Energy Conservation -- Multiple Unit Locomotive Throttle Control

M.E. JACOBS

Research Engineer, Mechanical Systems
Office of Freight Systems
Federal Railroad Administration
Washington, D.C.

ABSTRACT

During unit train tests performed on the Burlington Northern and Union Pacific railroads, significant fuel savings were realized by using a semi-automatic throttle control device or "fuel saver" system to take one or more units of the locomotive consist off line when the available power and tractive effort exceeded the demand. This procedure effectively lowered the horsepower per ton ratio of the train and decreased the rate of fuel consumption. For the particular set of operating conditions tested the average fuel savings reached 9.8% and 12.4%. A prime ingredient for the effective use of such a device was the operating locomotive engineer.

INTRODUCTION

Reducing fuel consumption in rail freight transportation has become increasingly cost effective. As the price of diesel fuel continues to spiral upward, substantial investments in improved locomotive maintenance practices, operating efficiencies, and control devices to decrease fuel consumption have become a necessity.

Recognizing this need for increased fuel conservation, the Federal Railroad Administration sponsored a research study by J. N. Cetinich entitled Fuel Efficiency Improvement in Rail Freight Transportation*. This report presented an excellent discussion of how to design train operating policies specifically to conserve fuel while continuing to provide desired schedule and service performance. In addition to the presentation of an overall operating policy for the rail industry, the author discussed nine items characterizing the ideal diesel road locomotive from the standpoint of fuel efficiency. Accordingly, the ideal diesel locomotive would:

1. Be easily maintained
2. Have 3000 horsepower
3. Have high adhesion
4. Be four axle
5. Be turbocharged without a parts catcher
6. Use low pressure drop engine air filters
7. Have controllable cooling fans and air compressor disengagable when not needed
8. Have clean cut-off fuel injectors
9. Have a built-in control logic to automatically take individual units in a locomotive consist on and off line.

With respect to the last item, the objective of such a control device would be to keep a working turbocharged consist at its most

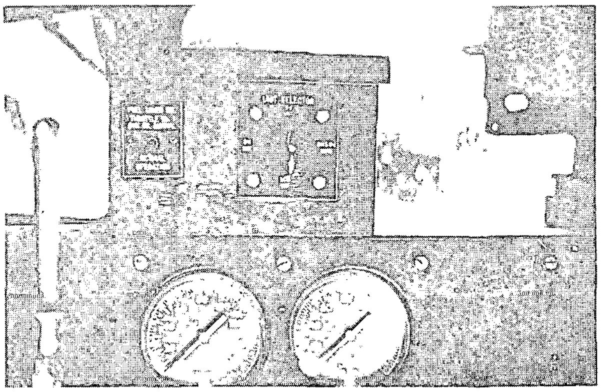

Fig. 1 Fuel saver control box on locomotive control stand

* Available from the National Technical Information Service; Springfield, VA. 22161; NO. PB 250673.

efficient seventh or eighth throttle position as much of the time as is operationally feasible by reducing to number one throttle those units in excess of the normal operational requirements. This procedure effectively lowers the horsepower per ton ratio of the train and decreases the rate of fuel consumption. In a practical field application, the number one throttle position is selected in preference to the idle position in order to maintain the dynamic brake capability of the units selected for throttle reduction. Because of the principles involved in using the control device, a decrease in fuel consumption can be expected for those trains operating on level grades, on lesser uphill grades, and on lengthy downhill runs where the number of operational units in the locomotive consist is most likely to exceed the power requirements.

The objective of this paper is to quantify the actual fuel savings resulting from the usage of one such a device in an operating locomotive consist. Commonly referred to as the "fuel saver" system, the device itself is amazingly simple. It consists of a control box mounted on the control stand in the lead unit of the consist (Fig. 1) and a "fuel saver set up switch"

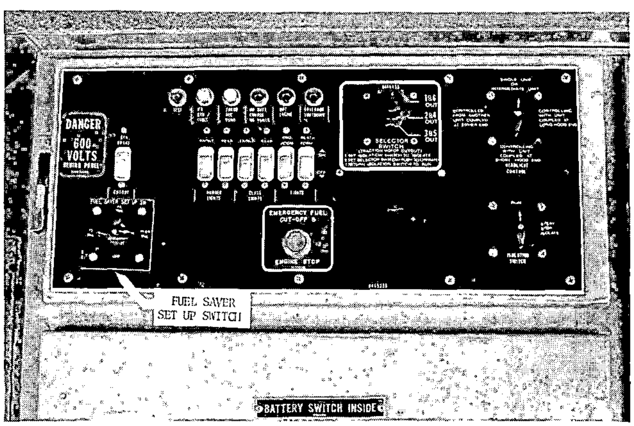

Fig. 2 "Fuel saver set up switch" on locomotive isolation panel

located on the isolation panel of each unit in the consist (Fig. 2)

The electrical wiring is accomplished through two available pins in the jump cable between the individual locomotives. It should be emphasized that the locomotive remote control capability of the system functions through the interconnecting jump cables of the consist and is not radio frequency controlled.

