1	7200	0	37	39	65	2787	794	2.6	60	30.0	303	552	157	TOFC
SP 7-2	7200	0	46	48	83	3584	1172	2.0	227	40.1	1218	668	218	TOFC
SP 8-1	7200	34	40	76	76	4643	1214	1.5	227	43.9	1607	656	171	MIXED
SP 8-2	7200	34	30	66	56	4161	1214	1.7	60	32.7	453	551	161	MIXED
AVG	7200	0	20	82	35	5138	2060	1.8	153	38.0	1061	825	343	

TOTALS: 15 RUN SEGMENTS, 2296 MILES

AVG. TON-MI/GAL = TOTAL TON-MI/TOTAL GALLONS
OTHER AVERAGES NOT WEIGHTED

NOT REPRODUCIBLE

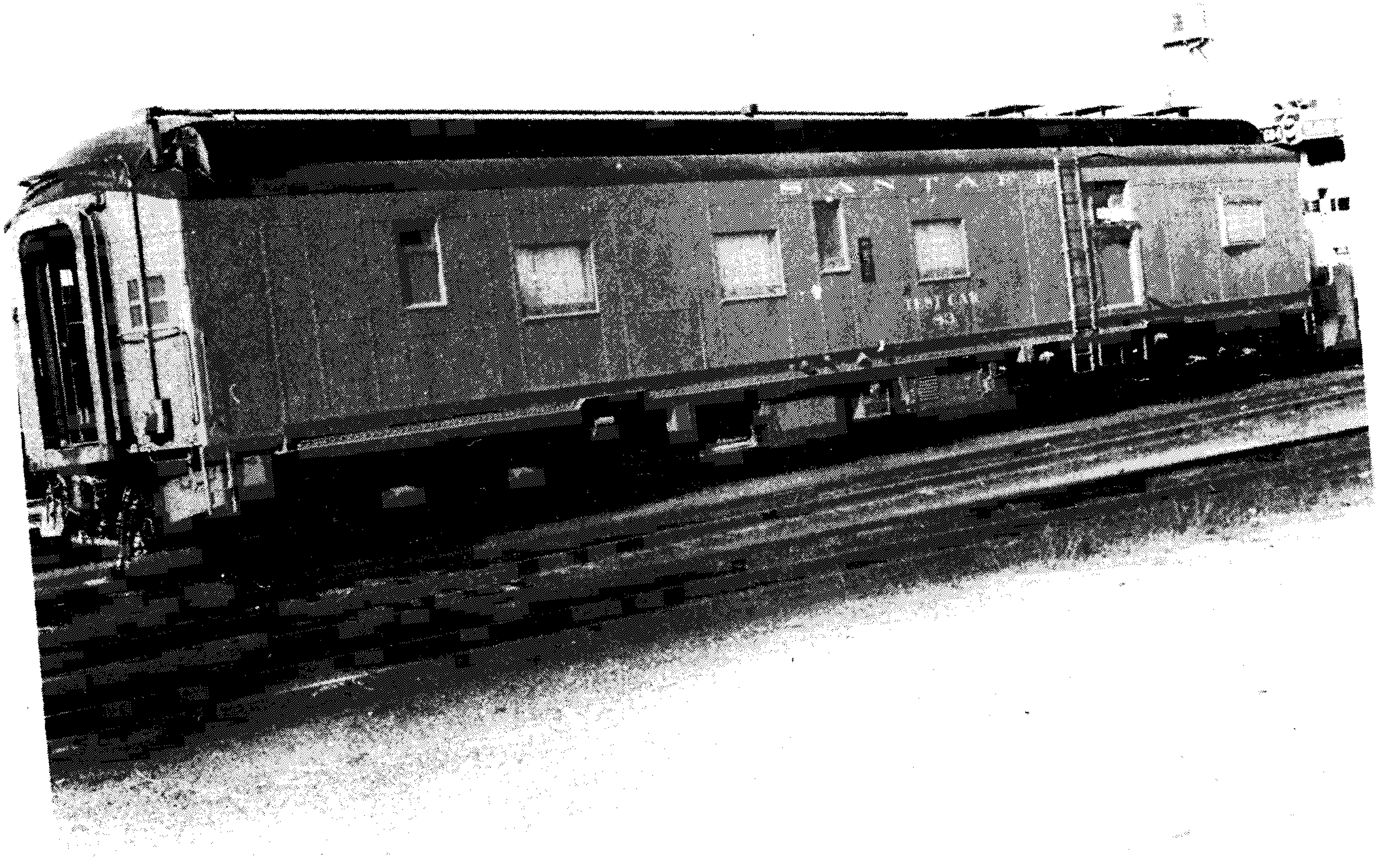

FIGURE 3. ATSF TEST CAR (EXTERIOR VIEW)

