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FUEL EFFICIENCY IMPROVEMENT IN RAIL FREIGHT TRANSPORTATION

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16. Abstract

Railroad diesel fuel conservation is becoming increasingly cost-effective. The price of diesel fuel has increased almost two and one-half times since the October 1973 Embargo. The estimated value of diesel fuel, if in short supply, is over 1 dollar a gallon.

A comparison of the fuel performance of 10 selected railroads, before and after the Embargo, showed improvement in net-ton-miles hauled per gallon of diesel fuel. However, some roads used fuel less efficiently from an operating standpoint, as measured in gross-ton-miles per gallon.

The most promising immediate avenue for conserving diesel fuel is designing train operating policies specifically to conserve fuel while continuing to provide desired schedule performance. Reducing horsepower-per-ton assignment to trains is a preferable strategy to that of reducing maximum allowable train operating speeds. The key to successful implementation is the appropriate short term regulation of the locomotive fleet.

The basic deisel locomotive now used was designed during an era of plentiful fuel supply at a relatively low price. Many features can be improved to provide greater fuel efficiency.

Corporate strategies need re-examination in the light of the high cost and uncertain supply of diesel fuel. The control of fuel must be improved and contingencies for a fuel shortage should be planned.

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PREFACE

The assessment described in this report was carried out under Contract DOT-TSC-1105 by The Emerson Consultants, Inc., in the context of an overall program at the Transportation Systems Center to provide a technical basis for the improvement of Transportation service, efficiency, and productivity. This program is sponsored and directed by the Federal Railroad Administration, Office of Research and Development.

Conclusions and recommendations contained here are generally based upon fuel considerations only. Their applicability and value in actual situations may vary significantly depending upon a variety of operational, technical, and economic factors which determine overall freight service productivity, efficiency, and costs in a particular situation. Further, it must be recognized that in some cases these conclusions are necessarily based in part upon the informed opinion of the author, and other knowledgeable individuals may legitimately differ with either inclusion or exclusion of specific recommendations. This report, published in the interests of information exchange, is not to be interpreted as necessarily embodying the official views of the U.S. Department of Transportation or any of its parts.

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EXECUTIVE SUMMARY

Railroad diesel fuel conservation is becoming increasingly cost-effective. As fuel prices increase, more investments become justifiable for improved fuelling devices and controls, for enabling reductions in other train delays, and for improving locomotive utilization. When availability of fuel determines the ability to accept traffic, the value of diesel fuel to a railroad probably exceeds 1 dollar per gallon.

The locomotive fuel consumption rate is dependent upon the amount of power required to overcome all resistances encountered and to supply auxiliary equipment on the locomotive. The typical serviceable road diesel locomotive operates at an average of between 50 and 65 percent of full load about 50 percent of the time, and runs at idle the other 50 percent.

Several conclusions can be drawn by the examination of a selected group of 10 major railroads. Comparison of their fuel performance during 1972 (before the 1973 embargo) and during 1974 indicates that the performance of all 10 railroads did improve, based upon the numbers of net-ton-miles carried per gallon of diesel fuel. However, the performances were mixed. Some roads, in fact, used fuel less efficiently from an operating standpoint when measured in total gross-ton-miles per gallon of fuel, indicating that the savings came from other than operating improvements. The cost of fuel has increased more than 140 percent during the 2 year period, while the estimated value of shorted fuel has increased about 22 percent. However, the value of shorted fuel was estimated to be over five times that of the 1974 average price. Based upon the comparatively favorable performance of some railroads, there is considerable potential for further fuel conservation by the others. The most promising immediate avenue for conserving diesel fuel is designing train operating policies specifically with that goal, while continuing to provide desired schedule performance. Since road freight operations consume the bulk of the fuel on American railroads, those operations deserve concentrated attention. For turbo-charged locomotives, which are predominant in road freight fleets, the most fuel-efficient throttle position is near full throttle. Therefore, to the extent that locomotives can be loaded with cars so as to operate as much of the time as is possible in seventh or eighth throttle position – consistent with over-all train schedule time – the more the fuel savings. The key to maintaining schedules is to reduce those train delays unrelated to horsepower to compensate for the loss of running time occasioned by reducing horsepower-per-trailing-ton ratios of the trains.

Reducing horsepower-per-ton locomotive assignment criteria for trains is a preferable strategy to that of reducing maximum allowable operating speeds. Power limitation requires less horsepower in the fleet for a given traffic level and loses less running time for a given level of fuel savings.

The key to successful implementation of this preferred strategy is appropriate short-term regulation of the locomotive fleet. This process requires short-term forecasts of amount of horsepower required in the fleet in order to meet all of the demands of traffic and maintenance; the remainder, if there is an excess, is stored spare-serviceable.

Train weights play an important part in implementing both improved fuel performance and use performance of locomotives. Using other than scale-weighed freight car weights in reporting encourages the assignment of more power to trains than is otherwise warranted, since dispatchers are more often criticized for delays to train because of insufficient power than for having excess power on trains. Since reported train weights can vary considerably from the actual train weights, the tendency is to assign more power, as insurance.

A locomotive idling seems a waste of fuel, until the economic consequences of shutting down the engine are considered. The potential damage to the engine and batteries in frequent starting and shutting down of the engine can be many times the value of even "shorted" fuel. A good rule of thumb is to shut down a locomotive if it is expected to be idling more than 4 hours in an ambient temperature of over 40°F.

Idling excess units of a train's locomotive consist when returning power to balance system locomotive requirements can save fuel. However, the fuel penalty is nominal compared with sizeable improvements in running time by working rather than idling that power over severe grades.

While the fuel saving potential is not great in reducing spillage and distribution losses, it does warrant a high level in maintenance of fuelling and distribution systems.

While there are even more compelling economic reasons for improving the utilization rate of locomotives, fuel conservation provides a bonus. Not only is idling reduced by having fewer units in the fleet, but the tendency is to operate in more efficient throttle positions, more of the time, as a result of improved locomotive utilization.

The basic diesel locomotive currently in use was designed during an era of a plentiful fuel supply at a relatively low price. Improved diesel locomotive design specifically to improve fuel performance should be pressed with the manufacturers of locomotives and replacement parts. The ideal diesel road locomotive from the standpoint of fuel efficiency would:

a. Be easily maintained

b. Have 3000 horsepower

c. Have high-adhesion

d. Be four-axle

e. Be turbo-charged without parts catcher

f. Use low-pressure-drop engine air filters

g. Have controllable cooling fans and the air compressor disengagable when not needed

h. Have clean cut-off fuel injectors

i. Have a built-in control logic to automatically take individual units of a locomotive consist on-and-off-line while the train is running and unit is not needed.

Most railroads have not had a coordinated diesel fuel control system. The critical events in controlling fuel are: on-hand fuel inventory, draw-downs from storage, deliveries to storage, and amount of fuel dispensed to locomotives and running net fuel balances with foreign roads in run-through operations. The ideal diesel fuel control system would have:

a. All freight cars scale weighed before being placed in a road train

b. Temperature-correcting meters both to and from major fuel storage tanks

c. Metering of all fuel dispensed to locomotive units and a fuel record maintained for each unit

d. All fuel meter information in machine readable form

e. A computer-based system for simulating the fuel effects of changing operating policies

f. Budgeting of fuel based upon expected supply and desired operating performance.

Since a dependable supply of fuel is essential to performing railroad services, the prospect of diesel fuel shortages should prompt a re-examination of corporate policies and goals. The estimated value of diesel fuel when its unavailability prevents the acceptance of offered incremental traffic is well over one dollar per gallon. Increasing the net loading of cars increases fuel efficiency considerably.

In order to accommodate sudden fluctuations in the supply of fuel and demand for services, it appears that a 15-day on-hand supply should provide the lead time to make the necessary adjustments on large railroad systems.

While some railroads have more potential for fuel savings than others, at some point all means of further conserving fuel will be exhausted. For that contingency, each road should develop a policy to cover the situations when it cannot handle all available traffic for lack of fuel.

Electrification increasingly provides an attractive long-term alternative to diesel power. Unfortunately, the extremely high initial investments required involve high risk except over lines of high density with a reasonably certain volume. Railroad fundings in recent years have precluded pursuing this alternative.

While railroads have made considerable progress in conserving diesel fuel, there is further potential for improvement. Most roads have not exploited the tremendous potential in designing operating tactics specifically to conserve fuel while maintaining desired train schedules. Locomotive manufacturers should be strongly encouraged by railroad customers to improve the fuel efficiency of the diesel locomotive, which was spawned during an era of plentiful at a low price. Tighter fuel control through metering and budgeting appears warranted.

1. INTRODUCTION

The Transportation Systems Center of the United States Department of Transportation contracted with The Emerson Consultants, Inc., to carry out a preliminary assessment of the more promising means of increasing rail fuel efficiency within the constraints of existing operational requirements and basic locomotive technology. The purpose of this study is to provide relevant information to the railroad community; to facilite formulation, guidance and implementation of future Federal Railroad Administration research; and to provide a sound base for general policy development.

Accordingly, the primary task was to comprise a review, analysis, and assessment of all significant practical avenues to improve rail freight transportation fuel efficiency, with estimation of the magnitude of benefits possible and delineation of the size and causes of uncertainty in the estimates. Where possible, relevant costs and other disadvantages associated with implementation of these possible changes were to be indicated. Areas specifically warranting attention were to include but not necessarily be limited to:

A. Operations/Policy

   1. Line-haul
   2. Terminal and others

B. Locomotives

   1. In-service equipment
   2. Improvements within technical state-of-the-art.

1.1 THE PROBLEM

Recent sharp increases in the cost of fuel oil and the national objective of reduced usage require careful examination of the means by which rail freight transportation fuel consumption can be reduced. This first necessitates an accurate knowledge of existing consumption under various circumstances.

Determination of changes in operations and rolling stock which offer a potential for significant improvement in fuel efficiency can be generated only through detailed and comprehensive understanding of existing practices and hardware. The basic need which this study addresses is the generation of a foundation document which will provide a firm information base in this area.

1.2 DIESEL FUEL ENERGY

Basic to the understanding of railroad fuel use is the conversion of diesel fuel energy into performing railroad transportation work.

The amount of energy per gallon of diesel fuel varies with viscosity and its chemical composition; however, it is generally between 130,000 and 140,000 British Thermal Units (1 BTU = 778.2 foot-pounds = 0.0003930 horsepower-hours). For 32°API gravity, one gallon of diesel fuel contains 132,100 BTU's as a lower heating value. If <u>all</u> of this energy could be converted to useful work, this one gallon would provide about 52 horsepower-hours of work.

However, the diesel locomotive loses much of the energy in the conversion of this chemical energy to perform mechanical work. The most important loss is associated with the diesel engine thermal efficiency at the crankshaft, which varies between about 32 percent at no-load and about 38 percent at full load for a turbocharged engine. For a normally aspirated engine, this efficiency varies from the same 22 percent at no-load to about 37 percent at one-half load and reduces to about 34-1/2 percent at full load.

The other important loss is due to the transmission efficiency between the engine input to the generator for traction and the horsepower delivered at the rail. This efficiency varies with the speed of the locomotive and ranges from about 50 percent at 1 mile per hour to about 87 percent at 25 miles per hour or greater.

In addition to producing tractive effort, the diesel engine must provide power for auxiliary purposes such as lights, fans, controls, and other appurtenances. Dynamic braking also requires power.

1.3 TRAIN RESISTANCES

The tractive effort required from a locomotive is dependent upon the resistances it must overcome (including acceleration). The train resistances that have been identified as being the most important are journal resistance, flange resistance, and air resistance. The journal resistance varies with the loading or weight of the train and ambient temperature. Flange resistance varies with the speed of the train, number of axles, and track conditions; air resistance varies with some power of the speed and number and type of locomotive units and cars.

The other important moving resistances are grade resistance, curve resistance, wind resistance, and the force required for acceleration. Grade resistance varies with the degree of incline and weight of the train and amounts to approximately 20 pounds per ton of train weight per per cent of grade. Curve resistance varies with the weight of the train and is normally taken as 0.8 pound per ton per degree of curve.

Wind resistance is not to be confused with air resistance; air resistance is that encountered in still air. Wind resistance depends upon intensity and direction relative to the train.

Tractive effort is also required to accelerate a train to a higher rate of speed. Only that portion of tractive effort not required to overcome the other resistances is available for acceleration.

All of the resistances identified above pertain to a train in motion and apply to both the locomotive units and its trailing cars. Starting resistance is much higher than the moving resistances and must be overcome to start moving a train. (An excellent treatment of train resistances is contained in Railroad Engineering, Volume One by William W. Hay, 1953, and in other works in the Bibliography.)