TEST DESCRIPTION

The two test series presented in this paper, Table 1 & Table 2, involved two distinctly different train configurations operating in two distinctly different rail environments. In the first test series, conducted on the Burlington Northern, four turbocharged SD 40-2 locomotives pulled a slow, heavy 14,000 ton 110 car unit coal train across the predominantly level 682 miles between Lincoln, NE, and Metropolis, ILL., at an average speed of 25 MPH. This was in marked contrast to the second test, a high priority "Super Van" TOFC train of the Union Pacific. Powered by two EMD DD 40's and one SD 40-2 for a total of 16,200 hp, the 2500 ton 30 car Super Van reached an average speed of 50 MPH in spite of the extremely variable and somewhat mountainous 1519 mile terrain between North Platte, NE, and Los Angeles, CA. The advantages of testing dedicated unit trains operating between points A and B were the predictable operating speeds and the relatively constant trailing gross tons and number of cars per train. This type of test effectively eliminated the three most predominant variables encountered in testing manifest freight locomotive consists: speed, trailing gross tons, and number of cars.

For both the BN and UP test series, one round trip was conducted with the fuel saver system "off" as a control or data base (D.B.) test and one round trip was conducted with the fuel saver system "on" designated in the data analysis as the fuel saver (F.S.) test. The accumulated mileage per round trip totaled an impressive 1364 miles for the BN unit coal train and more than double that or 3038 miles for the UP unit TOFC train. The BN unit coal train actually comprised two tests. For the outbound leg, the coal train was loaded. After dumping the coal at the end point of Metropolis, the train returned on the inbound leg empty. All testing proceeded within the normal operational framework of each railroad.

Scale weighing both the coal and the cars insured less than a 3% variation in trailing loads per test for the loaded unit coal train. However, such information was not readily available for TOFC trains. Instead the gross tons per car were determined by adding the tare weight to the estimated trailer plus lading weight supplied by the shipper. As noted in Table 2, the UP west or outbound TOFC fuel saver test for zones #1 through #8 included an average value for both the number of cars and the total trailing gross tons due to a bad order car exchange at the mid trip point. The number of cars varied by one and the tons varied from 2372 to 2627 for an average of 2500 tons.

The test parameters recorded via trip logs and analog chart recorders included the following:

* Times
* Mileposts
* Fuel consumption per locomotive
* Refueling readings at trackside fueling racks
* Throttle position vs. time
* Speed vs. time
* Average % time in fuel save per locomotive
* Number of crew changes and stops
* Fuel oil temperature (pump-up & return), °F
* Lube oil temperature at the oil pump, °F
* Traction motor exhaust air temp., °F (BN only)
* Alternator current vs. time (BN only)
* Spectographic lube oil analysis (BN only)
* Lube oil additions (BN only)

Table 1 BN Unit Coal Train
Summary of Fuel Saver Test Results

OPERATING CONDITIONS*	LOADED COAL TRAIN TEST ZONES 1 TO 6			UNLOADED COAL TRAIN TEST ZONES 6 TO 1		
	D.B.TEST	F.S.TEST	% DIFF.	D.B. TEST	F.S. TEST	% DIFF.
1. TOTAL HP (SD 40-2, FOUR)**	12000	12000		12000	12000	
2. NUMBER OF COAL CARS	110	110		110	110	
3. SCALE WEIGHT OF CARS, TONS	14,368	13,958	- 2.8	3370	3375	+ 0.1
4. AVER. CABOOSE WT., TONS	27	27		27	27	
5. TRAILING GROSS TONS, TGT	14,395	13,985	- 2.8	3397	3402	+ 0.1
6. HP/TGT	.83	.86	+ 3.6	3.53	3.53	
7. MILES TRAVELED	682.1	682.1		682.1	682.1	
8. % TOT. MILES/GRADE RANGE						
a. LEVEL 0 ± 0.49%	79.4			79.5		
b. ASCENT 0.50 - 0.70%	9.5			8.2		
0.71 - 1.50%	0.9			1.7		
1.51 - 2.50%	0.0			0.0		
c. DESCENT 0.50 - 0.70%	8.3			9.2		
0.71 1.50%	1.9			1.4		
1.51 2.50%	0.0			0.0		
9. TOTAL TIME IN MOTION, HR.	27.90	29.15	+ 4.5	27.54	23.90	- 13.2
10. AVER. SPEED, MPH	24.4	23.4	- 4.1	24.8	28.5	+ 14.9
11. NUMBER OF CREWS	6	6		6	6	0
12. NUMBER OF STOPS	31	27	-12.9	32	31	- 3.1
13. AVER. % TIME IN FUEL SAVE		***			***	
14. AVER. % TIME/THROTTLE NO.						
a. IDLE (IN MOTION)	8.0	9.0	+12.5	6.1	7.2	+ 18.0
b. THROTTLE #1	7.7	10.7	+39.0	12.5	8.1	- 35.2
c. THROTTLE #2	13.9	7.0	-49.6	20.0	6.2	- 69.0
d. THROTTLE #3	12.4	6.3	-49.2	11.7	5.2	- 55.5
e. THROTTLE #4	10.7	4.6	-57.0	13.1	7.4	- 43.5
f. THROTTLE #5	10.1	6.9	-31.7	9.5	5.8	- 38.9
g. THROTTLE #6	7.5	5.7	-24.0	5.5	5.4	- 1.8
h. THROTTLE #7	4.3	4.7	+ 9.3	5.0	7.7	+ 54.0
i. THROTTLE #8	25.4	45.1	+77.6	16.6	47.0	+183.0
15. FUEL CONSUMPTION, GALS.	7566	7700	+ 1.8	6278	4927	- 21.5
16. TGTM/GAL.	1297.8	1238.8	- 4.5	369.1	471.0	+ 27.6
17. GAL./1000 TGTM	0.77	0.81	+ 5.2	2.71	2.12	- 21.8