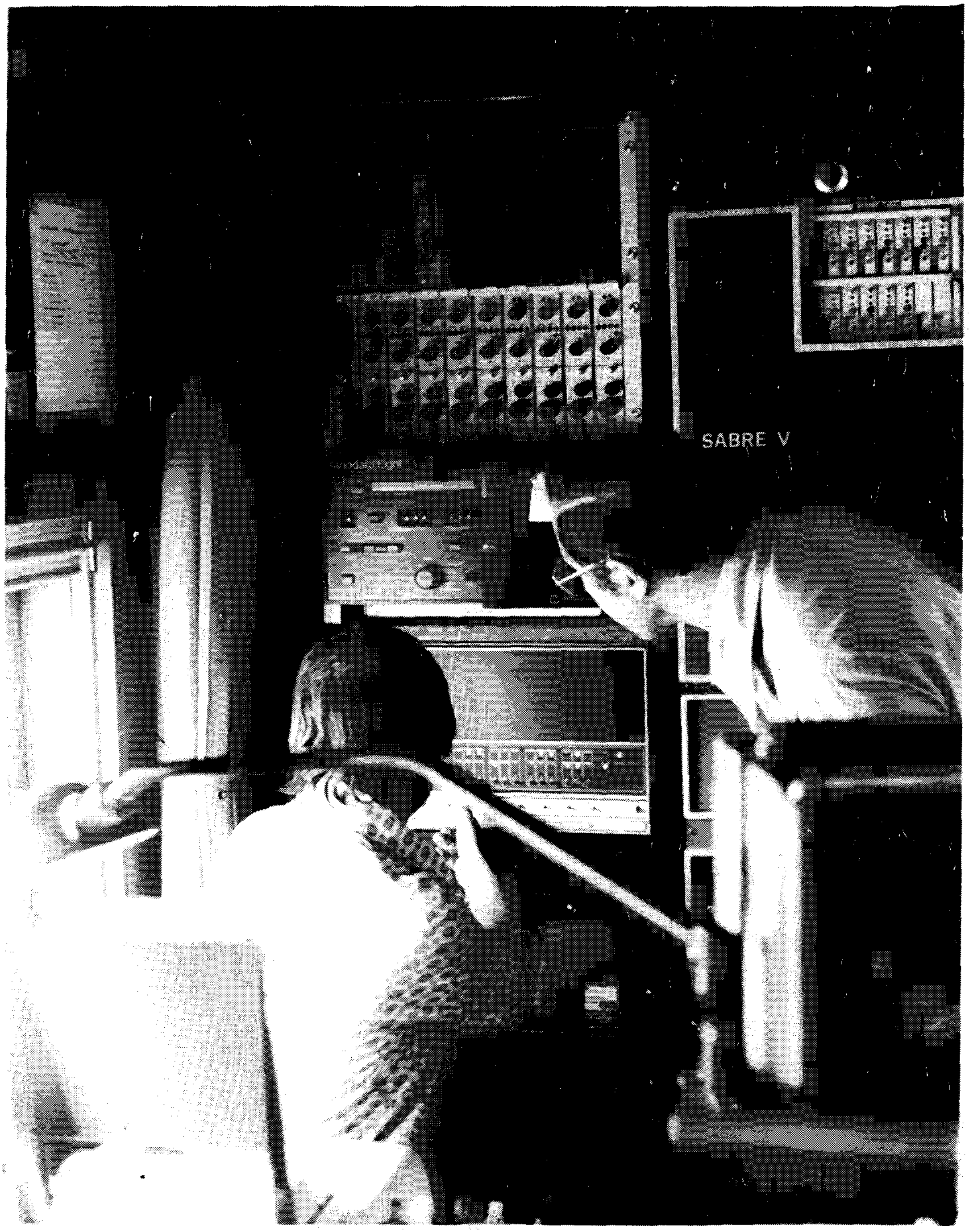

FIGURE 4. ATSF TEST CAR (INTERIOR VIEW)