1.4 LOCOMOTIVE FUEL CONSUMPTION CHARACTERISTICS

The fuel consumption rate is therefore dependent upon the amount of power required to overcome all resistances and to supply auxiliary equipment on the locomotive. A typical example of a 3000 horsepower turbo-charged, two-cycle-engine diesel locomotive is the EMD SD-40, which has a nominal fuel consumption rate which varies from 5-½ gallons per hour when idling to 168 gallons per hour under full load at the eighth throttle position, and 25 gallons per hour when in full dynamic braking. A comparable four-cycle-engine locomotive, also 3000 horsepower, is the GE U-30C with respective consumption rates of 5 gallons per hour at idle, 149 gallons per hour at full load and 26 gallons per hour at full dynamic brake. (Appendix A contains the average consumption rates of a number of locomotives in current use).

The typical serviceable road diesel locomotive operates at between about 50 and 56 percent of full load for about 50 percent of the time and runs at idle about 50 percent of the time.

An example of the amount of work done by a locomotive relative to the fuel consumed in a typical serviceable unit day is shown in Table 1. This example is comparable to the locomotive duty cycles resulting from studies conducted by engine manufacturers and railroads. (There is an excellent discussion of duty cycles in <u>A Study of Fuel Economy and Emission Reduction Methods for Marine and Locomotive Diesel Engines</u>, by J. O. Storment, C.D. Wood, and R. J. Mathis, U.S. Department of Transportation, Office of the Secretary and U.S. Coast Guard, September 1975, DOT-TSC-OST-75-41, CG-D-124-75.) The approximate fuel consumption per unit of

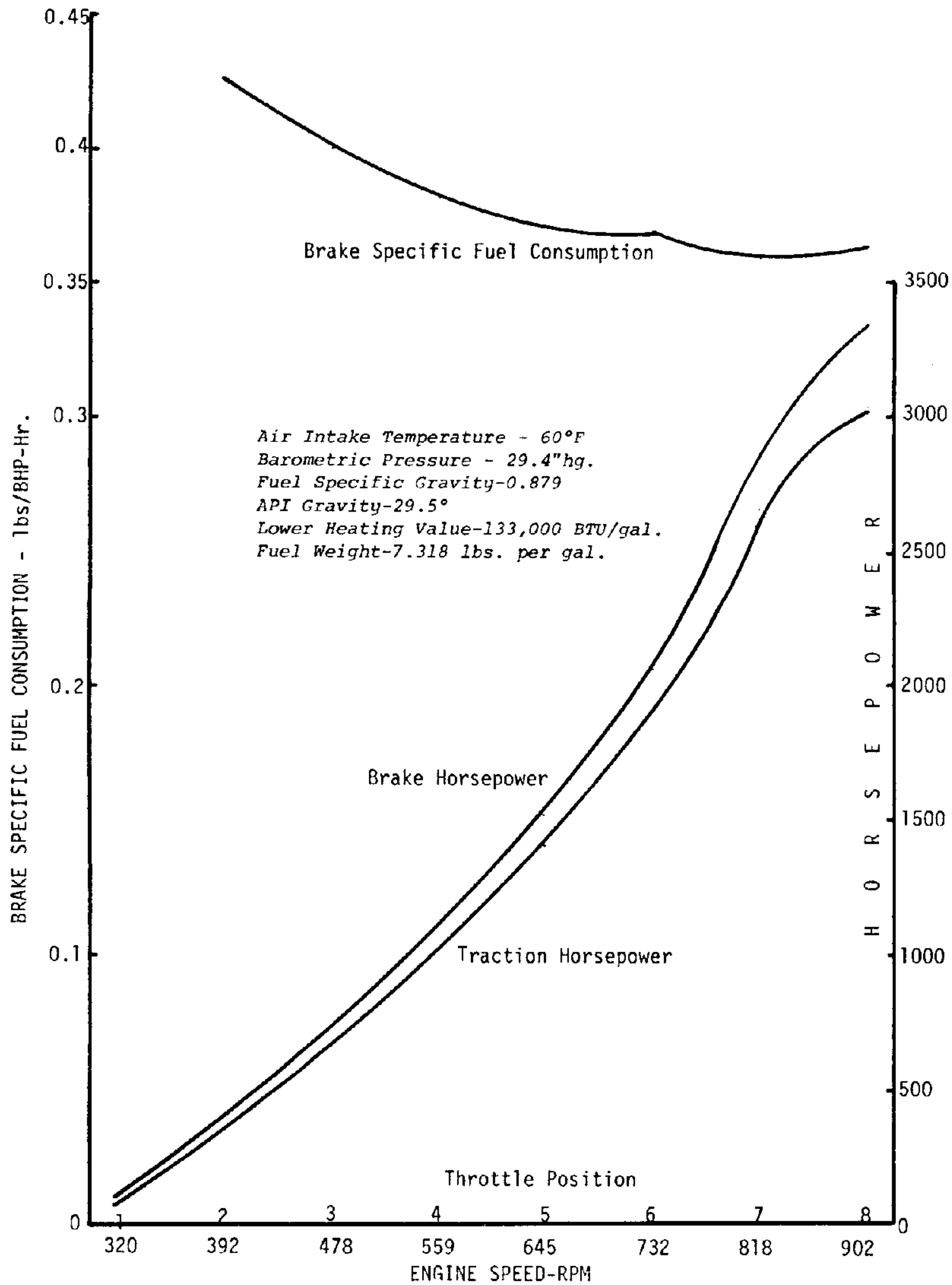
TABLE 1. EXAMPLE OF A TYPICAL DAILY EMD SD-40 DIESEL LOCOMOTIVE UNIT OPERATION

Throttle Position	Delivered Horsepower	Operation (Hours)	Work Delivered (hp-hrs)	Fuel Rate (gals/hr)	Consumption (gallons)
8	3100	3.6	11160	168	605
7	2550	1.0	2550	146	146
6	2000	1.0	2000	108	108
5	1450	1.0	1450	79	79
4	950	1.0	950	57	57
3	500	1.0	500	41	41
2	200	1.0	200	25	25
1	58	1.2	70	7.5	9
idle	*	12.0	500	5.5	66
Dyn.Brake	*	1.2	240	25	30
Total	-	24.0	19620	-	1166

* Power required is not comparable to horsepower indicated for throttle positions, but is estimated to be proportional to respective fuel consumption rates at lower throttle positions.

work done in the example is 1,166 gallons per 19,620 horsepower-hours or about 17 horsepower-hours of work per gallon of fuel. This is to be compared with the total energy contained per gallon of diesel fuel of 52 horsepower-hours. The indicated overall efficiency from this realistic example is 32 percent.

The fuel and horsepower diagram for the 16-645E3 engine of the EMD SD-40 locomotive is shown in Figure 1. The brake horsepower is the output of the engine to operate the auxiliary devices of the locomotive and provide locomotive tractive effort. The traction horsepower is that amount of engine output available for traction.



Source: Electro-Motive Division, General Motors Corp.,La Grange, Ill.

Figure 1. 16-645E3 Engine Performance (SD40-2 Diesel Locomotive)

1.5 RAILROAD CONSUMPTION PARAMETERS

In order to better understand the potential for improvement in rail fuel use, some perspective of recent railroad uses of fuel is necessary. The patterns prior to the October 1973 embargo provide insight into industry practices during the era of plentiful supply at a relatively low price.

Based upon a group of 10 railroads (See Appendix B) selected to represent the industry during the year of 1972, the price of fuel was generally between $0.10 and $0.12 per gallon. These roads produced about 198 net ton miles of freight transportation per gallon of fuel, but in the process generated 496 total gross ton miles per gallon of fuel to effect this performance. The portion of total train weight represented by locomotives was about 12 percent and the net-to-tare ratio was 0.82.

The value of "shorted" fuel was between $0.95 and $1.48 per gallon. This value of shorted fuel was determined as the amount of gross revenue margin that would be lost due to not having sufficient fuel to handle all of the traffic offered. It is assumed that 40 percent of incremental revenues is available to cover fixed overhead and profit.

Based upon a comparison of 1972 ICC statistics for these selected railroads and a selected group of long-haul competing truckers, the rail mode was over three times as fuel-efficient in terms of net ton miles hauled per gallon of fuel.

During 1974, the first full year since the embargo, the selected group of railroads produced 212 net-ton-miles per gallon of fuel, had a 0.86 net-to-tare ratio, and had 11 percent of total train weight represented by locomotives. The value of shorted fuel ranged between $1.14 and $1.73 per gallon.

This comparison indicates that all 10 railroads improved their net-ton-miles-per-gallon performance, the gain ranging from 1.1 to 13.3 percent and averaging 6.9 percent. They increased their net-to-tare ratio 4.3 percent and decreased the amount of train weight represented by locomotives almost 4 percent. The total gross-ton-miles-per-gallon increased only 3.9 percent, while the net-ton-miles-per-gallon increased 6.8 percent. This 3 percent difference in improvement is due primarily to the effect of the improved net-to-tare ratio. Note also that the price of fuel for the year 1974 was over 2.4 times the average price for 1972.

Because of the importance of the Penn Central to the railroad industry and its special status, it was evaluated separately. Table 2 below summarizes the comparison. A portion of its freight operations is electrified, but its net- and gross-ton-mile statistics are not separately identified. Thus, an equivalent diesel fuel consumption was estimated. Based upon a number of independent electrification studies that were performed on the Penn Central, the concensus conversion factor of 13 kilowatt-hours per gallon of

TABLE 2. PENN CENTRAL FUEL CONSUMPTION CHARACTERISTICS 1974 VS. 1972

Item	1972 (a)	1974 (b)	Change Amount	Change Percent
Freight Revenues	$1631.6	$1972.9	$341.3	20.9
Cost Freight Fuel:				
Diesel Oil	$ 48.89	$ 121.50	$ 72.61	148.5
Electricity	6.45	9.22	2.77	42.9
TOTAL	$ 55.34	$ 130.72	$ 75.38	136.2
Freight Fuel Used:(millions)				
Diesel Oil-Gals.	404.86	417.24	12.38	3.1
Electricity-Kw.Hr.	338.81	364.85	26.04	7.7
*Equivalent Diesel Fuel Gals.(millions)	430.92	445.31	14.39	3.3
Average Price per Equivalent Gal.	$ 0.1284	$ 0.2935	$0.1651	128.6
Net-ton-Miles(millions)	83873	87909	4036	4.8
NTM per Gal.	194.6	197.4	2.8	1.4
Loco. GTM (millions)	21527	21526	-1	-
Trailing GTM(millions)	192062	195330	3268	1.7
Total GTM (millions)	213589	216856	3267	1.5
Net-to-tare Ratio	77.5	81.8	4.3	5.5
Loco GTM/Total GTM	10.1	9.9	-0.2	-1.5
Total GTM per Gal.	495.7	487.0	-8.7	-1.8
Value Short Fuel	$ 1.515	$ 1.772	$0.257	17.0

* 1 gallon diesel fuel is estimated to equal 13 kilowatt-hours

Sources: (a) Railroad Annual Report Form A to ICC
(b) Annual Report R-1 to ICC

diesel fuel was used. With that slight adjustment, the improvement of net-ton-mile per equated gallon performance fell within the range of the 10 selected railroads. However, its gross-ton-miles per gallon performance decreased almost 2 percent. This indicates that the improved net-to-tare ratio effect overcame the deterioration of the gross-ton-mile per gallon performance of 1.8 percent to achieve the 4.8 percent increased net-ton-miles per gallon performance.

The amount of fuel consumed by type of service performed is also important in assessing potential for improvement. For the selected railroads during 1974, 92 percent was consumed in performing road freight service, less than 7 percent in performing switching service, and less than one-half of 1 percent for work trains. (See Table 3 below.) This selected group of railroads consumed just over 1 percent for its passenger operations (excluding Amtrak). During 1974, the Penn Central consumed about 77 percent of its fuel (both diesel and electric) in its road freight operations, 5 percent for its passenger operations, about 18 percent in yard switching, and less than one-half of 1 percent for work trains.

TABLE 3. SELECTED RAILROADS FUEL CONSUMPTION BY SERVICE TYPE-1974
(MILLIONS OF GALLONS)

Railroad	Freight	Passenger	Switcher	Worktrain	*Total
ATSF	313.4	-	16.8	1.3	331.5
BN	308.1	3.1	30.6	0.6	342.4
CRIP	96.5	1.7	7.3	0.4	105.9
DRGW	46.5	0.6	2.3	0.2	49.6
ICG	110.4	15.9	15.6	0.5	142.4
MOP	141.0	-	8.1	0.6	149.7
N&W	205.8	0.0	20.2	0.7	226.7
SOU	123.7	5.4	16.2	2.1	147.4
SP	357.2	2.1	10.8	1.2	371.3
UP	276.0	-	11.4	2.0	289.4
TOTAL	1978.6	28.8	139.3	9.6	2156.3
PERCENT OF TOTAL	91.8%	1.3%	6.5%	0.5%	100.0%

*Totals may not add due to rounding.

Sources: Annual Reports R-1 to ICC, Schedule 571.

2. FUEL-CONSERVATIVE OPERATING POLICIES

Improved control of fuel accounts, improved design of the diesel locomotive, and improved fuelling systems can conserve fuel. But the most promising immediate avenue is designing train operating policies specifically to conserve fuel, while continuing to provide desired schedule performance.