* TEST DATES: FEB. 14-22, 1977
** SAME LOCOMOTIVE CONSIST FOR ALL TESTS
*** INCOMPLETE DATA

Table 2 UP Unit TOFC Train
Summary of Fuel Saver Test Results

OPERATING CONDITIONS	WESTBOUND TEST ZONES 1 TO 8			WESTBOUND TEST ZONES 1,2,&4			EASTBOUND TEST ZONES 1,2,&4		
	D.B. TEST	F.S. TEST	% DIFF.	D.B. TEST	F.S.TEST	% DIFF.	D.B. TEST	F.S.TEST	% DIFF.
1. TOTAL HP	16,200	16,200		16,200	16,200		16,200	16,200	
2. TRAIN MAKE UP									
a. LOADED CARS	34	31*		34	32		46	31(21BOX)	
b. EMPTY CARS	1	2		1	2		1	2	
c. TOFC CARS	ALL BUT 3	ALL		ALL BUT 3	ALL		ALL BUT 6	10	
3. AVER. CABOOSE WT., TONS	27	27		27	27		27	27	
4. TRAILING GROSS TONS, TGT	2501	2500*	0.0	2501	2627	+ 5.0	3233	3155	- 2.4
5. HP/TGT	6.48	6.48	0.0	6.48	6.17	- 4.8	5.01	5.13	+ 2.4
6. MILES TRAVELED	1519	1519		605	605		605	605	
7. TOTAL TIME IN MOTION, HR.	31.38	29.70	- 5.4	11.70	11.21	- 4.2	11.03	11.36	+ 3.0
8. AVER. SPEED, MPH	48.8	51.5	+ 5.6	51.9	54.5	+ 4.9	55.3	53.4	- 3.5
9. NUMBER OF CREWS	8	8		3	3		3	3	
10. NUMBER OF STOPS	8	9		3	4		3	4	
11. AVER. % TIME IN FUEL SAVE									
a. LEAD POWER UNIT	0	**		0	**		0	0.0	
b. 3RD POWER UNIT	0	**		0	**		0	55.6	
c. 4th,5th POWER UNITS	0	47.4		0	59.7		0	60.7	
12 AVER. % TIME/THROTTLE NO.									
a. C-DYN. BRAKE, IDLE	30.3	42.9	+41.6	23.5	23.0	- 2.1	25.6	26.4	+ 3.1
b. THROTTLE # 2	4.1	3.5	-14.6	5.0	3.3	-34.0	3.3	3.7	+12.1
c. THROTTLE # 3	6.4	3.4	-46.9	5.2	6.5	+25.0	6.3	3.0	-52.4
d. THROTTLE # 4	8.5	3.5	-58.8	10.6	6.3	-40.6	9.2	3.0	-67.4
e. THROTTLE # 5	8.6	2.8	-67.4	5.8	3.4	-41.4	7.3	7.7	+ 5.5
f. THROTTLE # 6	9.6	4.1	-57.3	7.1	5.9	-16.9	13.5	6.1	-54.8
g. THROTTLE # 7	9.6	7.5	-21.9	11.2	9.2	-17.8	9.7	5.5	-43.3
h. THROTTLE # 8	22.9	32.3	+41.0	31.6	42.4	+34.2	25.1	44.6	+77.7
13 FUEL CONSUMPTION, GAL.***	12,145	10,641	-12.4	5274	4491	-14.9	4617	4240	- 8.2
14 TGTM/GAL	312.8	356.9	+14.1	286.9	353.9	+23.3	423.6	450.2	+ 6.3
15 GAL/1000 TGTM	3.20	2.80	-12.5	3.49	2.83	-18.9	2.36	2.22	- 5.9

* AVERAGE: CAR EXCHANGE AT MID TRIP POINT.
** USED BUT NOT RECORDED
*** WESTBOUND INCLUDES SOME DERIVED DATA

NOTES

1. TEST DATES: MARCH 29, 1977 TO APRIL 5, 1977
2. SAME LOCOMOTIVE CONSIST AND ORDER FOR ALL TESTS

LEAD, #2	#3	#4, #5
DD40	SD 40-2	DD 40
6600hp	3000hp	6600hp

To aid in the subsequent analysis, the above data was supplemented with track profiles, track diagrams, and mileage tables. All speeds, temperatures, throttle positions, and alternator currents were recorded for the lead locomotive only. In addition, a set numeric order for manually recording all other pertinent locomotive data was established and adhered to throughout the tests.