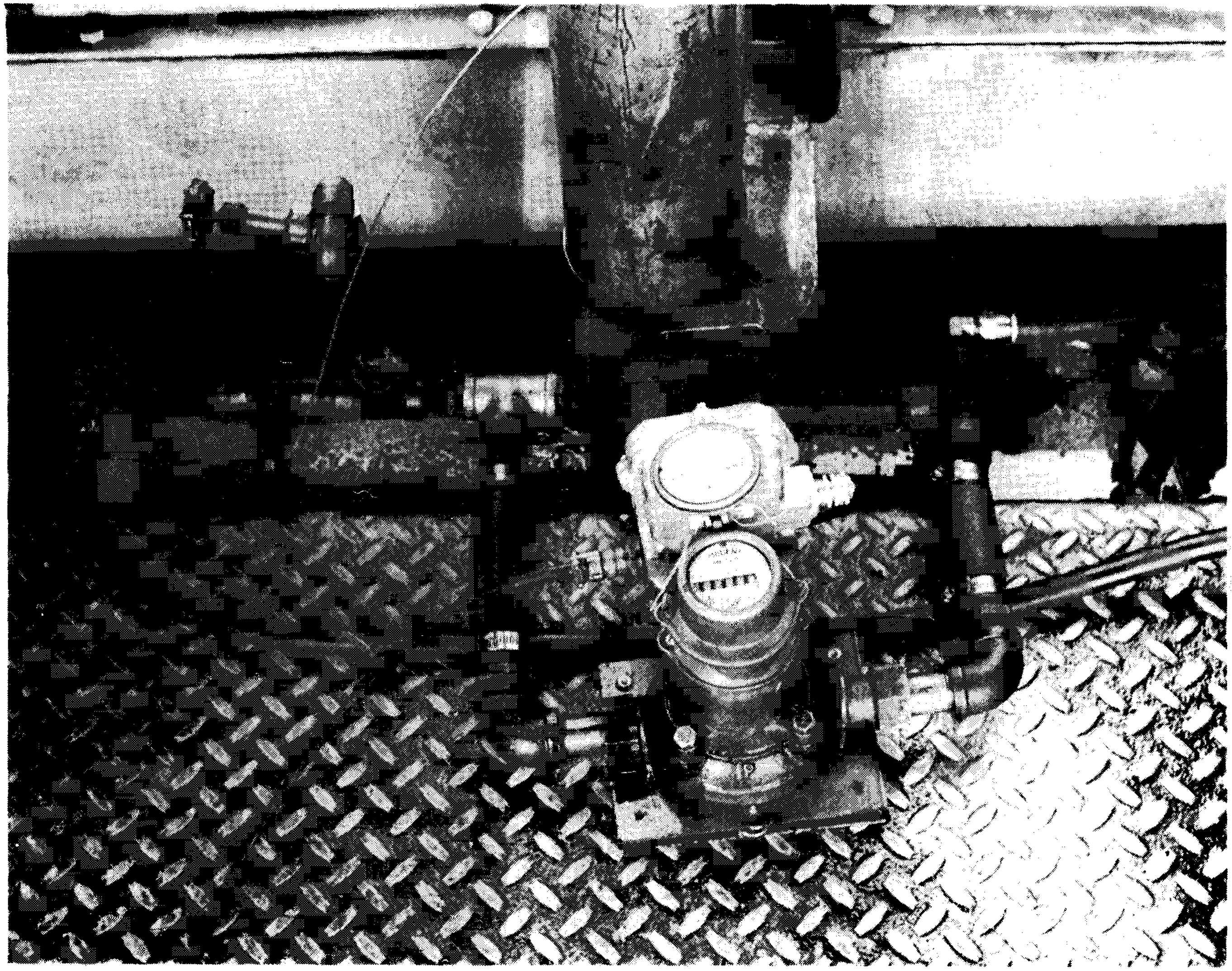

FIGURE 5. MOUNTED FUEL METER

on downgrades (with locomotives at idle), but could apply power only up to 55 MPH. For this analysis the round trips are broken into separate segments, as indicated in Table 6. The Kansas City - Clovis element is relatively level, with a moderate continually-ascending grade, rising from an elevation of 768 feet to 4262. West of Clovis, several mountain ranges are crossed, with substantial and sometimes very lengthy grades (both ascending and descending); the maximum elevation on the run is 7350 feet. Results of data taken on these runs are displayed in Table 7. The westbound TOFC trains generally carried a full complement of loaded trailers; when eastbound, the trailers were predominantly empty. All trains were weighed on in-motion scales, with net values based upon manual subtraction of bill-of-lading weights. For the TOFC trains, the overall average energy intensity was 439 gross-trailing-ton-miles per gallon, or 13.3 trailer-miles per gallon. (The GTTM/gal figure is seen to be very close to that obtained in the BN tests, for similar power/weight and terrain.)

2.5 LONG-DISTANCE TESTS (ILLINOIS CENTRAL GULF)

In 1976, 13 runs were carried out by the Illinois Central Gulf Railroad involving routes between Chicago and New Orleans and from Omaha to Chicago. There were 7 TOFC, 2 COFC, and 5 manifest freight trains; segments, train type, and route are indicated in Table 8. Several locomotive types were involved, with GP-40's (3000 HP) and GP-38-2's (2000 HP) predominating. In this case no test car was used, but a strip chart recorder in the lead locomotive accumulated data concerning speed and throttle notch; fuel meters on each locomotive were read at several points during the run. Relatively numerous consist changes occurred, not always fully documented, so that mileage-weighted averages are used for the car and weight values in Table 8; several runs will be seen to have been divided into segments, sometimes fairly short, for this reason. It was not possible to record the time associated with various stops and delays, particularly at intermediate terminals, so the average speeds listed are presumably substantially lower than typical running speeds. Weighing of the

TABLE 6. ATCHISON, TOPEKA AND SANTA FE TEST RUNS

SUMMARY OF FUEL CONSUMPTION RUNS

RUN CODE	CARS		CONSIST TYPE	GR TR TONS	HP/ TON	DIST (MI)	ROUTE (ORIGIN - DEST.)
	L	E					
ATSF 1-1	54	3	TOFC	3997	3.6	635	KANSAS CITY - CLOVIS
ATSF 1-2	49	2	TOFC	3693	3.9	973	CLOVIS - BARSTOW
ATSF 1-3	62	2	TOFC	3634	4.0	1116	LOS ANGELES - CLOVIS
ATSF 1-4	62	2	TOFC	3634	4.0	632	CLOVIS - KANSAS CITY
ATSF 2-1	47	2	TOFC	3563	3.0	633	KANSAS CITY - CLOVIS
ATSF 2-2	47	2	TOFC	3616	3.0	1115	CLOVIS - LOS ANGELES
ATSF 2-3	55	3	TOFC	2640	4.1	1116	LOS ANGELES - CLOVIS
ATSF 2-4	55	3	TOFC	2640	4.1	633	CLOVIS - KANSAS CITY
ATSF 3-1	62	2	BOX	4530	3.2	634	KANSAS CITY - CLOVIS
ATSF 3-2	61	2	BOX	4450	3.2	1113	CLOVIS - LOS ANGELES
ATSF 3-3	67	2	MIXED	4462	3.2	970	BARSTOW - CLOVIS
ATSF 3-4	67	2	MIXED	4462	3.2	634	CLOVIS - KANSAS CITY

TABLE 7. ATCHISON, TOPEKA AND SANTA FE FUEL CONSUMPTION MEASUREMENTS

MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: ALL
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TON" = "HORSEPOWER PER GROSS TRAILING TON"

RUN CODE	HP	NR OF CARS BOX	TTX	TOTAL	NR OF TRLRS	WEIGHT GR TR	NET	HP/ TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL GR TR	NET	CONSIST TYPE
ATSF 1-1	14400	0	55	57	100	3997	1316	3.6	635	46.8	6455	393	129	TOFC
ATSF 1-2	14400	0	49	51	93	3693	1206	3.9	973	43.9	8879	405	132	TOFC
ATSF 1-3	14400	0	62	64	119	3634	672	4.0	1116	46.5	10763	377	70	TOFC
ATSF 1-4	14400	0	62	64	119	3634	672	4.0	632	43.7	4593	500	92	TOFC
ATSF 2-1	10800	0	47	49	90	3563	1247	3.0	633	40.5	3994	565	198	TOFC
ATSF 2-2	10800	0	47	49	91	3616	1269	3.0	1115	42.0	7378	546	192	TOFC
ATSF 2-3	10800	0	56	58	109	2640	0	4.1	1116	39.1	8255	357	0	TOFC
ATSF 2-4	10800	0	56	58	109	2640	0	4.1	633	43.3	2986	559	0	TOFC
ATSF 3-1	14400	62	0	64	0	4530	1815	3.2	634	44.4	5933	484	194	BOX
ATSF 3-2	14400	61	0	63	0	4450	1753	3.2	1113	45.7	9928	499	197	BOX
ATSF 3-3	14400	37	30	69	60	4462	1640	3.2	970	40.3	8836	490	180	MIXED
ATSF 3-4	14400	37	30	69	60	4462	1640	3.2	634	44.9	3264	867	319	MIXED
AVG	13200	0	41	60	79	3777	1102	3.5	850	43.4	6772	472	137	