2.1 SWITCHING SERVICE

As indicated in the previous section, switching service normally consumes less than 10 percent of a railroad's total fuel consumption. More effective utilization of switcher locomotives is the key to conserving this fuel, while maintaining acceptable levels of service. Long periods of idling during the working shifts while awaiting instructions provide opportunity for savings. Another attractive prospect for savings is review of the practice of making repeated long "special" moves to a demanding industrial client. This practice is particularly costly when the client is on a branch line at a considerable distrance from the train yard.

Locations where one unit is assigned to protect one-shift-per-day service are often good candidates for improved utilization, and hence improved fuel efficiency. Assigning higher reliability units at outlying points improves use as well as fuel efficiency.

Balancing the number of switch crew assignments per shift, particularly at larger system yards and industrial areas, reduces the total number of units necessary to protect switching requirements.

Quite often, the daylight shift has a greater number of yard crew assignments, whereas it may be possible to change the workload among the shifts. For example, if 25 crews work daylight, with 20 each on the other 2 shifts, and if it is possible to rearrange the workload so as to require 1 additional crew on each of these 2 shifts while reducing the daylight shift to 23, it would result in saving 2 units in the fleet, with measurable fuel savings.

2.2 WORK TRAINS

Work trains normally consume less than 1 percent of a railroad's fuel use; yet, this type of service is often drastically curtailed during periods of short fuel supply. This curtailment further aggravates the already deteriorated condition of most railroad plants. As will be discussed later, there are many more attractive areas for saving 1 percent or more with much less adverse effect on the health of the railroad.

2.3 LOCAL FREIGHT SERVICE

As with yard and industrial switching service, the key to improved fuel use in local freight service is the improved utilization of road switchers. Both are improved by assigning more reliable locomotive units at outlying locations and reducing the number of repeated special moves to individual industries.

Most locomotives units used in road switcher or local freight service are normally-aspirated (not turbo-charged). The most fuel efficient throttle position is around fifth throttle (or about one-half full power). To the extent that more of the operations can be conducted at this throttle position, the fuel savings can accrue.

Also, all other things being equal, use of four-axle (B-B) units rather than six-axle (C-C) units in this service will further reduce fuel consumption due to the great difference in weight between the two types. The six-axle unit is about 50 percent heavier for locomotives of the same horsepower. Since the locomotive weight in local freight service is a substantial portion of the total gross weight of the train during most movements, the fuel penalty of a six-axle unit can be substantial.

2.4 ROAD FREIGHT SERVICE

Road freight service demands by far the greatest amount of fuel in railroad operations. While regularly reported fuel consumption statistics do not discriminate between road freight and road switcher service, it is estimated that the amount of fuel consumed in road freight service ranges between 60 and 80 percent of a major railroad's total diesel fuel consumption. (One special study by the author, which analyzed fuel usage of a larger major railroad by type of service, showed approximately 75 percent was attributable to road freight train operations.)

Since many locomotives units in this service, if not most, are turbo-charged, the most efficient throttle position is around seventh or eighth position, or full power. Therefore, to the extent that locomotives can be operated more nearly under full load to produce the required road freight transportation, substantial fuel savings will result.

The principal means of conserving fuel in road freight service through policies controllable by operating management are reduction of maximum speeds allowable and reducing horsepower-per-trailing-gross-ton used on trains. However, both of these policies will directly affect fleet horsepower requirements and minimum train running times, in addition to fuel consumption.

An extensive study of these vital relationships was made for a major railroad in order to improve fuel efficiency while maintaining acceptable levels of train performance. The following section discusses the general conclusions resulting from this in-depth analysis and implementation. (A logical framework was developed to investigate these relationships. It is called the FUEL Model and is described in Appendix C.)

The result of developing these relationships was a set of graphs of fuel consumption and minimum running time at varying horsepower-per-ton and maximum allowable speed levels. A system average for train size and weight was determined, by direction, between all power change points. The resulting performance characteristics for these average trains were then determined for all territories (by direction) in the entire road freight system network, using computer simulation techniques. Figures 2 and 3 contain an example of the results of two simulated average trains operating over a 700 mile route in mountainous territory; Figure 2 for the Westbound movements and Figure 3 for the Eastbound. These graphs provide a preliminary visual determination of the points of diminishing returns for variation of horsepower-per-trailing gross-ton and maximum allowable train speeds. For instance, the Westbound average train gains, at best, only a few minutes in minimum running time at any maximum speed, but the train will consume about one thousand gallons more fuel when operating the train with 6 horsepower-per-trailing gross-ton instead of 5 horsepower-per-trailing gross-ton. Further, assume that the desired schedule of this Westbound train is 16 hours, of which 2 hours are currently required for fuelling, meets,and other "normal" train delays. This would require a minimum running time of 14 hours. At a maximum speed of 70 miles per hour, this would require assigning about 4 horsepower-per-ton of trailing gross weight. Assume that one-half hour of "normal" train delays could be eliminated. Retaining the 70 miles per hour maximum speed, the train could be operated at a horsepower-per-ton ratio of three, with a resulting fuel savings of about 1000 gallons, or about 10 percent.

These preliminary analyses permit the development of the parameters necessary to investigate the fuel effects of alternative operating strategies involving reduction of maximum allowable train speeds and horsepower-per-trailing gross-ton ratios, or both.

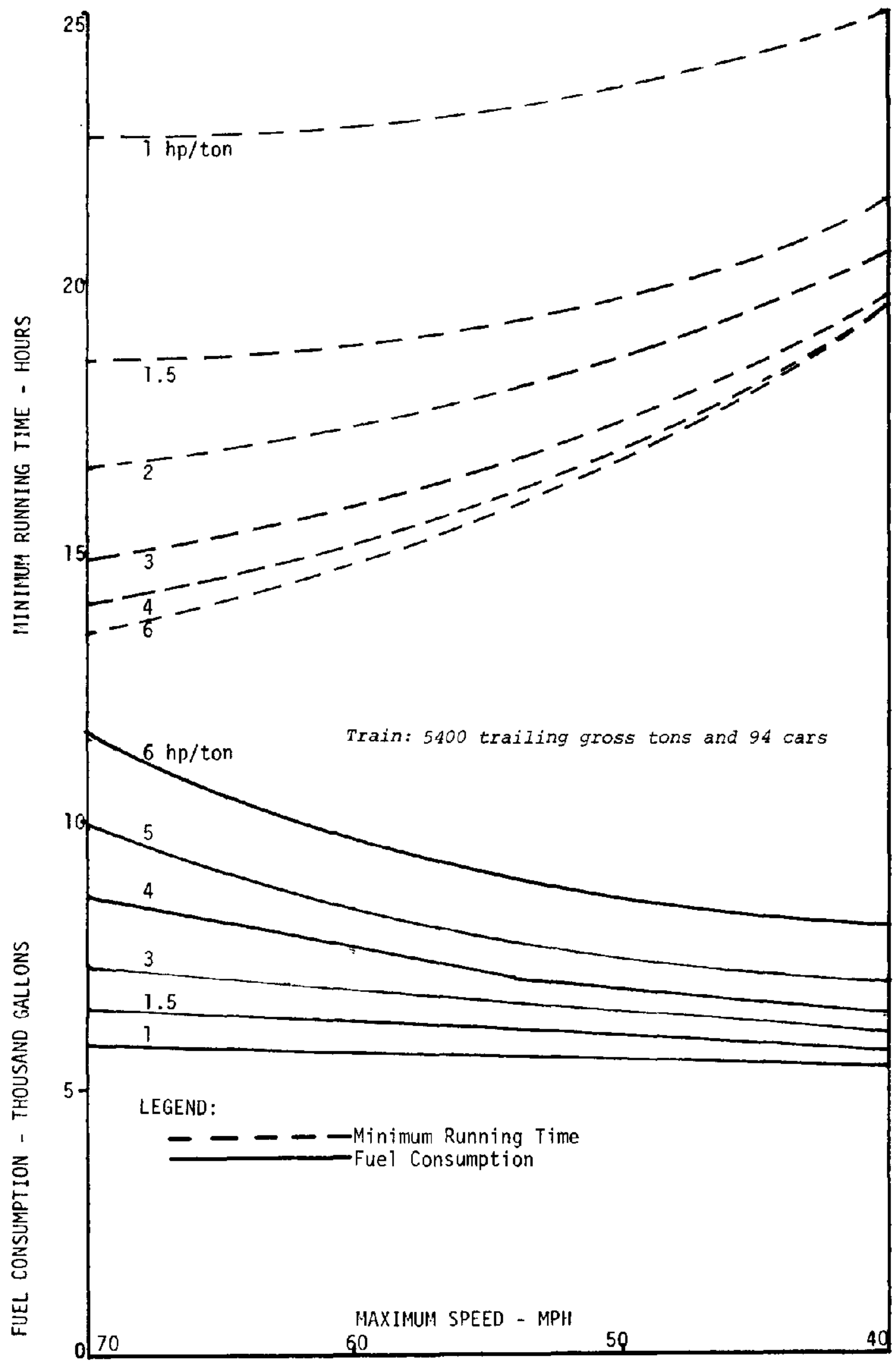


Figure 2. Fuel Consumption and Minimum Running Time Curves — Westbound — Mountainous Territory, 700 Miles

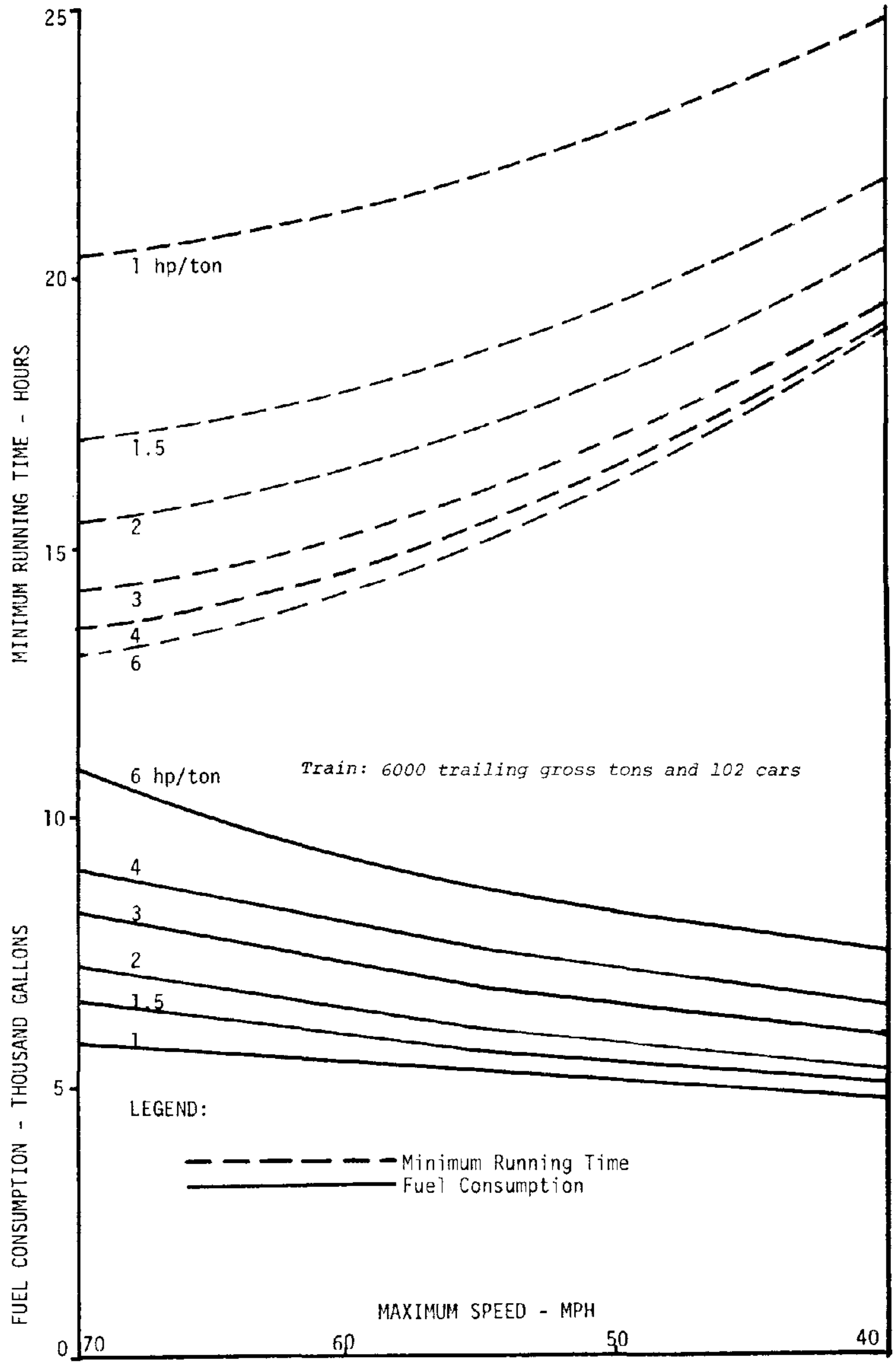


Figure 3. Fuel Consumption and Minimum Running Time Curves — Eastbound — Mountainous Territory, 700 Miles

2.5 ALTERNATIVE OPERATING STRATEGIES

2.5.1 Strategy A — Reduce Maximum Speeds Allowable

One extreme operating strategy A would be to reduce maximum allowable train operating speeds down to a selected minimum level without changing horsepower-per-ton ratios. After reaching the lowest maximum speed levels, further fuel savings would be made by reducing horsepower-per-ton ratios to some ultimate level (such as the minimum continuous ratings of the locomotives operating). The result of this one extreme strategy is shown in Figure 4, with an example indicated by dashed lines.