The locomotives assigned to both test consists had all been screened for potential problems in regularly scheduled fifteen or thirty day inspections just prior to testing. Hence their performance characteristics and fuel efficiencies were considered to be typical of the average locomotive operating under similar conditions. The designated lead and trailing power units never varied from one test to the next and were set up to operate in the fuel save mode either individually or in a preset combination. Although all SD 40-2 locomotives could be operated independently in fuel save, both power units of the 6600 hp DD 40 were wired to simultaneously reduce power when in fuel save . In this case the DD 40 represents a special class of locomotive. The decision to monitor the two power plants as a single unit was based on the prevailing route profile grades and the relatively high track speeds.

To record diesel fuel consumption to the nearest gallon, two calibrated volumetric flow meters were installed in each of the four locomotives of the BN unit coal train and in each of the five power plants of the three locomotive UP unit TOFC train. The difference in meter readings between the supply line and the return line to the fuel tank indicated the fuel consumed per locomotive. The meter readings were recorded manually at the end of each test zone as well as for any delay encountered. Because of the number of crew changes per test and the importance of the locomotive engineer in evaluating the performance of the fuel saver system, a test zone was defined as that distance traveled before a crew change occurred.

In addition to the on-board meters, trackside tank refueling readings were also recorded, where possible, to determine a comparability factor between the on-board meter readings and the quantity of fuel supplied to each fuel tank. For the purpose of these tests, the BN installed in the pump line of their refueling racks an accurate high volume flow meter calibrated by the Nebraska Bureau of Weights and Measures. The most recent calibration dates of the UP trackside refueling meters were not known, but the meters themselves were less than a year and a half old.

As an indicator of the variation in train handling techniques with and without use of the fuel saver system, throttle positions vs. time were recorded continuously on the BN tests and at discrete time intervals on the UP tests using a millivolt vs. time recorder wired to the various solenoid valve combinations.

In the course of each test it was found that the on-board locomotive speed recorders were considerably inaccurate for speeds less than 20 MPH and greater than 35 MPH. Standard procedure per crew change involved calibrating the speed recorder with wristwatch and milepost to correlate indicated recorder speed with the actual track speed. Therefore, it was not possible to continuously monitor speed vs. distance as a means of comparability between any data base and fuel saver test series. Instead, average trip times in motion per crew change were calculated by matching the start and end times per crew change with the analog brush charts recording locomotive throttle positions vs. time. The average operating speeds per test zone were then calculated by dividing the known distance traveled by the total test time the train was moving.

To accurately record the desired temperatures, all of the iron-constantan thermocouple leads were checked for breaks and precalibrated prior to testing. The sensing elements inserted into the various fluids through drain plugs or special fixtures varied from a multi-twisted wire to a dip stick configuration to a completely compensated insulator sleeve emersion thermocouple. Temperature recording methods included direct readings from a pyrometer at the turn of a switch (BN) and continuous readings at discrete time intervals using a millivolt vs. time chart recorder with temperature vs. time paper (UP).

Located on the back of each fuel saver system control box were hour counters to accumulate actual time in use to the nearest tenth of an hour. The data was available but unfortunately was not recorded in all of the fuel saver tests on a per test zone per locomotive basis. On the West or outbound leg of the UP fuel saver test the third fuel saver system was inoperative. While repairs were being made, both the first power unit of the lead DD 40 locomotive and the third SD 40 unit were manually isolated to simulate fuel saver test conditions. Therefore, time in fuel save per locomotive was not available for this type of situation.

Effective use and operation of the throttle control device was highly dependent on the skill of the locomotive engineer. Skill in this instance was indicated by the engineer's ability to match the use of the fuel saver to the track profile and the power requirements. For each fuel saver test on the BN and UP, the locomotive operating engineer was instructed by on-board test personnel to keep the locomotive consist at the seventh and eighth throttle positions as much of the time as possible. The fuel saver switches were employed to reduce power where necessary without sacrificing track speeds or operating schedule times. Because of the numerous crew changes on both the BN unit coal train and the UP unit TOFC train, the time and number of locomotives in fuel save varied considerably.

Looking at the East or inbound U.P. fuel saver test summary of results presented in Table 2, note that only three of eight test zones of data have been presented. Test zones #5 to #8 were eliminated because the assigned fuel saver test train was mixed freight and did not match the data base TOFC train in configuration or number of cars. Midway through the test route the train was changed, but again it was mixed freight with only one third TOFC.

DATA REVIEW AND ANALYSIS

Within each test series conducted on the BN and UP, test comparisons were made on the basis of the fuel consumed with and without use of the fuel saver in trains of similar configurations, trailing gross tons and operating speeds. The two methods employed to compare fuel efficiencies included the evaluation of the percent decrease in fuel consumed and the calculation of the ratio of one thousand trailing gross ton miles per gallon of fuel (1000 TGTM/GAL). An increase in the ratio of 1000 TGTM/GAL denoted an increase in the fuel efficiency.

BURLINGTON NORTHERN UNIT COAL TRAIN

With 79% of the route miles at less than 0.5% grade, the overall average percent decrease in fuel consumed round-trip was 9.8%. This figure represented an average of approximately zero fuel savings recorded for the loaded coal train and the striking 21.5% fuel savings recorded for the unloaded coal train (Table 3). Though the average fuel saver test speed for the unloaded case was 15% greater than the data base run, it must be remembered that the percent difference technique is deceiving for low numbers and that the actual difference was only 3.5 MPH from one test to the next.