TOTALS: 12 RUN SEGMENTS, 10203 MILES

AVG. TON-MI/GAL = TOTAL TON-MI/TOTAL GALLONS
OTHER AVERAGES NOT WEIGHTED

TABLE 8. ILLINOIS CENTRAL GULF TEST RUNS

SUMMARY OF FUEL CONSUMPTION RUNS

RUN CODE	CARS L	CARS E	CONSIST TYPE	GR TR TONS	HP/ TON	DIST (MI)	ROUTE (ORIGIN - DEST.)
ICG 1-1	35	2	TOFC	2575	3.3	188	NEW ORLEANS - JACKSON
ICG 1-2	50	2	TOFC	2880	2.9	216	JACKSON - MEMPHIS
ICG 2	36	2	TOFC	2700	4.4	535	MEMPHIS - CHICAGO
ICG 3-1	11	1	TOFC	636	12.3	290	CHICAGO - DUQUOIN
ICG 3-2	28	1	TOFC	1907	4.1	245	DUQUOIN - MEMPHIS
ICG 4	25	1	TOFC	1550	5.1	404	MEMPHIS - NEW ORLEANS
ICG 5-1	25	2	TOFC	1778	4.4	188	NEW ORLEANS - JACKSON
ICG 5-2	44	7	TOFC	2930	2.7	216	JACKSON - MEMPHIS
ICG 6-1	15	2	TOFC	884	10.2	290	CHICAGO - DUQUOIN
ICG 6-2	33	1	TOFC	2127	4.2	246	DUQUOIN - MEMPHIS
ICG 7	23	4	TOFC	1578	5.7	404	MEMPHIS - NEW ORLEANS
ICG 8-1	36	117	BOX	6796	1.2	489	CHICAGO - MEMPHIS
ICG 8-2	36	117	BOX	5147	1.5	198	MEMPHIS - JACKSON
ICG 8-3	70	55	BOX	7224	1.1	178	JACKSON - NEW ORLEANS
ICG 9-1	16	58	BOX	3130	2.6	45	NEW ORLEANS - HAMMOND
ICG 9-2	5	41	BOX	1615	4.9	52	HAMMOND - MCCOMB
ICG 10	47	18	BOX	5025	1.6	787	MCCOMB - CHICAGO
ICG 11	67	80	BOX	9106	1.0	97	NEW ORLEANS - MCCCMB
ICG 12	79	1	COFC	5387	2.3	526	COUNCIL BLUFFS - CHICAGO
ICG 13	63	1	COFC	4075	2.9	526	COUNCIL BLUFFS - CHICAGO
ICG 14-1	35	56	MIXED	4143	2.9	267	CHICAGO - WATERLOO
ICG 14-2	39	69	BOX	5118	2.3	99	WATERLOO - FT. DODGE
ICG 14-3	37	28	MIXED	3711	3.2	136	FT DODGE - COUNCIL BLUFFS

trains was not feasible, and gross values are based on car-type weights carried in the ICG information system computer; net weights are estimated as for the Burlington Northern tests. These runs differed from most of the others reported here in that they involve lower speeds and more en-route stops, factors which tend to have opposite effects on fuel usage. Overall, the data show reasonable consistance with the other results, although the scatter is relatively large. The basic results of the tests are presented in Tables 9 (TOFC only) and 10 (all others).

2.6 LONG-DISTANCE TESTS (UNION PACIFIC)

Additional fuel consumption data was collected in a cooperative effort with the Union Pacific Railroad. A round trip between North Platte, Nebraska, and Los Angeles was monitored, with a loaded TOFC consist westbound and a COFC train returning. This was a highly powered train, with the locomotive consist comprising one SD-40 and two DD-40's (twin-diesel, 4-axle-truck units), for a total of 16,200 HP. The total run, over predominantly mountainous terrain, was 1519 miles (each way), run at speeds often near or exceeding 70 MPH. The data for these trips are presented in Table 11. Indicated average speeds exclude known stops. On the first run a fuel meter malfunction occurred. The fuel figure given in Table 11 is based instead upon fuel delivered at refueling stations, which in other instances has been 1 to 2 percent high. Extrapolation based upon those meters which were working, however, suggests a substantially lower number (approximately 12,200 gallons, as opposed to 13,700). High winds were noted during the North Platte - Salt Lake City portion of that run, which would be consistent with higher fuel consumption than found on the eastbound run.

2.7 UNIT COAL TRAIN OPERATIONS

In conjunction with another FRA research project, several runs have also been made for unit trains carrying coal, and returning to the mine empty. The Burlington Northern participated in a test covering a round trip from Lincoln, Nebraska, to Metropolis,

TABLE 9. ILLINOIS CENTRAL GULF FUEL CONSUMPTION MEASUREMENTS (TOFC ONLY)

MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: TOFC
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TCN" = "HORSEPOWER PER GROSS TRAILING TON"

RUN CODE	HP	NR OF CARS			NR OF TRLRS	WEIGHT		HP/ TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL		TR-MI /GAL
		BOX	TTX	TOTAL		GR TR	NET					GR TR	NET	
ICG 1-1	8450	0	36	37	62	2575	923	3.3	188	31.5	1153	420	150	10.0
ICG 1-2	8450	0	51	52	90	2880	1350	2.9	216	30.0	1749	356	167	11.1
ICG 2	12000	0	37	38	68	2700	1020	4.4	535	33.6	3918	369	139	9.3
ICG 3-1	7850	0	11	12	18	636	270	12.3	290	31.5	902	204	87	5.8
ICG 3-2	7850	0	28	29	52	1907	785	4.1	245	28.8	1075	435	179	11.9
ICG 4	7850	0	25	26	46	1550	686	5.1	404	38.2	1950	321	142	9.5
ICG 5-1	7850	0	26	27	46	1778	690	4.4	188	31.3	967	346	134	8.9
ICG 5-2	7850	0	50	51	82	2930	1230	2.7	216	41.1	1597	396	166	11.1
ICG 6-1	9000	0	16	17	28	884	423	10.2	290	34.8	1185	216	104	6.9
ICG 6-2	9000	0	33	34	63	2127	945	4.2	246	27.2	1330	393	175	11.6
ICG 7	9000	0	26	27	43	1578	639	5.7	404	30.2	2092	305	123	8.2
AVG	8650	0	31	32	54	1959	815	5.4	293	32.6	1629	347	143	9.6