For a hypothetical railroad, at a given level of traffic, a desired fuel saving of 5 percent (lower horizontal axis) would correspondingly increase minimum train running time by 10 percent (left vertical axis) and require a corresponding increase of 5 percent more horsepower (right vertical axis) to handle same amount of traffic. This requirement for increased horsepower is due to the slower return of units. The reduction in maximum allowable train speed to effect this 5 percent fuel savings would be from 60 miles per hour to 50 miles per hour (upper horizontal axis).

Further reduction of maximum speed (while maintaining the same horsepower-per-ton policy) to 40 miles per hour would produce a fuel saving of about 11 percent while minimum running time would increase 24 percent and would require 15 percent more horsepower in the fleet to accommodate the same level of traffic.

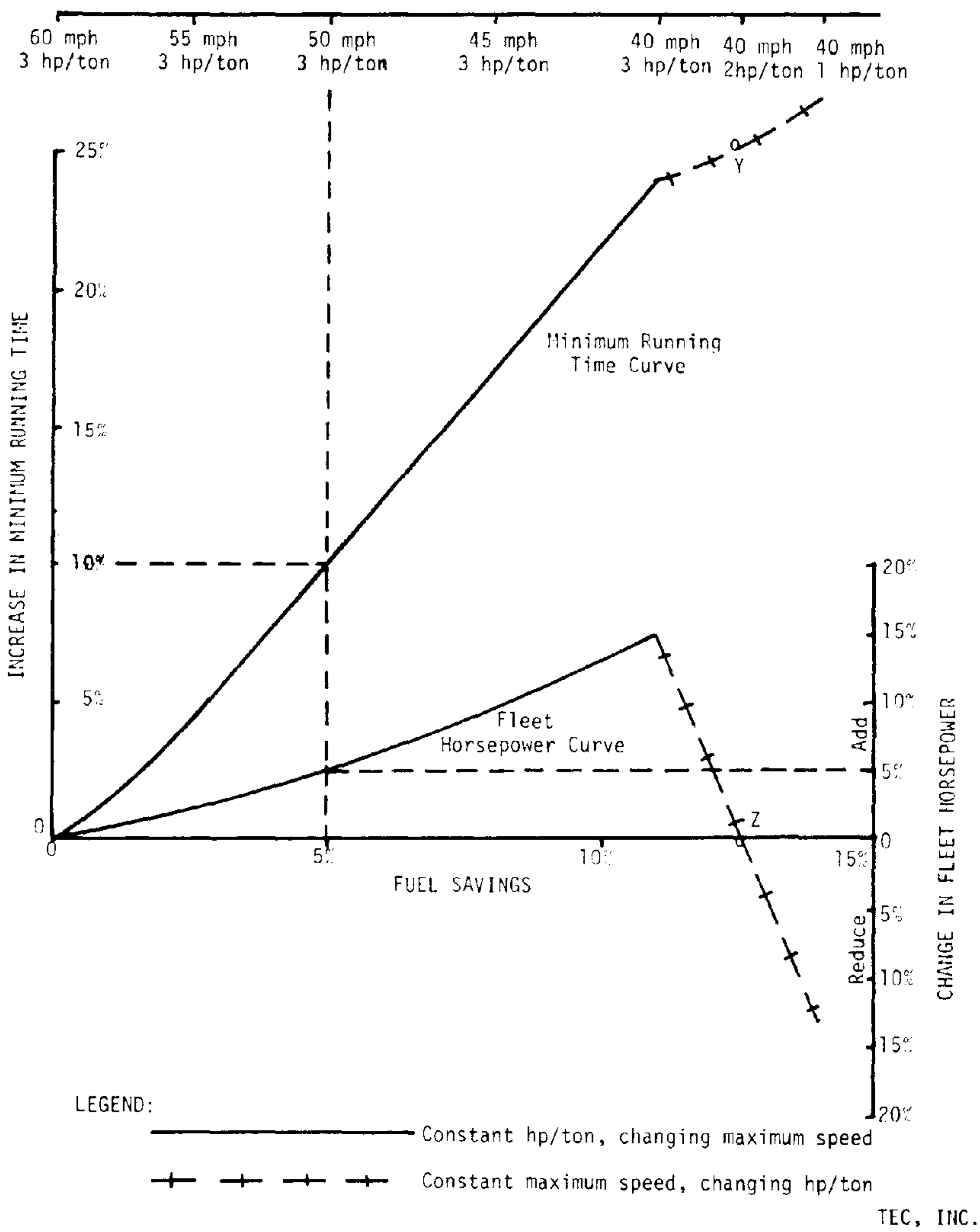


Figure 4. Strategy A — Reduce Maximum Speed, <u>Then</u> Reduce Hp/Ton

Assuming that it is not desired to reduce the maximum allowable train speed below 40 miles per hour, then further fuel savings would require reducing horsepower-per-ton ratios for powering the trains. Reducing the horsepower-per-ton ratio from the previously prevailing 3 horsepower-per-ton to 2 horsepower-per-ton would save 12-½ percent fuel (point "Z" on Fleet Horsepower Curve in Figure 4) but would increase minimum running time over 25 percent (point "Y" on Minimum Running Time Curve in Figure 4). Importantly, it would require no change in amount of power in the locomotive fleet to handle the same traffic level.

Assuming that 1 horsepower-per-ton was the lower limit due to minimum continuous rating of the locomotives on ruling grades on this hypothetical railroad, this determines a 14 percent maximum fuel savings potential from operations. (This is the end point for the curves of Figure 4). However, this savings level would increase minimum running time 27 percent. To achieve this full level of savings, the amount of horsepower used in the fleet for the same level of traffic should be reduced by 13 percent. The reason net motive power is saved when reducing amount of power assigned per train for a given level of traffic is that there is a 50 percent reduction of power per train from the former level cited, with minimum running time increased only about 8 percent from former level. Because of the Operating conditions on the hypothetical railroad, a net of 13 percent of the total fleet horsepower is saved at the 1 horsepower-per-ton, 40 miles per hour level compared to the 2 horsepower-per-ton, 40 miles per hour level.

2.5.2 Strategy B — Reduce Horsepower-Per-Ton

Another extreme operating strategy would be to reduce the amount of horsepower assigned to trains for a given level of traffic, while maintaining maximum train speed allowable. This reduction would continue to be made for further fuel savings down to the level at which minimum continuous rating occurs on ruling grades (usually at locomotive line speeds between 9 and 12 miles per hour, depending upon the particular specifications of individual locomotive types). Further fuel savings would require then reducing maximum train speeds allowed. This other extreme strategy is illustrated in Figure 5 for the same hypothetical railroad.

With this strategy, at the same traffic level of the previous example, a desired fuel savings of 5 percent would increase minimum train running time by 5 percent, retaining maximum allowable speed at 60 miles per hour and reducing horsepower-per-ton from 3 to 2. Fleet horsepower would

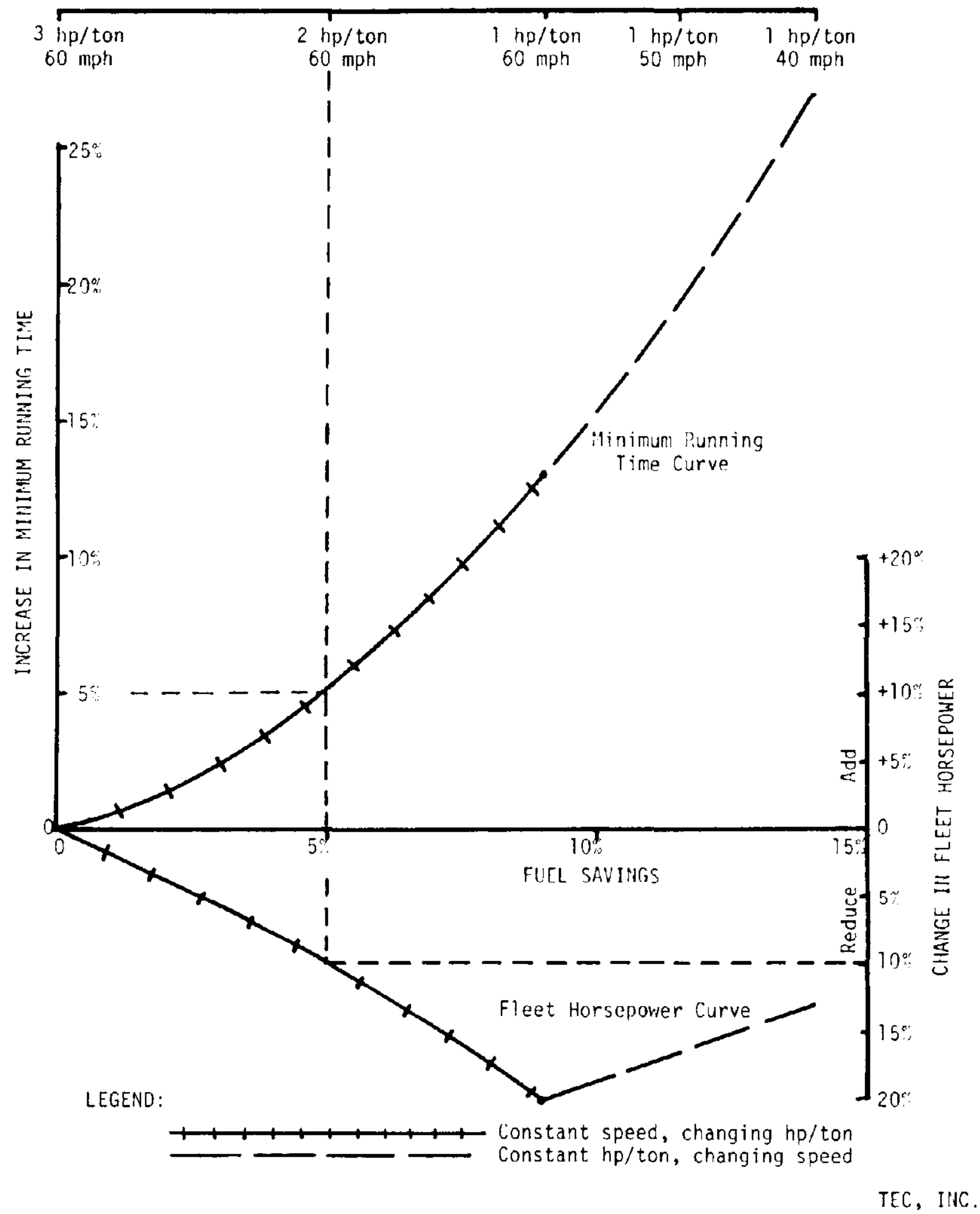


Figure 5. Strategy B — Reduce Hp/Ton, Then Reduce Maximum Speed

have to be reduced by 10 percent to effect this savings level.

Further reduction of horsepower-per-ton to 1 horsepower-per-ton (retaining same 60 miles per hour maximum speed) would produce a fuel savings of about 9 percent, provided fleet horsepower is reduced 20 percent. Minimum running time would increase about 13 percent from the original condition.

Assuming that 1 horsepower-per-ton is at or near the minimum continuous rating of locomotives in the fleet, further fuel savings would require reducing the maximum allowable train speeds. A further reduction to 40 miles per hour maximum (fron original 60 miles per hour) would provide the ultimate fuel savings of about 14 percent, increase minimum running time 27 percent, and require a reduction of 13 percent of total fleet horsepower (as in the previous strategy).

2.5.3 Strategy C — Maintain Fleet Size

An intermediate operating strategy would be to maintain the locomotive fleet size for a given level of traffic and find the combination of maximum allowable train speed and horsepower-per-ton level which will produce the desired fuel savings level. This strategy is illustrated in Figure 6 for the same hypothetical railroad. In this case, the previous Fleet Horsepower Curve becomes a horizontal line at 0 percent on the "Change in Fleet Horsepower" axis (by definition). In its place has been added a Fleet Horsepower Diagram comprising isograms of maximum speeds and horsepower-per-ton from which those values yeilding a desired fuel saving can be read.

With this strategy, a desired fuel savings of 5 percent will require simultaneously reducing maximum allowable speed from 60 miles per hour to about 53 miles per hour and horsepower-per-ton from 3.0 to 2.6 horsepower-per-ton. Minimum train running times would increase about 8 percent.