Significant pattern changes were exhibited in the average percent time spent per throttle position between the data base and fuel saver tests. As shown in Fig. 3, operating in fuel save dramatically reduced the accumulated hours in throttle positions #2 and #5 by 30-50% and 40-70% respectively for the loaded and unloaded coal trains. However, the time spent in throttle position #8 almost doubled and tripled with increases of 78% and 183% respectively for the two test cases. Due to time gaps in the paper tape recordings, only three of six test zones of representative throttle data have been presented in Fig. 3.

Looking at the loaded coal train test results (Table 3), the differences in fuel consumption ranged from an increase of 24.1% or 129 gallons for test zone #4 to a decrease of 11.4% or 170 gallons for test zone #4. The average speeds of 25 and 23 MPH for these two test zones were similar and the number of stops were

Table 3 BN Unit Coal Train-Fuel Consumption
Per Locomotive Per Test Zone

TEST ZONE	TYPE OF TEST	MILES	SPEED, MPH ZONE AVER	SPEED, MPH % DIFF	% TIME IN FUEL SAVE PER LOCOMOTIVE 2ND	3RD	4TH	FUEL CONSUMED, GALLONS PER LOCOMOTIVE LEAD	2ND	3RD	4TH	AVER.	CONSIST TOTAL	PERCENT DIFF.
(LOADED) 1	DB	141.6	27.8	-11.9				234	383	542	532	422.8	1691	+10.9
	FS		24.5					558	327	370	620	468.8	1875	
2	DB	113.1	32.1	-10.0				219	195	281	287	245.5	982	+ 5.0
	FS		28.9					388	176	188	279	257.8	1031	
3	DB	117.4	26.2	- 3.4				357	295	423	410	371.2	1485	-11.4
	FS		25.3					405	254	330	326	328.7	1315	
4	DB	69.4	23.2	- 0.9				117	113	147	158	133.7	535	+24.1
	FS		23.0		TEST ZONES 1 to 5:			228	137	137	162	166.0	664	
5	DB	134.4	19.4	+ 5.7	24.7	39.0	28.5	336	330	463	482	402.7	1611	± 2.6
	FS		20.5					531	386	314	338	392.2	1569	
6	DB	106.2	21.7	- 6.9				292	250	363	357	315.5	1262	- 1.3
	FS		20.2		TEST ZONES 6 to 6:			418	269	269	290	311.5	1246	
(UNLOADED) 6	DB	106.2	21.8	-12.8	39.6	56.1	56.1	174	164	239	249	206.5	826	- 8.8
	FS		19.0					381	171	80	121	188.2	753	
5	DB	134.4	19.3	+ 8.3	*	*	*	145	162	250	271	207.0	828	- 9.3
	FS		20.9					465	132	55	99	187.7	751	
4	DB	69.4	18.5	+54.6	*	*	*	156	134	198	141	157.2	629	-46.1
	FS		28.6					109	75	72	83	84.7	339	
3	DB	117.4	43.5**	-11.0	*	*	*	305	252	362	424	335.7	1343	-15.6
	FS		38.7					482	175	231	246	283.5	1134	
2	DB	113.1	33.4	+26.9	*	*	*	314	253	367	367	325.2	1301	-15.4
	FS		42.4					372	210	258	261	275.2	1101	
1	DB	141.6	33.2**	+13.6	*	*	*	317	263	384	387	337.7	1351	-37.1
	FS		37.7					386	98	173	192	212.2	849	
AVERAGE VALUES														
LOADED 1 to 6	DB	682.1	24.5	- 4.5	*	*	*	1555	1566	2219	2226	1891.5	7566	+ 1.8
	FS		23.4					2528	1549	1608	2015	1925.0	7700	
UNLOADED 6 to 1	DB	682.1	24.8	+14.9	*	*	*	1411	1228	1800	1839	1569.5	6278	-21.5
	FS		28.5					2195	861	869	1002	1231.7	4927	

* USED BUT NOT RECORDED **BASED ON AVAILABLE DATA

identical. However, the number of route miles per grade range were distinctly different.

In the loaded coal train test for test zone #4, 90% of the route miles were essentially level at ± 0.5% grade as opposed to 73% for test zone #3. From Fig. 4, the relative time spent in the lower throttle positions for test zone #4 indicated that most of the 90% "level" route miles were actually descending with increased periods in dynamic brake. Fuel saver usage in this situation was not as effective as for test zone #3 where the terrain was characteristically more undulating. Examining the histogram for test zone #3 more closely (Fig. 4), it was found that the recorded fuel savings for this zone were obtained by reducing the time spent in throttle notch #5 followed by smaller reductions for postions #1 and #2. The net result was more efficient power usage in the eighth throttle position and 11.9% fuel savings in spite of the heavy 14,000 ton trailing load.

For the unloaded coal train, there were fuel savings on every test zone. As shown in Table 3, the decreases in consist fuel consumption ranged from 8% to 15% on four out of six test zones. However, for test zones #4 and #1 the fuel savings exceeded 30%. For these two test zones as well as for test zone #2, the fuel saver test operating speeds were significantly higher than the data base tests, yet the fuel consumed was definitely less for the fuel saver tests. Combining this fact with higher ratios of ton miles per gallon and extensive shifts in throttle usage patterns, Fig. 5, indicated a possible trend toward greater fuel savings when using the fuel saver system at increased operating speeds for the 3.5 horsepower per ton power assignment.