TOTALS: 11 RUN SEGMENTS, 3222 MILES

AVG. TON-MI/GAL = TOTAL TON-MI/TOTAL GALLONS; SAME FOR TR-MI/GAL
OTHER AVERAGES NOT WEIGHTED

TABLE 10. ILLINOIS CENTRAL GULF FUEL CONSUMPTION MEASUREMENTS (ALL EXCEPT TOFC)

MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: ALL
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TCN" = "HORSEPOWER PER GROSS TRAILING TON"

RUN CODE	HP	NR OF CARS BOX			NR OF TRLRS	WEIGHT GR TR		HP/ TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL GR TR		CONSIST TYPE
		BOX	TTX	TOTAL		GR TR	NET					GR TR	NET	
ICG 8-1	8000	152	0	153	0	6796	1800	1.2	489	21.0	3866	860	228	BOX
ICG 8-2	8000	152	0	153	0	5147	1800	1.5	198	17.8	1710	596	208	BOX
ICG 8-3	8000	124	0	125	0	7224	3500	1.1	178	14.0	1675	768	372	BOX
ICG 9-1	8000	73	0	74	0	3130	800	2.6	45	19.3	385	366	94	BOX
ICG 9-2	8000	45	0	46	0	1615	245	4.9	52	28.4	279	301	46	BOX
ICG 10	8000	64	0	65	0	5025	2370	1.6	787	21.1	5926	667	315	BOX
ICG 11	9000	146	0	147	0	9106	3350	1.0	97	32.9	1069	826	304	BOX
ICG 12	12100	0	79	80	150	5387	1800	2.3	526	31.8	4773	594	198	COFC
ICG 13	12000	0	63	64	125	4075	1500	2.9	526	33.9	4373	490	180	COFC
ICG 14-1	12000	73	11	91	19	4143	1293	2.9	267	29.4	2594	426	133	MIXED
ICG 14-2	12000	93	8	108	11	5118	1623	2.3	99	26.2	1102	460	146	BOX
ICG 14-3	12000	50	8	65	11	3711	1523	3.2	136	27.7	1058	477	196	MIXED
AVG	9931	0	14	98	25	5046	1787	2.3	269	25.4	2301	612	224	

TOTALS: 13 RUN SEGMENTS, 3499 MILES

AVG. TON-MI/GAL = TOTAL TON-MI/TCTAL GALLONS
OTHER AVERAGES NOT WEIGHTED

TABLE 11. UNION PACIFIC FUEL CONSUMPTION MEASUREMENTS

MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: TOFC
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TON" = "HORSEPOWER PER GROSS TRAILING TON"

RUN CODE	HP	NR OF CARS BOX	NR OF CARS TTX	NR OF CARS TOTAL	NR OF TRLRS	WEIGHT GR TR	WEIGHT NET	HP/ TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL GR TR	TON-MI/GAL NET	TR-MI /GAL	ROUTE (ORIGIN - DEST.)
UP 1	16200	0	34	35	68	2501	1020	6.5	1519	50.3	13679	278	113	7.6	NORTH PLATTE-LOS ANGELES
UP 2	16200	0	46	47	92	3233	1380	5.0	1519	49.5	12888	381	163	10.8	LOS ANGELES-NORTH PLATTE
AVG	16200	0	40	41	80	2867	1200	5.7	1519	49.9	13284	328	137	9.1	

TOTALS: 2 RUN SEGMENTS, 3038 MILES

AVG. TON-MI/GAL = TOTAL TON-MI/TOTAL GALLONS; SAME FOR TR-MI/GAL
OTHER AVERAGES NOT WEIGHTED

AVG. (UNWEIGHTED) GROSS TON-MI/GAL (INCL. LOCO.) IS 409 WITH STD DEVIATION OF 76.4

NET WEIGHT ESTIMATED ASSUMING 50 NET TONS PER LOADED BOXCAR, 15 NET TONS PER LOADED TRAILER

NOT REPRODUCIBLE

Illinois, a distance of 704 miles. The power consist of four SD-40-2's provided 12,000 HP. The loaded movement involved a power-weight ratio near unity, and speeds in the vicinity of 20 MPH. A similar operation on the Boston & Maine Railroad, between Mechanicville, New York, and Bow, New Hampshire, (207 miles) yielded similar data. In that case, six GP-38's were used, also providing 12,000 HP. The results for both railroads are presented in Table 12. As in previous tables, the average speeds exclude known stops. The substantially greater fuel efficiency of the BN runs, compared to those for the B&M, may partially be related to the considerably more uneven terrain for the latter case, and the substantial net vertical drop (approximately 700 feet) for the BN in the loaded direction. In addition, one would anticipate a substantial variation associated with pattern of stops, different train handling practices for the different topography, etc.

2.8 SUMMARY OF INTERMODAL RESULTS

All TOFC runs described above are summarized in Table 13, and the two COFC cases are presented in Table 14. While these tests are not truly comparable to one another, due to differences between consists, terrain, speeds, etc., they provide a reasonably consistent pattern with respect to fuel usage for TOFC service. The overall TOFC average of 10.9 trailer-miles per gallon is relatively uniform from railroad to railroad, although substantial variations do occur, particularly as a function of power/weight and percentage of empties. The maximum value (for loaded trailers) is 16.5, and the minimum (excluding one 12.3 HP/ton case) is 6.6.