The isograms of maximum speeds and of horsepower-per-ton limits are shown only on the "Fleet Horsepower" diagram in Figure 6, but apply similarly to the "Running Time" diagram as well. Note that the shaded areas in both diagrams show the respective consequences of combinations of maximum speed reductions and horsepower-per-ton reductions which would require

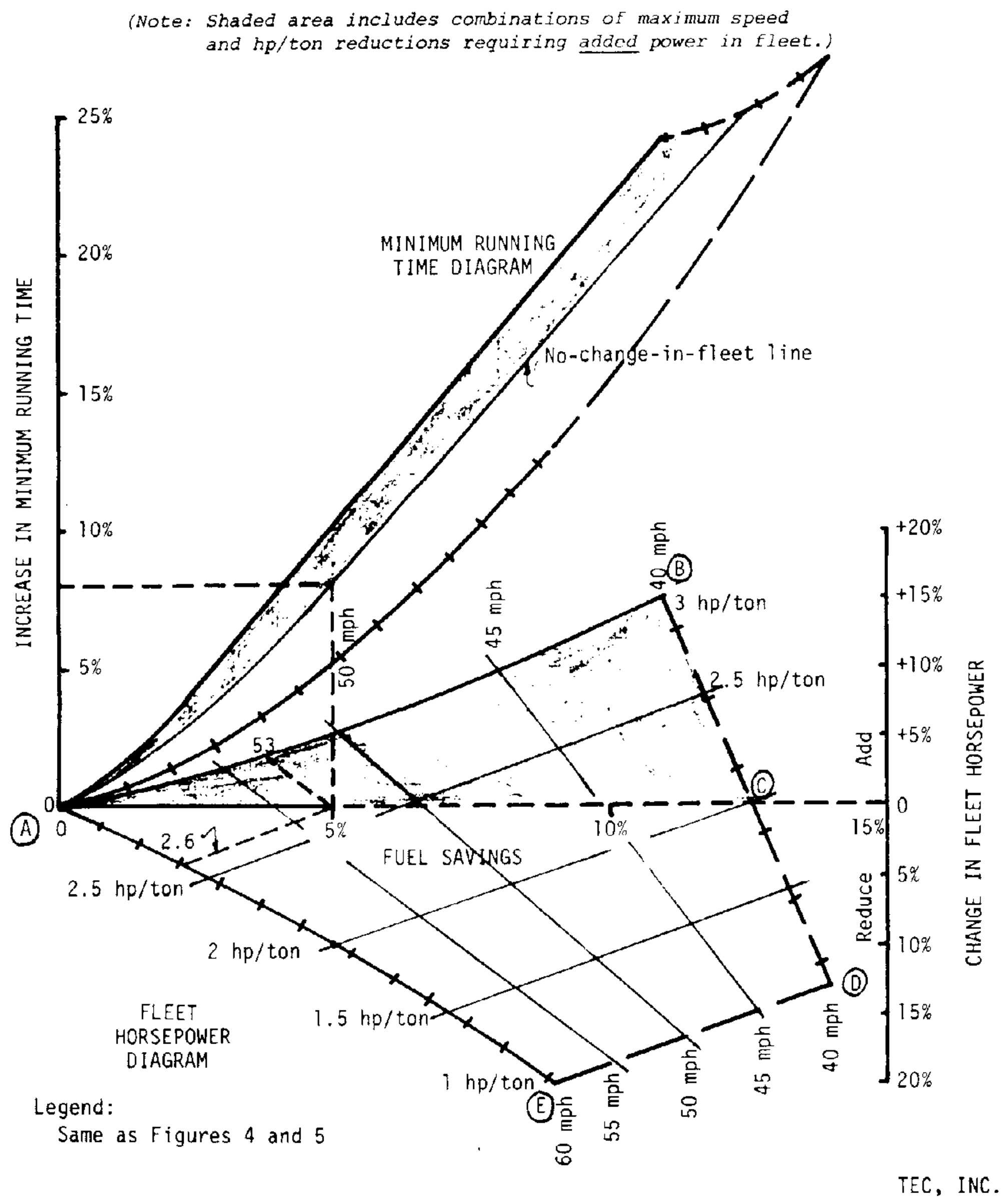


Figure 6. Strategy C - Maintain Fleet Size, Simultaneously Reduce Both Maximum Speed and Horsepower-Per-Ton

added horsepower in the fleet in order to implement the related fuel savings. (This represents still other strategies.)

2.5.4 Operating Strategy Conclusions

The extreme operating strategies A and B actually form the "envelopes" of all feasible operating combinations for conserving fuel as shown in Figure 6, "Fleet Horsepower" and "Running Time" diagrams. A previous in-depth analysis of individual routes and territories as well as of an entire railroad system confirmed that the relationships shown in Figure 6 apply. While the size of the "envelopes" vary with the physical operating environment, the relationships remain the same. That is, reducing the horsepower-per-ton assignments to trains, while maintaining the maximum speed levels, produces the greatest savings relative to increases in minimum over-the-road train running times. This strategy will normally require a reduction of horsepower in the serviceable locomotive fleet.

From a practical standpoint, it is not feasible to handle the same traffic level with the same size locomotive fleet if maximum speeds only are reduced without also reducing horsepower-per-ton levels as well.

If the serviceable fleet horsepower is not regulated, and fuel savings are desired, then a reduction in maximum allowable speeds will force a reduction in horsepower-per-ton assigned to trains for the same level of traffic handled.

For the hypothetical railroad used to illustrate the various fuel conserving operating strategies, Table 4 summarizes the findings for a desired 5 percent fuel savings.

TABLE 4. SUMMARY — HYPOTHETICAL FUEL SAVINGS

ITEM	STRATEGY		
	A	B	C
Maximum Allowable Speed, mph	50	60	53
Average hp-per-ton	3.0	2.0	2.6
Increase in Min. Run Time	10%	5%	8%
Change in Fleet Horsepower	+5%	-10%	0%
Fuel Savings	5%	5%	5%

From the foregoing, the preferred operating strategy to conserve fuel is to reduce train horsepower-per-trailing gross-ton assignments for a given traffic level. If further savings beyond threshold horsepower-per-trailing gross-ton limits are desired, maximum allowable speeds should be reduced.

Decreasing maximum operating speeds is the "easiest"strategy to implement but sacrifices more running time for a given fuel savings level and may require either more horsepower in the fleet to handle a given level of traffic or some service reduction.

Seeking fuel savings while maintaining fleet size demands reductions in both horsepower-per-trailing gross-ton and maximum allowable speed.

The results of all three strategies have been verified by actual field testing. A year-long, in-depth fuel study and full implementation of the preferred strategy (B) for a major railroad resulted in a fuel rate savings of over 10 percent for the year 1974 when compared with the pre-embargo full year of 1972. A minimum running time increase of less than 10 percent was off-set by reductions in other train delays (See Appendix D) so that train schedules were maintained at the same levels.

The key to maintaining desired train schedule performance or dock-to-dock transit times while implementing fuel conserving operating policies is more intense concentration on reduction of these "other" delays. Seemingly, the "easiest" way to improve train performance is to add more horsepower. This is expensive, due to the many costs surrounding ownership and maintenance of locomotives, as well as increase in fuel cost. Often times,reduction in delays at terminals,by better dispatching and more care by maintenance-of-way forces, can be achieved without increased investments. It does, however, require a commitment by operating officers to reduce these delays rather than reduce train running times in order to achieve a desired level of operating performance. In some instances, cost-effective investments can be made to reduce these transit delays, such as hot-box detectors, improved signaling and better track arrangements for trains arriving and departing from train yards.

2.6 LOCOMOTIVE FLEET REGULATION

The key to successful implementation of the preferred strategy (B) is the appropriate short-term regulation of the locomotive fleet. It is suggested that gross-ton-miles per available-horsepower-day be the overall criterion for regulating the road freight service. This regulation will require short-term forecasts of the following variables and their relationships:

a. Expected traffic expressed in gross-ton-miles,

b. Expected horsepower of the owned and used freight locomotive fleet,

c. Expected horsepower balance of run-through freight trains with "foreign" (connecting) roads,

d. Expected horsepower out-of-service for mechanical attention,

e. Attainable locomotive utilization levels,

f. Expected horsepower changes required to accommodate fuel conserving policies.

With a target rate of gross-ton-miles per available horsepower-day for the coming forecasted period, the net horsepower available during that period will determine whether power must be added to the fleet or excess units stored.

Short-term additions to the fleet can come from modifying discretionary maintenance and repair policies for that period. Alternately, it might be possible to negotiate a temporary arrangement with connecting railroads for greater contribution of motive power in run-through train operations during the critical period. It might also be possible to negotiate arrangements with shippers to hold some traffic from delivery during that period, such as coal and ores which may be susceptible to stockpiling.

Generally, however, the effect of fuel-conserving operating policies is generation of excess horsepower, particularly during low traffic level periods. This excess horsepower should be stored spare-serviceable, and provides many benefits beyond fuel savings.

Importantly, it provides a reservoir for momentary surges in horsepower requirements that may last for only a few days. This excess also provides more flexibility for the mechanical officers in their maintenance and repair policies. Probably the most lasting benefit is the discipline of all personnel handling motive power. In practice, this short-term regulation, of itself, has enabled greatly improved overall utilization of the fleet and a consequent reduction of fleet size. This has resulted in large capital savings in avoiding locomotive purchases.

This short-term regulation of the fleet, depending upon the variability of traffic to be hauled and the service requirements, has always made sense even if fuel conservation was not the goal. Holding the fleet relatively constant with varying traffic loads results in similarly varying service performance or a waste of power.

2.7 TRAIN WEIGHTS

The primary criteria for assignment of horsepower to trains in a given territory are the priority rating and the reported weight of the train. The priority rating is based upon the desired schedule performance of that train. The reported train weights are usually based upon a small number of average tare weights to represent a large number of varied types of cars for the weight of an empty car. The net waybill weights reported by the shipper is usually the basis for determining the weight of the contents in a loaded car. Railroads using tare weights from the UMLER (Universal Machine Language Equipment Register) file maintained by the Association of American Railroads have a better tare weight basis. But the actual weight of a loaded car cannot be determined unless weighed by a scale.

In current railroad practice, most freight cars are not scale weighed. Experience concerning train performance in relation to reported train weights tends to bias power distribution personnel toward assigning more power than the reported train weight appears to warrant. Otherwise, at very low levels of horsepower-per-trailing gross-ton (near minimum continuous rating of the most limiting unit in the locomotive consist), train stalls on grades can result from the actual weight (felt by the locomotive) being greater than the reported weight. In a preliminary investigation on a major railroad, primarily utilizing dynamometer car data, it was found that the error in reporting car weights ranged from a minus 10 percent to a plus 5 percent compared with the actual weight. This finding suggests that the average train is about 5 percent heavier than reported.

Reporting of train weight must improve if short-term fleet regulation can be performed with confidence by railroad operating personnel in attempting to maximize potential fuel savings.

2.8 IDLING UNITS

While elimination or reduction of the amount of time locomotive units are idling appears attractive for conserving fuel, some perspective is important.

The maximum savings potential is estimated to be about 5 percent of system fuel consumed if <u>all</u> idling is eliminated. (Assuming a unit averages about 6 to 8 hours idling while not entrained, at an idle rate of about 1-3/4 gallons per 1000 horsepower-hours, this results in a consumption of about 5 percent for the average fleet.)

However, elimination of idling is not a simple matter. The starting of a diesel locomotive is a major shock to the entire locomotive system. Particularly during cold weather, the potential damage from freezing units and damage to the batteries can be extremely costly in diesel repairs and disruption of train operations. As a guide, if the ambient temperature is less than 40°F and the unit is expected to idle less than 4 hours, the engine should not be shut down. To the extent that unit idling can be reduced without potential damage to the locomotive, it is to be encouraged. But, if in doubt, it is recommended that the locomotive not be shut down. There are many more cost-effective means to conserve diesel fuel than the elimination of idling of stationary units.

Prolonged nonessential idling can have undesirable effects other than fuel consumption. Exhaust emissions are produced. Some engine manufacturers contend that wear rates of piston rings and cylinder liners are highest at idle. Carbon build up on injector tips can degrade injector performance and combustion efficiency.

One equipment manufacturer claims savings of over 80 percent of fuel consumption during idling by installation of its engine heater system. While some installations have been made, their cost-effectiveness may not be universal. It appears that cost analyses should be undertaken by individual railroads to determine whether a favorable cost-benefit ratio can be realized.

(The Storment, Ward, and Mathis report previously cited, <u>A Study of Fuel Economy and Emission Reduction Methods for Marine</u>

and Locomotive Diesel Engines, presents an excellent discussion of nonessential engine operation.)

Locomotive units in a train that are in excess of those required for dynamic braking might be idled rather than worked on lengthy downhill runs. Also, units in excess of operating requirements on level and lesser grade uphill runs could be idled, on the basis that the remaining units in the locomotive consist would be forced to operate at more efficient throttle positions.