Installing calibrated meters in the pump lines of the trackside fueling racks enabled a direct comparison between the quantity of fuel added to the locomotive fuel tanks and the actual fuel used as recorded by the on-board fuel flow meters. The percent variation between the two fuel recording methods was extremely small; less than one percent. The advantage of the on-board meters was that fuel consumed in-motion could be differentiated from fuel consumed when the train was stopped. Therefore, a variation in the number and length of stops between tests could be effectively eliminated as a test variable by considering only the fuel consumed when the train was in motion. The fact that the stops occurred would of course be recorded and evaluated in the overall locomotive operational performance.

Using a sampling technique for recording fuel and lube oil temperatures (Tables 4 & 5) rather than continuous monitoring indicated two trends. First, for the ambient conditions tested, the average temperatures changed very little per round trip after 55 and 53 hours in motion with the same number of crew changes and a similar number of stops. Second, the average temperatures were slightly elevated for the fuel saver tests as could be expected with increased time in the higher throttle positions.

More specifically, for the data base round trip test (loaded plus unloaded train route), the average temperatures ranged from 90°F to 100°F respectively for the pump-up and return fuel oil lines with the lube oil at 162°F. For the fuel saver round trip test, the average pump-up and return fuel oil temperatures ranged from 95°F to 108°F respectively while the lube oil temperature increased to the 172-178°F range.

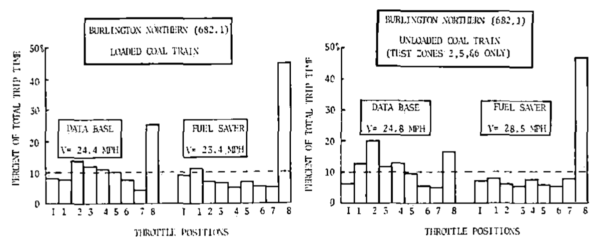

Fig. 3 Histogram of time vs. throttle position

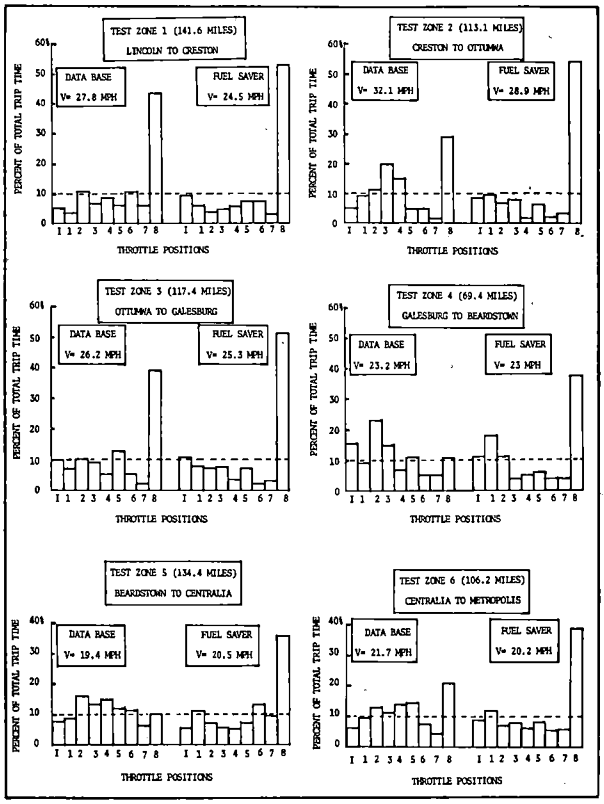

Fig. 4 BN loaded coal train-Histogram of time vs. throttle position per test zone

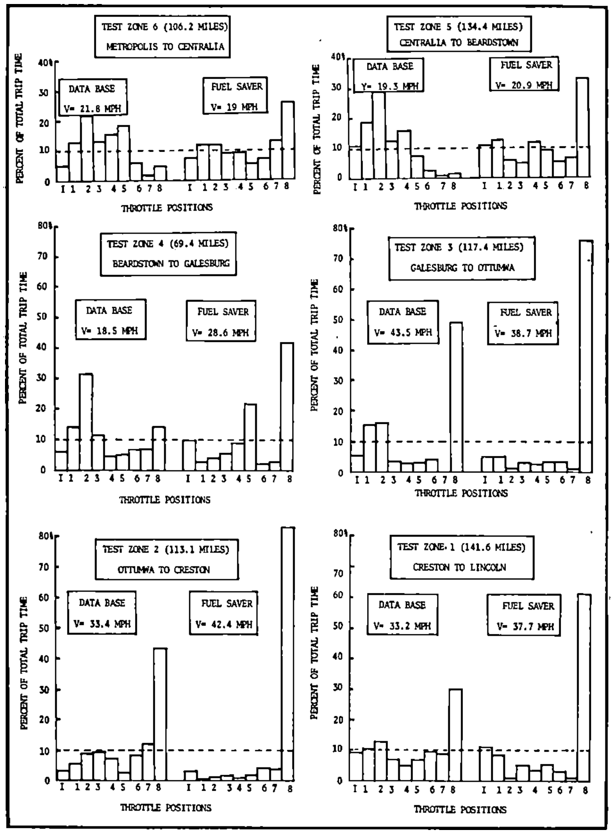

Fig. 5 BN unloaded coal train-Histogram of time vs. throttle position per test zone