The COFC data are rather limited, but do fall within the range that would be expected. The data are inadequate to provide rigorous substantiation of the expected fuel efficiency advantage over TOFC, but consistent results are observed. If one ignores those runs characterized by power-to-weight ratios of greater than 4 HP/ton (COFC operations were at 2 to 3 HP/ton), the COFC shows 46 percent greater efficiency in terms of container-miles gallon, and 40 percent for gross trailing ton miles per gallon. (Inclusion of all ICG TOFC runs gives 56 percent and 65 percent,

TABLE 12. UNIT COAL TRAIN FUEL CONSUMPTION MEASUREMENTS (BURLINGTON NORTHERN AND BOSTON & MAINE)

```
MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: ALL
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TON" = "HORSEPOWER PER GROSS TRAILING TON"

  RUN          HP       NR OF CARS     NR OF     WEIGHT     HP/   DIST  AVG.    FUEL  TON-MI/GAL  CONSIST        ROUTE
  CODE                 BOX  TTX TOTAL  TRLRS  GR TR   NET   TON   (MI) SPEED   (GAL)  GR TR  NET   TYPE     (ORIGIN - DEST.)

  BN 61      12000     110    0  111      0  14395 10998  0.8   682  24.8    7566  1298   991   UNIT     LINCOLN - METROPOLIS
  BN 62      12000     110    0  111      0   3397     0  3.5   682  21.3    6278   369     0   UNIT     METROPOLIS - LINCOLN
 B&M  1      12000      95    0   96      0  12192  9315  1.0   207  21.6    3894   648   495   UNIT     MECHANICVILLE - BOW
 B&M  2      12000      86    0   87      0   2877     0  4.2   207  23.0    1828   326     0   UNIT     BOW - MECHANICVILLE

 AVG         12000     100    0  101      0   8215  5078  2.4   445  22.7    4892   780   482

TOTALS:   4 RUN SEGMENTS,  1778 MILES

AVG. TON-MI/GAL  = TOTAL TON-MI/TOTAL GALLONS
OTHER AVERAGES NOT WEIGHTED


AVG. (UNWEIGHTED) GROSS TON-MI/GAL (INCL. LOCO.) IS  728 WITH STD DEVIATION OF 441.5


NET WEIGHT ESTIMATED ASSUMING 50 NET TONS PER LOADED BOXCAR, 15 NET TONS PER LOADED TRAILER
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NOT REPRODUCIBLE

TABLE 13. SUMMARY OF TOFC FUEL CONSUMPTION MEASUREMENTS

MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: TOFC
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TON" = "HORSEPOWER PER GROSS TRAILING TON"

RUN CODE	HP	NR OF CARS BOX	NR OF CARS TTX	NR OF CARS TOTAL	NR OF TRLRS	WEIGHT GR TR	WEIGHT NET	HP/TON	DIST (MI)	AVG. SPEED	FUEL (GAL)	TON-MI/GAL GR TR	TON-MI/GAL NET	TR-MI /GAL	ROUTE (ORIGIN - DEST.)
BN 1-1	10800	1	36	38	65	2670	1012	4.0	922	51.8	5498	448	170	10.9	CHICAGO - MINOT
BN 1-2	10800	0	33	34	60	2390	905	4.5	1257	50.8	4601	653	247	16.5	MINOT - SEATTLE
BN 2-1	10200	1	23	25	42	1804	658	5.6	922	56.7	3985	417	152	9.8	CHICAGO - MINOT
BN 2-2	10200	0	18	19	33	1479	501	6.9	1257	51.2	4050	459	156	10.4	MINOT - SEATTLE
BN 3-1	10500	1	33	35	63	2611	982	4.0	922	56.4	5170	466	175	11.2	CHICAGO - MINOT
BN 3-2	10500	0	27	28	49	2127	731	4.9	1257	51.4	4958	535	184	12.3	MINOT - SEATTLE
BN 4	10800	0	35	36	64	2718	957	4.0	922	55.2	4808	521	184	12.2	CHICAGO - MINOT
BN 5	10500	0	22	23	40	1513	594	6.9	922	57.3	3952	353	139	9.2	CHICAGO - MINOT
BN 6-1	10800	0	18	19	33	1221	491	8.9	922	54.1	3268	344	138	9.2	CHICAGO - MINOT
BN 6-2	10800	0	16	17	29	1038	428	10.4	1257	49.9	3115	419	173	11.5	MINOT - SEATTLE
BN 7	10200	1	24	26	40	2641	639	3.9	922	54.3	5646	431	104	6.5	CHICAGO - MINOT
BN 8-1	10200	1	30	32	53	2091	831	4.9	922	56.4	5605	344	137	8.7	CHICAGO - MINOT
BN 8-2	10200	0	25	26	41	1671	618	6.1	1257	50.2	5559	378	140	9.3	MINOT - SEATTLE
BN 9	10200	1	32	34	57	2356	897	4.3	922	54.2	5398	402	153	9.8	CHICAGO - MINOT
BN 10	13800	1	37	39	70	2675	1087	5.2	922	53.1	7124	346	141	9.0	CHICAGO - MINOT
BN 11	10500	1	35	36	65	2585	1018	4.1	922	54.8	5360	445	175	11.2	CHICAGO - MINOT
BN 12-1	9900	0	21	22	35	1425	525	6.9	922	55.5	3618	363	134	8.9	CHICAGO - MINOT
BN 12-2	9900	0	16	17	29	1283	428	7.7	1257	46.4	3674	439	146	9.8	MINOT - SEATTLE
BN 13	10800	0	15	16	26	1055	386	10.2	922	54.6	3562	273	100	6.6	CHICAGO - MINOT
BN 29	10200	6	45	52	85	3744	1544	2.7	922	50.2	6307	547	226	12.4	CHICAGO - MINOT
SP 1-1	7200	0	29	31	49	2233	618	3.2	60	55.5	314	426	118	9.4	ROSEVILLE - STOCKTON
SP 1-2	7200	0	30	32	50	2347	685	3.1	115	53.1	477	566	165	12.1	STOCKTON - FRESNO
SP 1-3	7200	0	31	33	50	2298	596	3.1	112	42.0	430	599	155	13.0	FRESNO - BAKERSFIELD
SP 7-1	7200	0	37	39	65	2787	794	2.6	60	30.0	303	552	157	12.9	ROSEVILLE - STOCKTON
SP 7-2	7200	0	46	48	83	3584	1172	2.0	227	40.1	1218	668	218	15.5	STOCKTON - BAKERSFIELD
ATSF 1-1	14400	0	55	57	100	3997	1316	3.6	635	46.8	6455	393	129	9.8	KANSAS CITY - CLOVIS
ATSF 1-2	14400	0	49	51	93	3693	1206	3.9	973	43.9	8879	405	132	10.1	CLOVIS - BARSTOW
ATSF 1-3	14400	0	62	64	119	3634	672	4.0	1116	46.5	10763	377	70	12.3	LOS ANGELES - CLOVIS
ATSF 1-4	14400	0	62	64	119	3634	672	4.0	632	43.7	4593	500	92	16.4	CLOVIS - KANSAS CITY
ATSF 2-1	10800	0	47	49	90	3563	1247	3.0	633	40.5	3994	565	198	14.3	KANSAS CITY - CLOVIS
ATSF 2-2	10800	0	47	49	91	3616	1269	3.0	1115	42.0	7378	546	192	13.8	CLOVIS - LOS ANGELES
ATSF 2-3	10800	0	56	58	109	2640	0	4.1	1116	39.1	8255	357	0	14.7	LOS ANGELES - CLOVIS
ATSF 2-4	10800	0	56	58	109	2640	0	4.1	633	43.3	2986	559	0	23.1	CLOVIS - KANSAS CITY