In many railroad territories, the preponderance of traffic or motive power requirements is in one direction. This means that the locomotive units returned may not be fully loaded. Often times these units are moved back to the originating terminal "light," or without a trailing load. Many times these units are "worked" back to provide the balance required in the system by adding the balancing units to the normal train locomotive consist. If power "worked" back is greatly in excess of the normal requirements, then idling these excess units can effect considerable fuel savings. But, from a practical standpoint, if working power back to balance involves moving over severe grades, the fuel penalty is nominal compared with the sizeable improvement in running time.

2.9 FUELLING AND DISTRIBUTION LOSSES

It is estimated that the aggregate loss associated with distribution of diesel fuel on a railroad system from fuelling of locomotive units and spillage en route averages about 3 percent of the total diesel fuel used.

Losses in distribution come from evaporation, leaking pipeline fittings and pumps, leaking storage tanks, and breaks in the distribution pipe lines. Estimates of these losses on railroads range from about 1 percent to as high as 4 or 5 percent. However, given the current high cost and relatively criticality of diesel fuel, it appears that it is currently being held to less than 2 percent.

Spillage while fuelling locomotives is generally a more visible source for improvement, but probably accounts for less than 1 percent of total fuel used. (Some estimates are substantially higher than this.) The loss can be highly variable depending upon the fuelling system used. There are several automatic fuelling systems that greatly reduce spillage during fuelling operations. However, the amount of loss depends upon how well the systems are maintained. On most, if not all, railroads this maintenance responsibility is divided between maintenance-of-way for the fuelling nozzles and mechanical personnel for the locomotive fittings. Generally, the spillage occurs at the fitting between the fuelling nozzle and the opening to the locomotive fuel tank. When diesel fuel was 10 cents a gallon, the initial investment of costly fuelling systems and their high maintenance cost may not have been cost-effective. However, with fuel at 35 cents per gallon and the prospect of frequent shortages (worth over a dollar a gallon), it appears that installing improved fuelling systems or better maintenance for existing systems can be highly remunerative.

Spillage from the locomotive tanks while en route is another source of loss. From attempts to estimate this loss, it appears that the actual loss is nominal, probably less than an average of one-half of 1 percent. Most automatic fuelling systems have a cut-off level well below the over-flow level in the locomotive fuel tanks. Also, most fuel tanks are baffled to dampen the movement of fuel in the tanks. However, spillage is visible when moving up heavy grades after fuelling, if filled too close to the over-flow level of the tank.

2.10 LOCOMOTIVE UTILIZATION

Improved locomotive utilization is an excellent avenue for improved fuel efficiency. While there are even more compelling reasons for improving the use of that costly resource, fuel savings provide a bonus.

Lesser units in the fleet otherwise required to handle a given transportation effort will reduce the amount of idling, and will generally have the locomotive units operating at the higher, more fuel-efficient throttle positions during more of the locomotives' cycle life.

3. LOCOMOTIVE FEATURES IMPACTING FUEL USE

The basic diesel locomotive currently in use on railroads was designed and improved during an era of a plentiful supply of diesel fuel at a relatively low price. Diesel fuel is now considerably more expensive (about three times the cost) and is expected to become more scarce. It appears that the diesel locomotive design should be re-examined in the light of appropriately revised criteria.

3.1 ENGINE

The four-cycle diesel engine has exhibited fuel efficiencies compared with the two-cycle engine. Several railroads have made tests comparing the relative fuel consumption characteristics of comparable four-cycle and two-cycle engines of different major manufacturers. The consensus of these tests was that the four-cycle exhibits about 5 percent fuel savings compared with operating like two-cycle engines.

Fuel injectors influence the efficiency of fuel use by the diesel engines. Improved spray tips now available not only increase combustion efficiency thereby improving fuel economy, but reduce smoke and gaseous emissions and reduce engine deposits. It is estimated that these improved injector spray tips have increased fuel efficiency by one-quarter to one-half of 1 percent compared with former models. Currently, railroads have replaced or are in the process of replacing fuel injectors on most locomotive units.

Engine air intake filtration also influences fuel consumption. However, there are compromises between protection of the engine and the amount of pressure drop across the filter, which requires more horsepower and hence slightly greater fuel consumption. It is estimated that the average pressure difference is about 5 inches of water on most road locomotives in current use. Recent measurements indicate that a fifteen hundredths of 1 percent increase in fuel consumption occurs per inch of water pressure drop; if no filter is used, a savings of three-quarters of 1 per cent fuel savings could be realized. Several railroads have made comprehensive tests of various filter types, having wide differences in characteristics and costs. Unfortunately, those with the lowest pressure drop are either very expensive or they unload when reaching a saturated condition. Those such as the paper-type which normally provide good protection for the engine can plug, unnecessarily creating a higher pressure drop, and hence using more fuel for a given horsepower delivered. Competing filter manufacturers are working on improving the economics of air filtration, including the fuel consumption considerations.

There is no known control logic on present locomotives to automatically take individual units of a locomotive consist off-line or bring them back on-line. However, it is technically feasible to provide such a set of controls. The objective would be to keep the working locomotive consist at its most efficient throttle position (seventh or eighth for a turbo-charged locomotive) as much of the time as is operationally feasible. The logic might include taking units in excess of dynamic braking requirements off-line when moving down grades. The economic benefits of such an installation in terms of fuel savings might not yet be sufficient to support such an innovation. However, as fuel supply becomes critically short or considerably more expensive, it could become economically feasible. It is estimated that the potential fuel savings could be as high as 5 percent.

3.2 TURBO-CHARGES

The turbo-charged locomotive normally as a lower fuel consumption rate for delivered horsepower at higher throttle settings compared to a normally aspirated engine. This is even more pronounced when operating in higher elevations.

Operating comparison tests on a major railroad with heavy grades at higher elevations indicated a savings in favor of the turbo-charged locomotive of about 5 percent. The main disadvantage is the cost of maintenance, which is somewhat higher for the turbo-charger compared to a Roots Blower.

The turbo-charger parts-catcher, on some power, produces a sizable pressure drop, whereas some turbo-chargers do not. From preliminary tests that have been made, there is an estimated 2 to 4 percent fuel savings between the two types of turbo-chargers.

3.3 PARASITIC LOADS

The external parasitic load constitutes about 10 percent of the crankshaft horsepower of diesel locomotives currently in use. This load is associated primarily with the air compressor, radiator cooling system and auxiliary generators. It is estimated that there is a technically feasible potential improvement of over 1 percent reduction in fuel consumption per horsepower delivered at the rails, by reducing the horsepower required for these parasitic loads.

The air compressors on all diesel locomotives are directly connected to the prime mover and operate at the same rpm (revolutions per minute) as the prime mover. When there is no need for air, the air compressor is unloaded, but continues to operate; the load on the prime mover remains at a reduced level, but is measurable. Potential fuel savings from clutching or turning off the air compressor when not needed is estimated to be about one-eighth of 1 percent at a 4 percent load factor. However, the control or clutching mechanism required does not appear to be cost-effective at current fuel cost and supply levels.

The cooling fans of certain locomotives take a considerable amount of horsepower, being driven directly from the prime mover without a clutch. It is estimated that as much as 1 percent fuel saving is realized for those locomotive types having a clutching mechanism.

3.4 LOCOMOTIVE WEIGHT

Weight on drivers is important for the tractive effort required from a locomotive, particularly at starting. Currently, the adhesion factor in starting with sand on dry rail is about 25 to 30 percent. Despite rather sophisticated wheel-slip devices now on U. S. diesel locomotives, there are European electric locomotives capable of higher adhesion, permitting lower locomotive weight per horsepower and tractive effort produced. On U.S. roads, the average weight of the locomotives constitutes between 8 and about 16 percent of the total weight of the train. At lower speeds and on ascending grades, the train weight (including that of the locomotive) is the principal source of resistance experienced by a locomotive. For example, using the Davis formula for train resistances and 20 pounds per ton of train weight for each percent of grade, for a freight train with an average car weight of 50 tons operating on level tangent track at 30 miles per hour, the weight factors account for almost one-half of the total resistance encountered; for that same train ascending a 1 percent compensated grade at 30 miles per hour, the weight factors account for almost 90 percent of the total resistance.

To the extent that the weight of a locomotive can be reduced and still provide equivalent transportation effort, consumption can be improved. Adhesion improvement is the key to locomotive weight reduction. While six-axle units may be desirable for some operations, from a fuel standpoint, wherever possible, four-axle locomotives are preferable to six-axle units of equivalent horsepower and other characteristics (a six-axle unit is approximately 50 percent heavier than same rated four-axle unit). It is estimated that fuel usage is increased by 1 percent when a six-axle unit is used where a four-axle unit will provide sufficient tractive effort. The potential benefit of substantial improvement in adhesion could be several times that amount of fuel savings, although this has been a difficult area in which to make advances.

3.5 LOCOMOTIVE MAINTENANCE

While fuel savings is not normally the primary purpose for proper maintenance of a locomotive, it does provide another incentive.

When a locomotive unit is not capable of delivering full power due to inadequate maintenance, requiring more locomotive weight in a train relative to traffic handled, then fuel is unnecessarily consumed. Rough idling of the locomotive is also a waste of fuel, and can be detrimental to the engine itself. The most visible lack of maintenance(from a fuel conservation standpoint) are fuel line leaks. Locomotive fuel tank leaks can be very costly from a fuel loss standpoint. Proper maintenance of fuel tank fittings is important in preventing spillage during fuelling operations.

While its cost-effectiveness is difficult to ascertain, installation of kilowatt-hour meters on locomotive units would be useful in determining the efficiency in use of fuel. It would also provide a diagnostic of the performance of the locomotive unit. Use of kilowatt-hours or fuel consumed should provide a better basis for preventative maintenance programs or other periodic maintenance than the currently used time or mileage operated bases.

3.6 "IDEAL" DIESEL LOCOMOTIVE

From the standpoint of fuel efficiency only, but deemed completely feasible, the following is a description of an ideal road diesel locomotive:

a. Easily maintained

b. Three thousand horsepower

c. High adhesion

d. Four-axle

e. Turbo-charged without a parts catcher

f. Using low-pressure-drop engine air filters

g. With controllable cooling fans and the air compressor disengageable when not needed

h. Clean cut-off fuel injectors

i. Built-in control logic to automatically take individual units of a locomotive consist on-and off-line while the train in running and unit is not needed.

Table 5 is a comparison between the "ideal" locomotive and both the currently least and most fuel-efficient road locomotives. These estimates are the author's consensus from a review of the results of tests conducted on individual railroads and discussions with knowledgeable railroad locomotive maintenance officers. In summary, the ideal locomotive has a potential improvement of about 5 to 17 percent compared with a relatively fuel-efficient model, which in turn is about 12 percent greater than one of the least fuel-efficient models. While the comparisons are admittedly "unfair" since the operating choice of units is also based upon a number of other considerations, it is used to show extreme differences in the fuel efficiencies of existing models.

TABLE 5. COMPARISON OF FUEL SAVINGS FROM LOCOMOTIVE FEATURES

Feature	Least Efficient Current Model	Most Efficient Current Model	Est. Ideal	
			Min.	Max.
Two vs. Four Cycle	0%	5%	5%	5%
Furel Injector	0	0	.5	.5
Engine Filters	0	0	.5	.5
Automatic On-Off Unit Control	0	0	1	5
Turbo-Charger	0	5	5	7
Turbo Parts Catcher	0	2	2	4
Cooling Fan	1	0	1	1
Parasitic Loads	0	0	1	3
Six vs. Four Traction Motors	0	1	1	1
Adhesion	0	0	1	3
TOTAL	1%	13%	18%	30%

4. CONTROL OF FUEL USE

Most railroads have not had a coordinated diesel fuel control system. The accounting,purchasing, mechanical, maintenance-of-way and operating departments all have various responsibilities in controlling fuel use.

Fuel is purchased and delivered into storage tanks by pipe line, railroad tank cars and tank trucks, or by direct tank truck delivery to locomotive. Thereafter, fuel is distributed by pipeline and hoses from storage tanks into the locomotive, and by transfer to in-house tank trucks for delivery to the locomotive. Another less visible source is the net fuel balance with foreign roads in run-through train operations.

The critical events in controlling fuel include: on-hand fuel inventory, draw-downs from storage, deliveries to storage, amount of in-house fuel dispensed to locomotives, amount of fuel dispensed to locomotives by outside suppliers by tank truck deliveries, and running net fuel balance with foreign roads in run-through operations.

4.1 FUEL CONTROL PROCEDURES

4.1.1 On-Hand Inventory

Most storage tank readings are taken from the float indication on above ground tanks or "stick" readings in underground tanks. These levels do not compensate for condensation that has occurred between successive readings. They are usually not temperature corrected, and the least count is wide on most gages. These factors all combine to greatly reduce the accuracy of these readings. The recommended procedure is to have temperature-correcting input and output meters on large storage tanks.

4.1.2 Deliveries to Storage Tanks

Deliveries by pipeline are usually measured by temperature-correcting meters which are certified. Delivery by tank car is usually taken as shell capacity of the car at $60^{o}F$.