UNION PACIFIC UNIT TOFC TRAIN

Examining the aggregate test results in Table 6 for the eight test zones in the Westbound direction indicated an overall average decrease in fuel consumption on the order of 12% at an average speed of 50 MPH. Individual test zone savings for this direction ranged from zero to a high of 23%. Due to a problem in matching the Eastbound fuel saver test train with the TOFC data base train, only selected test zones in this direction have been presented for analysis. Though the Eastbound comparison fuel saver test train was only one third TOFC, the fuel savings still averaged 8%. The trailing gross tons and speeds were similar for all test zones with the only marked variation in number of cars occurring in the Eastbound direction.

Test zone #3 was eliminated from the Eastbound data comparisons because the average test zone speed for the fuel saver test exceeded the data base test by 30%. In this test there was a reluctance on the part of the locomotive engineer to use the fuel saver system under the misapphrension that track speeds were going to be sacrificed as part of the test criteria. As might be expected, operating at eighth throttle more of the time without reducing power in the trailing units increased the fuel consumption and the average operating speed for that test zone.

As on the Burlington Northern, fuel usage on-board the locomotives was compared to the actual fuel added to the fuel tanks from the trackside refueling racks. Unfortunately, the method of refueling and the refueling personnel were not controllable elements of this test series. Consequently, the comparability between the two fuel recording methods varied from 2% to greater than 15%.

In the Eastbound direction, all on-board fuel meters were operational for both the data base and fuel saver tests. Such was not the case in the Westbound direction. Due to clogging in the "pump-up" fuel meters of two of the five power plants, it was necessary to derive some of the fuel data presented in Table 6. By determining the percent deviation from the average locomotive fuel consumption in the Eastbound direction, it was possible to develop coefficients to predict individual locomotive fuel consumptions for the Westbound data base test. This of course assumed that the individual locomotive performance characteristics within the consist were essentially constant throughout the 1519 route miles. Evaluating these fuel consumption coefficients on a per test zone basis (Eastbound) indicated that this was indeed the situation with only a few exceptions in test zones #4, #5, and #8. Note that not all of the Eastbound data was presented in this paper for reasons previously discussed.

Only a slightly different technique was used to derive fuel data for the fifth power plant operating Westbound in fuel save. Due to continual variation in the number of locomotives in fuel save at any given time, it was not possible to predict individual locomotive fuel consumptions from the consist average. However, the fourth and fifth power plants were wired to be simultaneously operated in and out of the fuel save mode. With similar duty cycles, and again assuming consistent performance characteristics throughout testing, the fuel consumed by the fifth power plant in the Westbound direction was derived from the parallel performance of the fourth and fifth power units. Both the data base and fuel saver test results (Eastbound) were included in the derivation.

As shown in Fig. 6, the total time accumulated per throttle position varied considerably between the data base and fuel saver tests. The letter "C" denoted an idle-dynamic braking sequence frequently encountered in the somewhat mountainous terrain. For test zones #1 to #8 inclusive Westbound from North Platte to Los Angeles, major decreases of 50% to 70% were recorded for throttle positions #3 to #5 accompanied by 40% increases in the idle-dynamic brake and throttle #8 positions. The pattern shift of time vs. throttle position for the three Eastbound test zones was slightly different.

Table 4 BN Loaded Coal Train Fuel and Lube Oil Temperatures

TEST*	DATA BASE TEST (TRIP TIME=27.90 HR.)				FUEL SAVER TEST (TRIP TIME = 29.15 HR.)			
SAMPLE	FUEL OIL TEMPERATURE, °F			LUBE OIL	FUEL OIL TEMPERATURE, °F			LUBE OIL
NUMBER	PUMP UP	RETURN	DIFF. °F	TEMP., °F	PUMP UP	RETURN	DIFF. °F	TEMP., °F
1	85	90	5	140	90	105	15	180
2	85	98	13	140	90	110	20	180
3	90	110	20	157	95	105	10	180
4	95	120	25	175	95	105	10	180
5	85	100	15	170	95	115	20	180
6	85	95	10	165	100	105	5	180
7	90	100	10	175	100	120	20	180
8	80	90	10	165	95	105	10	180
9	95	105	10	170	100	105	5	180
10					90	105	15	170
11					95	110	15	170
12					100	115	15	180
AVER.	88	101	13	162	95	109	14	178

Table 5 BN unloaded Coal Train Fuel and Lube Oil Temperatures

TEST*	DATA BASE TEST (TRIP TIME=27.54 HR.)				FUEL SAVER TEST (TRIP TIME=23.90 HR.)			
SAMPLE	FUEL OIL TEMPERATURE, °F			LUBE OIL	FUEL OIL, TEMPERATURE, °F			LUBE OIL
NUMBER	PUMP UP	RETURN	DIFF., °F	TEMP., °F	PUMP UP	RETURN	DIFF., °F	TEMP., °F
1	90	95	5	150	100	105	5	150
2	85	90	5	150	95	110	15	175
3	90	95	5	155	90	100	10	150
4	90	100	10	160	95	105	10	185
5	100	110	10	175	100	115	15	185
6	100	110	10	170	95	105	10	175
7	95	100	5	175	100	115	15	185
AVER.	93	100	7	162	96	108	12	172