ICG 1-1	8450	0	36	37	62	2575	923	3.3	188	31.5	1153	420	150	10.0	NEW ORLEANS - JACKSON
ICG 1-2	8450	0	51	52	90	2880	1350	2.9	216	30.0	1749	356	167	11.1	JACKSON - MEMPHIS
ICG 2	12000	0	37	38	68	2700	1020	4.4	535	33.6	3918	369	139	9.3	MEMPHIS - CHICAGO
ICG 3-1	7850	0	11	12	18	636	270	12.3	290	31.5	902	204	87	5.8	CHICAGO - DUQUOIN
ICG 3-2	7850	0	28	29	52	1907	785	4.1	245	28.8	1075	435	179	11.9	DUQUOIN - MEMPHIS
ICG 4	7850	0	25	26	46	1550	686	5.1	404	38.2	1950	321	142	9.5	MEMPHIS - NEW ORLEANS
ICG 5-1	7850	0	26	27	46	1778	690	4.4	188	31.3	967	346	134	8.9	NEW ORLEANS - JACKSON
ICG 5-2	7850	0	50	51	82	2930	1230	2.7	216	41.1	1597	396	166	11.1	JACKSON - MEMPHIS
ICG 6-1	9000	0	16	17	28	884	423	10.2	290	34.8	1185	216	104	6.9	CHICAGO - DUQUOIN
ICG 6-2	9000	0	33	34	63	2127	945	4.2	246	27.2	1330	393	175	11.6	DUQUOIN - MEMPHIS
ICG 7	9000	0	26	27	43	1578	639	5.7	404	30.2	2092	305	123	8.2	MEMPHIS - NEW ORLEANS
UP 1	16200	0	34	35	68	2501	1020	6.5	1519	50.3	13679	278	113	7.6	NORTH PLATTE-LOS ANGELES
UP 2	16200	0	46	47	92	3233	1380	5.0	1519	49.5	12888	381	163	10.8	LOS ANGELES-NORTH PLATTE
AVG	10351	0	34	36	62	2370	801	5.0	742	45.4	4257	415	140	10.9	

TOTALS: 46 RUN SEGMENTS, 34136 MILES

AVG. TON-MI/GAL = TOTAL TON-MI/TOTAL GALLONS; SAME FOR TR-MI/GAL
OTHER AVERAGES NOT WEIGHTED

NOT REPRODUCIBLE

TABLE 14. SUMMARY OF COFC FUEL CONSUMPTION MEASUREMENTS

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MEASURED FUEL CONSUMPTION DATA
CONSIST TYPE: COFC
CAR TOTAL INCLUDES TEST CAR, IF PRESENT, AND CABOOSE
"GR TR" = "GROSS TRAILING"; "HP/TON" = "HORSEPOWER PER GROSS TRAILING TON"

 RUN        HP       NR OF CARS    NR OF    WEIGHT    HP/  DIST  AVG.   FUEL  TON-MI/GAL  CN-MI        ROUTE
 CODE               BOX  CX TOTAL  CNTRS  GR TR  NET  TON  (MI) SPEED  (GAL)  GR TR  NET  /GAL    (ORIGIN - DEST.)

 ICG 12    12100     0   79   80    150   5387  1800  2.3   526  31.8   4773   594   198   16.5   COUNCIL BLUFFS - CHICAGO
 ICG 13    12000     0   63   64    125   4075  1500  2.9   526  33.9   4373   490   180   15.0   COUNCIL BLUFFS - CHICAGO

 AVG       12050     0   71   72      0   4731  1650  2.6   526  32.8   4573   544   190   15.8

TOTALS:   2 RUN SEGMENTS,  1052 MILES

AVG. TON-MI/GAL  = TOTAL TON-MI/TOTAL GALLONS; SAME FOR CN-MI/GAL
OTHER AVERAGES NOT WEIGHTED


AVG. (UNWEIGHTED) GROSS TON-MI/GAL (INCL. LOCO.) IS  608 WITH STD DEVIATION OF  78.2


NET WEIGHT ESTIMATED ASSUMING 50 NET TONS PER LOADED BOXCAR, 15 NET TONS PER LOADED TRAILER
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respectively). However, different routes were involved, so this comparison must be used with great caution.

The relationship of net ton-miles to the gross ton-mile and trailer-mile figures used here remains somewhat uncertain, since there may be a substantial difference among trailer and container load weights. This element, coupled with uncertainties previously stated, emphasizes the importance of utilizing these numbers only as indicators, rather than as proof of a specific COFC fuel efficiency advantage over TOFC. Further, any generalization to overall transportation efficiency would require inclusion of effects of empty backhauls, typical loads, and terminal and pick-up/delivery energy usage.

2.9 COMPARISON WITH COMPUTER SIMULATIONS

Direct comparison of experimental data and computer simulations is generally a more challenging task than might at first appear to be the case. The acquisition of detailed track data (curvature, speed limits, and elevations or grades) is a problem which plagues all researchers in this field. Data is often available only in the form of track charts, thus requiring very labor intensive and tedious manual interpretation. Even computer-readable data assembled by others often proves to contain errors, "adjustments", or forms of presentation which entail much correction or re-interpretation. Further, the speed limits obtained thereby do not include slow orders or other temporary delays which may affect an actual train movement, nor can they include stops occasioned by congestion or setting out of bad-order cars. The detailed information provided to TSC by several railroads in this series of tests does permit reconstruction of the actual speed profile, but this, too, is very time consuming.

For these and other reasons, serious attempts at simulation of these runs has begun only recently at TSC. The simulations which have been carried out to date are, for the most part, based on rough approximations to the actual speed profiles, and must be considered to be very preliminary in nature. However, they do show fairly good agreement with experiment, generally differing by no more than 5 percent to 10 percent in running time and fuel consumption. Some cases are quite close, while a few deviate markedly, for reasons not yet ascertained. Results in this area should be viewed in terms of the many factors identified elsewhere in this paper which bear upon the accuracy of the experimental figures, including such variables as the energy content of the particular fuel used, temperature, and barometric pressure, as well as locomotive variations. Other considerations not readily simulated include details of train-handling techniques, such as application of power and brakes simultaneously in order to maintain the train in a stretched condition.