Tank car delivery deserves special attention if not metered into storage. Depending upon the unloading method, the residual amount of fuel remaining in the car after completion of unloading can be considerable. Top unloading leaves the greatest amount of fuel (about one-half of 1 percent), although bottom unloading does leave small but measureable amounts (one-tenth of 1 percent). If the unloading track is other than level, the respective residuals left in the car will be amplified. The recommended procedure is to have temperature-corrected metering of fuel delivered into storage. Also, billing from the supplier should be based upon fuel metered into the tank car rather than billing on the basis of shell capacity of the car. (In one field check, it was found that as much as 13,000 gallons of fuel were still contained in a supposedly empty 20,000 gallon tank car awaiting refilling.)

4.1.3 Draw-Downs from Storage

If the distribution network from storage is extensive, then meters positioned in the out-flow line should be installed to measure how much fuel is drawn from storage. Even if distribution network is short, simple out-flow meters should be installed if fuel is not metered to individual locomotive units.

4.1.4 Fuelling of Locomotives

Usually the amount of fuel dispensed at a given locomotive fuelling location is taken from the differential (or successive) reading of the float guage on above-ground storage tanks or stick readings in underground tanks. Even where differential meters are installed to and from storage tanks, there is a loss of control from distribution leaks, spillage during servicing, or theft. The recommended procedure is to meter fuel to individual units. There are currently fuel recording systems that generate machine readable reportings for computer processing of fuel data. This metering of fuel to individual units also provides a sound basis for locomotive maintenance cycles.

Fuel dispensed by tank truck deliveries from outside suppliers, either to storage or directly into the locomotive is metered and poses no problem unless machine readable data is required. Fuel dispensed by in-house tank truck delivery should also be metered.

4.1.5 Net Fuel Balance with Foreign Roads

Usually fuel exchanges in run-through agreements are based upon the respective fuel use during a brief test period at the inception of the run-through operation. After an exhaustive review of many run-through agreements, it was found by the author in a previous study that operations many times have changed substantially from those exisitng at the time of the initiation of the outstanding agreement.

It is recommended that all run-through agreements should be evaluated to determine whether the operating conditions have changed. This can be accomplished by measuring the amount of fuel remaining in the locomotive tank at interchange points where run-through trains change crews for going off-line. A month of daily readings is sufficient. Then, when significant changes occur by either party to the agrrement, this taking of readings should be made again. The fuel balances with foreign roads should be monitored at least on a monthly basis. In times of tight supply, the amount of fuel placed into locomotive fuel tanks could be regulated so as to maintain a net zero balance or an equalizing of fuel use with its run-through partners.

4.2 FUEL CONTROL ORGANIZATION

The recommended control organization should be headed by an operating officer reporting to the Vice President-Operations and should be responsible for monitoring the operating use of diesel fuel, coordinating the various activities for controlling fuel, and continually evaluating changes in operations required in order to meet fuel-use goals. This Director of Fuel Control would also be responsible for establishing a fuel budget, particularly during periods of expected short supply. This control of fuel use should include periodic operations audits if the existing information system does not contain the prerequisite information for evaluating fuel use.

4.3 OPERATIONS AUDITS

Using logic similar to that described for the FUEL Model (See Appendix C), a method has been developed to audit current operations. Only selected data from train dispatcher sheets and locomotive speed tapes are used as input for this audit procedure. The outstanding assessments possible from the audit are: the difference in rate of fuel use per gross-ton-mile, either compared with a simulated base period or a simulation of the current policy; the relative rate of use of horsepower; the comparison of minimum running times; the portion of fuel consumption that was controllable under existing traffic balances by direction; and the impact of exceeding maximum allowable train speeds.

4.4 MEASURES OF EFFECTIVENESS

The recommended measure for evaluating corporate effectiveness in diesel fuel use is net-ton-miles per gallon of fuel consumed. This overall measure embraces the performances in heavier loading of cars, reduction of empty car miles, more fuel efficient train operations, reduction of fuel spillage and distribution losses, and better control of all fuel activities.

The recommended measure for assessing the fuel-effectiveness of railroad operating departments in freight train operations is total gross-ton-miles (based upon weight of both locomotive and trailing loads) per gallon of total fuel consumed. Complementary measures providing additional useful information of freight train operations are: trailing gross-ton-miles per gallon of fuel and the ratio of locomotive gross-ton-miles to total gross-ton-miles.

All of these measures demand both consistent ton-mile and fuel-consumed data. Most present accounting and fuel control systems do not maintain these data on a current basis and consistent with the time periods for both sets of data. The ability to control fuel use depends on good train weight data for the ton-mile determinations and the amount of fuel consumed during the period of the generated ton-miles, both net and gross. For example, if a goal is established for achieving 500 total gross-ton-miles per gallon of fuel consumed, then current weekly or monthly evaluations must be founded upon total fuel taken from inventory during that period and total gross-ton-miles generated during that same period.

4.5 IDEAL FUEL CONTROL SYSTEM

In the ideal fuel control system the following elements exist:

a. All freight cars are scale weighed before being placed in a road train.

b. The major fuel storage tanks have temperature-correcting meters both to and from storage

c. All fuel dispensed to locomotive units is individually metered and a fuel record maintained for each unit

d. All metered fuel information is generated in machine readable form.

e. Logic similar to the FUEL Model is computerized for simulating the fuel effects of changing operating policies

f. Diesel fuel is budgeted based upon expected supply and desired operating performance.

5. CORPORATE STRATEGIES

Since adequacy of fuel is essential to performing railroad service, the prospect of diesel fuel shortages should prompt a re-examination of corporate policies and goals. The economics of investment alternatives have changed drastically with the recent greatly increased price of diesel fuel.

5.1 VALUE OF "SHORTED" FUEL

The value of diesel fuel when necessary to prevent the rejection of offerred incremental traffic is currently well over 1 dollar per gallon. (See Appendix B).

Assuming a 60 percent variable cost for incremental traffic results in a 40 percent gross margin available for overhead, fixed charges, and profit. Based upon current revenues and amount of fuel consumed in earning these revenues, this value in 1974 ranged from $1.14 to $1.73 for the 10 representative railroads evaluated. Theoretically, this amount would be in addition to the average price paid for fuel by these same roads of 24¢ and 27¢, respectively, since the cost of fuel is considered as a portion of the 60 percent variable cost assumed. The variable cost relationship does vary among railroads, and this value of shorted fuel cannot be determined precisely; however it does appear that 1 dollar per gallon is a conservative estimate of the worth of diesel fuel in railroad operation if not having fuel is the sole reason for not accepting traffic that would otherwise be handled by the railroad.

As with all averages, this value of "shorted" fuel is approximate for planning purposes for "average" traffic. It is suggested that the profitability of the specific traffic offered be determined before generating greatly higher cost fuel.

5.2 HEAVIER CAR LOADING

Increasing the net loading of cars can increase fuel efficiency considerably with minimal loss to schedules and nominal increases in horsepower required. The net-to-gross ratio on the 10 roads evaluated was 41 percent during 1974. Therefore, a 5 percent increase in loading cars moved would result in a 2.05 percent increase in gross-ton-miles and fuel consumed. This would amount to a net fuel savings of almost 3 percent. The same type of fuel savings is possible by reducing empty car miles. Promoting heavier loading by direct appeal to shippers or offering rate incentives could improve profitability as well as fuel efficiency for some traffic.

An evaluation of the aggregate change by the 10 railroads (Appendix B) from 1972 to 1974 indicates significant improvement in net ton miles per gallon compared to the gross-ton-miles per gallon of fuel, reflecting the railroads' progress in increasing the net-to-gross ratio.

5.3 ON-HAND SUPPLY

In order to accommodate sudden fluctuations in the supply of fuel and the demand for services, it appears that a 15-day on-hand supply should provide the lead time to make necessary adjustments to operations on a large railroad system. This 15-day criterion is particularly important for storage capacity at the major dispensing points.

5.4 CONTINGENCY PLANS

While some railroads have more potential for fuel savings than other roads, at some point all means of further conserving fuel will be exhausted. For that contingency, a railroad should develop a policy to cover when it cannot handle all available traffic for lack of fuel. The following considerations might be pertinent:

a. What degree of control exists for various segments of traffic (forwarded, received, interline, local)?

b. What service priorities are to be maintained or changed?

c. Should short-term profitability be an objective?

d. Is it an opportunity to improve long-term market share of a particular segment of traffic?

e. What political expediencies should be undertaken?

f. Should some traffic be embargoed?

g. Should operating stop altogether when fuel runs out?

5.5 ELECTRIFICATION

With the expected increasing scarcity of petoleum fuels and the rising price, electrification provides an attractive long-term alternative to diesel power. Aside from the fuel considerations, electrification also can provide sizeable savings in recurring maintenance of motive power costs.

Unfortunately, the extremely high initial investment for fixed facilities and conversion of the fleet from diesel to electric motive power involves a high risk except over lines where there is a certainty of extremely high density.

For the last 15 years, numerous common carrier freignt railroads and the government have pursued electrification studies, but none to date have been implemented. Actually, the amount of electrified trackage (other than transit) has decreased considerably over this period.

Unquestionably, the advantages of electrification are well recognized. Realistically, the demand for funds by the railroads is large and necessary capital is difficult to attract from the investment community. Internally generated funds are not sufficient to provide the necessary funding for most normal requirements, much less the almost unlimited funds demanded by even selective electrification of certain high density routes. It may be that federal government guarantees or direct grants will be required in order to finance even the highly cost-effective electrification candidates.

6. CONCLUSIONS

The railroads have made considerable progress in effectiveness of fuel use since the October 1973 embargo, as measured in net-ton-miles carried per gallon of diesel fuel. However, as evidenced by the significant improvement made by some railroads in gross-ton-miles per gallon, there is considerable remaining potential for improvement by the other railroads in operating efficiency of fuel use.

In the short-term, the most promising avenue for conserving fuel is design of operating tactics specifically to conserve fuel while maintaining desired service levels. The preferred strategy is reducing horsepower-per-ton limits for a given level of traffic. The former strategy results in less horsepower required in the fleet. All operating strategies for conserving fuel result in an increase in train running times. However, the overall schedule time should be the operating criterion. Reduction of other train delays in terminals and at interchanges, through improved train dispatching and elimination of car-handling errors and by improved equipment maintenance can be used to compensate for this loss of over-the-road running times occasioned by the fuel conservation measure. The key to successful implementation of this preferred strategy is the short-term regulation of the locomotive fleet.

Improved fuel controls are vital to assuring effective use of diesel fuel. As a minimum, metering of fuel to and from large storage tanks ahould be standard practice in order to have the necessary real-time information needed for control. Preferably, fuel would also be metered and records maintained for fuel use by individual locomotive units as well. These controls will become vital, if fuel supply becomes short and requires budgeting to support corporate goals.

In the long-range, railroads must have locomotives which are more fuel-efficient than current models. Even with currently available models, some diesel locomotives are considerably more fuel-efficient than others. It is believed that another 10 percent improvement is not only technically feasible, but is economically feasible, compared with the current most fuel-efficient models.

In the long-range, the conversion from diesel-electric to electric motive power may become necessary. However, it appears that the cost to the national economy will be much greater than the alternative of limiting private automobile use if allocation of an insufficient supply becomes mandatory.

The means of conserving diesel fuel described throughout this report should provide railroads with attractive economic returns for their efforts. If more incentive is needed, this conservation attitude will become a needed discipline should fuel users experience more frequent and more severe shortages. This same discipline will be required from all users of energy if the United States is to reduce its dependence on unreliable or limited sources to satisfy its demands on petroleum fuels. Hopefully, the railroad community will provide even more than its conservation share and lead all users toward conserving this increasingly precious resource.