In spite of such uncertainties and the constant presence of uncontrolled and possibly unknowable variables, the initial and preliminary results that have been obtained in the FRA/TSC studies suggest that computer calculations for a fully calibrated and validated model can yield results with an uncertainty of less than 5 percent for a wide variety of cases when train resistance equations have been sufficiently refined, with even better results in the more precisely defined situations.

3. SUMMARY AND CONCLUSIONS

The tests described here represent 53,000 train-miles of operations under a wide variety of conditions. Summary values of average gross trailing-ton-miles per gallon and miles of testing are shown in Table 15. (The "mixed" category involved such disparate consists and operations that a breakdown by railroad is not judged to be meaningful.) The many differences among the various test runs generally preclude meaningful comparison among these numbers, which are presented merely to indicate trends and representative values. For example, the ATSF boxcar trains were operated at relatively high speeds over mountainous terrain with a high power-to-weight ratio; the case was completely different for the Southern Pacific boxcar operation, and intermediate for the ICG. The resulting fuel usage is consistent with these differences. The relevance of the data in Table 15 to a particular purpose or interrpretation must be judged in terms of the detailed test descriptions presented in the body of this report. The 34,100 miles of TOFC operations yielded a mileage-weighted average of 10.9 trailer-miles per gallon. The relatively small number of COFC runs monitored suggest a fuel efficiency approximately 45 percent greater than for TOFC, although this finding should not be considered definitive. The scatter in the data typically showed a standard deviation equivalent to approximately 20 percent of these values, which is not unreasonable considering the variety of operations examined (particularly in speed and terrain) and the uncertainty in train weights in some cases. The limited relationship between running speed and overall averages and the narrow speed range covered by most of the tests do not permit identification of the energy intensiveness as a function of velocity. However, more detailed analysis of the ATSF data should make possible meaningful conclusions in this area.

Generalization to a more specific measure of effective transportation fuel efficiency, net ton-miles per gallon, is difficult, since lading density, car loading, and percentage of empty cars

TABLE 15. SUMMARY OF FUEL CONSUMPTION MEASUREMENTS

(Gross Trailing-Ton-Miles per Gallon/Miles of Testing)
Overall Average is mileage-weighted.
Unit coal train data is presented in Table 12.

RAILROAD	BOX	TOFC	COFC	MIXED
BN	-	433/20450	-	-
SP	959/1148	599/574	-	-
ATSF	493/1747	439/6852	-	-
ICG	699/1945	347/3222	544/1052	-
UP	-	328/3038	-	
ALL	678/4840	415/34136	544/1052	471/10878

can vary substantially. For the purpose of crude approximation, it can be noted that the ratio of car capacity (not necessarily load weight) to empty weight is typically in the range of 2 to 3 for freight cars, but is less than unity for TOFC service. At higher speeds, for which aerodynamic rather than weight sensitive energy dissipation begins to dominate, the effect of weight is less limited. Naturally, percentage of loaded and empty cars must be considered as well. (The overall national average ratio of net-to-gross train weight is approximately .4.) The marked effects of power-to-weight ratio are significantly reduced if one makes calculations in terms of gross rather than trailing weight, since locomotive weight is a principal reason for greater fuel usage at higher HP/ton.

These results are not in serious disagreement with most previous estimates. Close examination generally shows the expected varation with power/weight, train weight, and speed, and illustrates the range of fuel efficiency values which can occur. The various tests show a reasonable consistancy from railroad-to-railroad and for very different locations. Full analysis of these tests should provide a firm foundation for estimation of rail freight transportation fuel usage under a wide range of operating scenarios. The train movements which comprised these tests are now being simulated on the TSC train performance computer program, and it is anticipated that this process will contribute to selection of train resistance equations and other algorithms which will be valid and accurate for a wide range of cases. At the same time, the many pitfalls in this area must be kept clearly in mind. Variations in locomotive and track conditions, train-handling policies, details of route and speed profile, train consists, empty/loaded ratio, weather, etc., can all render simulations or "rule-of-thumb" estimates seriously in error. The numbers which have been mentioned here represent findings for specific cases, and generalization must be approached with great care.