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APPENDIX A

AVERAGE FUEL CONSUMPTION

SELECTED DIESEL LOCOMOTIVES (GALLONS DIESEL FUEL PER HOUR)

LOCOMOTIVE	THROTTLE POSITION 8	7	6	5	4	3	2	1	Idle	Dynamic Brake
EMD SW1000-1000hp	60	50	40	31	22	13	6	5	3	-
EMD SW1500-1500hp	93	80	62	52	39	25	12	6	4	-
EMD GP/SD7-1500hp	93	75	60	46	34	23	14	6	4	-
EMD GP/SD9-1750hp	108	82	68	52	37	24	13	5	4	-
GE U18B-1800hp	103	85	72	56	42	24	16	11	4	20
EMD GP20-2000hp	116	86	69	55	42	28	14	6	4	-
EMD GP/SD38-2000hp	122	103	83	64	47	31	16	7	5	25
EMD GP30-2250hp	125	102	75	61	45	31	19	7	4	-
GE U23B,C-2300hp	112	92	81	64	48	27	17	12	4	20
EMD SD24-2400hp	144	106	81	61	44	30	18	6	3	-
EMD GP/SD35-2500hp	144	124	96	72	51	35	21	11	5	-
EMD GP/SD40-3000hp	168	146	108	79	57	41	25	7	6	25
GE U30B,C-3000hp	149	127	102	81	62	34	22	16	5	26
GE U33B,C-3300hp	163	138	110	87	65	36	23	16	5	26
GE U36B,C-3600hp	177	150	119	94	69	39	24	16	5	26
EMD SD45-3600hp	194	172	127	92	68	48	28	10	6	25

APPENDIX B

SELECTED RAILROAD FUEL CONUSMPTION CHARACTERISTICS

1972 vs. 1974

			ATSF	BN	CRIP	DRGW	ICG	MOP	N&W	SOU	SP	UP	TOTAL*
A	Freight Revenues ($Millions)	1972 1974	822.4 1054.6	980.2 1258.2	294.5 351.7	111.1 138.7	390.8 544.9	443.2 617.3	775.0 956.8	461.1 555.7	1105.7 1301.7	763.4 978.9	6147.4 7758.5
B	Cost Freight Fuel ($Millions)	1972 1974	30.8 85.8	33.1 84.8	12.3 27.2	5.2 11.8	14.5 34.1	13.4 38.9	25.7 59.9	15.5 39.5	37.5 92.2	31.4 75.0	219.4 549.2
C	Freight Fuel Used (Million Gallons)	1972 1974	299.9 330.2	326.0 338.7	109.5 103.8	46.9 48.7	109.0 126.0	119.5 149.1	223.8 225.9	137.0 139.8	383.8 368.0	288.5 287.4	2044.0 2117.7
D	Average Price per Gal. (¢)	1972 1974	10.3 26.0	10.2 25.0	11.2 26.2	11.2 24.1	13.3 27.0	11.2 26.1	11.5 26.5	11.3 28.2	9.8 25.1	10.9 26.1	10.7 25.9
E	Net-Ton-Miles (Billions)	1972 1974	53.0 58.9	65.4 77.0	20.7 19.9	7.7 8.9	26.8 33.2	31.1 39.4	49.0 53.2	28.1 29.7	71.1 70.9	51.8 56.9	404.7 443.0
F	Net-Ton-Miles per Gallon	1972 1974	176.6 178.5	200.5 227.2	188.8 191.3	164.3 182.3	245.4 263.8	260.6 264.3	218.8 235.6	205.3 212.3	185.3 192.6	179.6 198.0	198.0 211.5
G	Loco. Gross-Ton-Miles (Billions)	1972 1974	22.9 24.2	18.5 19.8	5.2 4.6	2.7 2.8	5.2 5.9	6.6 7.5	9.1 8.8	6.3 6.5	23.2 21.8	17.7 19.6	117.5 121.5
H	Trailing GTM (Billions)	1972 1974	125.0 134.2	145.7 169.6	44.9 42.1	16.1 17.5	55.4 62.7	64.7 77.1	101.5 108.8	60.3 63.1	165.3 162.5	118.1 133.0	896.9 970.6
I	Total GTM* (Billions)	1972 1974	147.9 158.5	164.3 189.4	50.1 46.7	18.8 20.2	60.6 68.7	71.2 84.6	110.7 117.5	66.5 69.6	188.5 184.3	135.8 152.6	1014.4 1092.1
J	Locomotive GTM / Total GTM	1972 1974	15.5% 15.3%	11.3% 10.5%	10.3% 9.9%	16.7% 15.9%	8.6% 8.6%	10.1% 9.7%	8.3% 7.4%	9.5% 9.3%	12.3% 11.8%	13.0% 12.8%	11.6% 11.1%
K	Total GTM per Gallon	1972 1974	493.0 480.0	504.0 559.1	456.9 450.3	400.4 415.2	555.6 544.8	596.0 567.3	494.5 520.2	485.2 497.9	491.1 500.9	470.8 530.8	496.3 515.7
L	Value of Shorted Fuel (¢)	1972 1974	109.7 127.8	120.3 148.6	107.6 135.6	94.7 113.8	143.4 173.0	148.4 165.6	138.5 169.4	134.6 159.0	115.2 141.5	105.8 136.2	120.3 146.5
M	Change NTM/Gallon	1974/1972	+1.1%	+13.3%	+1.3%	+4.9%	+7.5%	+1.4%	+7.7%	+3.4%	+3.9%	+10.2%	+6.9%
N	Change TGTM/Gallon	1974/1972	-2.6%	+10.9%	-1.4%	+3.7%	-1.9%	-4.8%	+5.2%	+2.6%	+2.0%	+12.8%	+3.9%
O	Ratio Fuel Price	1974/1972	2.5	2.5	2.3	2.2	2.0	2.3	2.3	2.5	2.6	2.4	2.4

* Totals may not add due to rounding.

Source: Railroad Annual Report Form A for year 1972, and Railroad Annual Report R-1 for year 1974

APPENDIX C

FUEL MODEL DESCRIPTION

The FUEL (Fuel Utilized Effectively-Locomotives) Model was developed by The Emerson Consultants, Inc., for the Union Pacific Company. It employs input data readily available on most railroads. It is used to investigate the effect of train operating strategies upon consequent changes in: fuel consumption, horsepower required and minimum train running time. The model provides a comprehensive analysis of changes in train operating policies: maximum speeds allowed throughout the railroad and horsepower-per-trailing-ton(hp/ton) limits between all power change points (locations where train consist may change, either the locomotive set or trailing cars, or both). A simplified set of inputs and logic are used for conducting audits of train operations to evaluate projected versus actual results from changes in operating policies and changes in traffic levels.

Operating policies are simulated by FUEL for individual geographical railroad territories whose boundaries are the power change points within the train operating system. Trailing gross-ton-miles, by direction, are determined for a simulation base period. Trains operating over these territories are classified into two groups, premium and regular trains. Premium trains are of higher priority which are permitted to run at higher maximum allowable speeds and higher horsepower-per-ton than the regular trains.

An "average" train, by territory and direction, is developed from the analysis of all trains operated over those territories during the base period. Total tonnage and total number of cars are divided by the respective number of trains for each territory-direction to establish the average train set.

These average trains are then "run" through a Train Performance Calculation Computer Model over each territory at varying maximum speeds and at varying horsepower-per-ton, using the Modified Davis Formula for calculating train resistances.

Further, a Control and Reverse direction is identified for each territory. Essentially, the direction in which either grade conditions are more severe or more tonnage consistently moves becomes the Control direction, since it will be the determining basis for territory horsepower requirements. The other direction with lesser horsepower requirements becomes the Reverse direction and "absorbs" the horsepower in excess of its requirements in trains returning to the power change point.

C.1 INPUT

The primary sources of railroad information to provide the data for FUEL are:

a. Dispatcher's Record of Movement of Trains (Train Sheets)

b. Listing of premium and regular trains

c. Horsepower Master List (documents characteristics of each locomotive unit in the fleet to convert locomotive unit numbers on Train Sheets to horsepower)

d. Manifest Train Schedules (published train schedules to verify Train Sheet train information)

e. Locomotive Tonnage Rating Tables (these tables enable a determination of the necessary horsepower required to maintain minimum continuous speed for any class of locomotive operating on the ruling grades over each territory direction)

f. Condensed Profile (this is a schematic topographical profile of the railroad to assist in determining Control directions and tonnage ratings)

g. Recap of Premium and Regular Trains and Information extracted from the Train Sheets for each territory direction, segregated by Premium and Regular (through freight trains), showing train symbol or identification, horsepower used on each train, total trailing tons on each train)

h. Output from Train Performance Calculation Computer Model (by territory-direction at varying horsepower-per-ton and maximum allowable speed, fuel consumption tables and minimum running time tables are developed for respective average train)

C.2 MODEL LOGIC

Given the inputs described in the previous section, the FUEL Model Manual describes the logic sufficiently to perform the calculations manually or, if sufficient trials are to be made, by a computer program.

Essentially, the Model for a given maximum horsepower-per-ton limits and maximum speeds allowable for premium and regular trains, by territory direction, determines:

1. Change in horsepower requirements
2. Change in fuel consumption
3. Change in minimum train running time.

The territory-direction results can then be aggregated to determine the overall system results.

C.3 AUDIT OPTION

After operating policies were changed to conserve fuel, it was highly desirable to audit the actual operations to determine if the fuel savings were actually realized relative to the projections.

By comparing a sample of trains during the audit period with a sample during the base period, the differences are evaluated to answer the following questions:

1. What are the actual fuel savings (fuel rate change)?
2. What is the change in horsepower used (horsepower use rate change)?
3. What is the impact on minimum train running times (minimum running time rate change)?

Much of the same FUEL Model Simulation inputs are required using a simplified logic, but also required are actual speed tapes from the locomotive units of the trains sampled during the audit period. These speed tapes are required to determine compliance with the maximum speed policies. Also, should traffic changes occur by direction over a territory, then the locomotive requirements in the control direction is the criterion and may require an adjustment to reflect an increase in fuel consumption rate in the reverse direction (beyond that required during the base period). This may be due to increased traffic in the reverse direction and beyond the control of operating officers. Therefore, a determination is made during this simulated audit of how much change was controllable.

C.4 MODEL VALIDATION

Since the FUEL Model is highly dependent upon the Fuel Consumption Tables and Minimum Running Time Tables produced by the Train Performance Calculation computer program, it was necessary to validate the output of the TPC program in order to project real world expectations from simulations of the FUEL Model. Other elements of the FUEL data base were also validated as were the overall results of FUEL Model.

The TPC validation process consisted of a validation series and a sensitivity series of tests. The validation series consisted of three sets: 1) Thirty-four dynomometer car runs analyzed in depth and "run" through TPC and compared, mile-by-mile; 2) comparison with TPC programs developed by others using same dynomometer car run trains; 3) comparison with locomotive speed tapes. As a result of this validation series, it was found that factors for both fuel consumed and minimum running times were needed in order to calibrate the Model with the real world. Based upon an estimated accountability of all fuel consumed by the real world as compared with the amount of fuel accounted for in the TPC program used, it was determined that approximately 8 percent should be added to the TPC program fuel consumption output in order to approximate the amount of fuel consumed by the same train in the real world. Based upon a comparison with 34 dynomometer car test trains, it was determined that minimum running times from the TPC program output, coincidentally, should also be increased about 8 percent to obtain minimum train running times to be expected in the real world. These differences were mainly explained by the assumptions used in the TPC program of a "perfect" engineer handling a "perfect" locomotive, whereas these characteristics are rarely achieved in the real world.

The sensitivity series consisted of the following: Number of train stops to test TPC program's sensitivity to number of times train stopped en route and the respective changes in fuel and run time; with trains of constant weight and hp/ton, the fuel and run time effect of changing the number of cars; a constant trailing load train, but changing horsepower, and assessing fuel and run time effect; locomotive type set involved using different locomotive manufacturer units and assessing modeled fuel and run time effect when running the same train; speed set which became the basis for fuel consumed and minimum running time graphs for analysis and tables which were used for input to the FUEL Model.

The FUEL Model data base was also validated by comparing the horsepower, gross-ton-miles, fuel consumption results of the base run with actual used during that period. Also, an analysis was made to determine the error in using an "average" train to represent all trains over a certain territory-direction. Comparing the fuel consumed by a number of simulated "average" trains with that consumed by the aggregate of the same number of simulated individual trains (comprising the average), resulted in a 2 percent under-estimation of fuel consumed by using the average train.

Conclusions drawn from the extensive validation was that as long as FUEL Model simulations of operating policy changes are compared with a simulated base or a simulated existing policy, it should provide reasonably accurate differences in fuel consumed, horsepower required, and minimum running time.

APPENDIX D

TRAIN INTERFERENCE UNRELATED TO HORSEPOWER

A. Maintenance of Way
   1. Faulty signal indication
   2. False hot box detector indication
   3. Slow orders
   4. M of W occupying track section
   5. Broken rail
   6. Faulty switch
   7. Torpedoes on rail but no obstruction

B. Freight Equipment
   1. Shifted Load
   2. Break-in-two
   3. Faulty train air
   4. Bulkhead flats, high-wide loads, etc.,requiring reduced speeds
   5. Dragging equipment
   6. Heated journal
   7. Unscheduled set-out of bad-order car

C. Over-the-Road Operating
   1. Following train ahead
   2. Train ahead going into siding
   3. Opposing train going into siding
   4. Derailment ahead
   5. Hold for another train
   6. Waiting in siding
   7. Saw-by another train
   8. Pick-up and set-off dead-head crews
   9. Held out of yard due to lack of receiving tracks or yard congestion
   10. Make reverse move in double-track territory
   11. Meeting wide loads
   12. Missing train orders
   13. Train in trouble on opposing double track

D. Accidents
   1. Strike cattle, vehicles, or trespassers
   2. Sideswipes or train collisions
   3. Slides and washouts
   4. Derailment of train

E. Terminals
   1. Lack of ready power or cabooses
   2. Late make-up

3. Late in processing bills
4. Last minute diversions
5. Late call for crews
6. Late from connections
7. Congestion in outbound or inbound path

F. Other Causes
1. Speed restrictions due to city ordinances
2. Cut train at grade crossings
3. Poor visibility
4. Vandalism

APPENDIX E

REPORT OF INVENTIONS

A diligent review of the work performed under this contract has revealed no innovation, discovery, improvement, or invention.