Table 6 UP Unit TOFC Train-Fuel Consumption Per Locomotive Per Test Zone

TEST ZONE	TYPE OF TEST	MILES	SPEED, MPH ZONE AVER	SPEED, MPH % DIFF	% TIME IN FUEL SAVE PER LOCOMOTIVE LEAD	3RD	4TH,5TH	FUEL CONSUMED, GALLONS PER LOCOMOTIVE LEAD	2ND	3RD	4TH	5TH	AVER.	CONSIST TOTAL	FUEL SAVED %
(WEST) 1	DB	221	49.6	+ 7.0				552	497	515*	498	534*	519.2	2596	-23.5
	FS		53.0		0.0	**	45.6	523	460	556	200	248*	397.4	1987	
2	DB	173	53.6	+10.2				335	290	305*	292	315*	307.4	1537	- 9.6
	FS		59.0		0.0	**	58.0	358	311	266	203	252*	278.0	1390	
3	DB	135	40.5	+20.7				225	179	193*	178	199*	194.8	974	-20.3
	FS		48.9		**	**	54.4	131	256	228	72	89*	155.2	776	
4	DB	211	52.6	- 2.4				267	208	226*	207	233*	228.2	1141	- 2.4
	FS		51.3		**	**	75.4	316	286	348	73	91*	222.8	1114	
5	DB	207	60.5	- 3.4				331	283	290*	261	300*	293.0	1465	+ .6
	FS		58.5		**	**	45.2	299	428	290*	196	243*	291.2	1456	
6	DB	243	45.8	+ 3.1				368	287	321*	312	332*	324.0	1620	-12.3
	FS		47.2		**	**	19.4	279	333	320*	218	271*	284.2	1421	
7	DB	170	49.3	+ 4.6				357	294	313*	291	323*	315.6	1578	-14.2
	FS		51.5		**	15.1	30.3	306	331	281	193	243	270.8	1354	
8	DB	159	38.1	+11.5				282	227	244*	228	253*	246.8	1234	- 7.4
	FS		42.5		**	48.1	50.8	303	266	224	140	210	228.6	1143	
(EAST) 1	DB	221	51.9	+ 2.9				277	213	235	209	260	238.8	1194	-14.0
	FS		53.4		0.0	58.0	67.6	327	279	209	65	147	205.4	1027	
2	DB	173	59.0	- 7.0				299	266	270	256	301	278.4	1392	-13.8
	FS		54.9		0.0	57.1	60.3	315	230	234	184	237	240.0	1200	
4	DB	211	55.0	- 5.7				504	367	395	350	415	406.2	2031	.9
	FS		51.8		0.0	51.6	54.0	565	503	381	231	333	402.6	2013	
AVERAGE VALUES															
(WEST) 1 TO 8	DB	1519	48.8	+ 5.6				2717	2265	2407	2267	2489	2429.0	12,145	-12.4
	FS		51.5		**	**	47.4	2515	2671	2513	1295	1647	2128.2	10,641	
(WEST) 1,2,4	DB	605	51.9	+ 4.9				1154	995	1046	997	1082	1054.8	5274	-14.9
	FS		54.5		**	**	59.7	1197	1057	1170	476	591	898.2	4491	
(EAST) 1,2,4	DB	605	55.3	- 3.5				1080	846	900	815	976	923.4	4617	- 8.2
	FS		53.4		0.0	55.6	60.7	1207	1012	824	480	717	848.0	4240	

*DERIVED DATA **USED BUT NOT RECORDED

Though the time in throttle #5 varied little, significant decreases of 40-70% occurred in positions #3 and #4 as well as in #6 and #7 with a corresponding increase of 78% in throttle #8. Individual throttle histograms per test zone have been presented in Fig. 7 & 8.

In the Westbound direction, test zones #2, #3 and #8 exhibited higher operating speeds for the fuel saver tests but lower fuel consumption per test zone when compared to the data base tests. This same trend was observed on three of six test zones evaluated on the BN unloaded coal train tests.

To determine if there were any significant changes in the fuel and lube oil temperatures while testing, these temperatures were continuously monitored at the rate of one set of readings a minute. Breaks in the thermocouple leads were common and were difficult to avoid. All available temperature data was condensed to illustrate the distribution at the completion of regular time intervals per test zone (Tables 7 & 8). Data for the pump-up fuel oil temperature was not available. After 30 hours in motion Westbound, the maximum return fuel oil temperatures averaged 128°F both with and without the fuel saver, ranging from a low of 117°F to a high of 138°F. For all eight test zones the fuel saver return fuel oil temperatures were consistently similar to the data base comparison levels. The same trend was observed for the limited lube oil temperature data where the maximums ranged from 173°F to 184°F for the data base and fuel saver comparisons. Therefore, for these test conditions, operating at higher track speeds in fuel save did not affect the fuel and lube oil temperature levels.

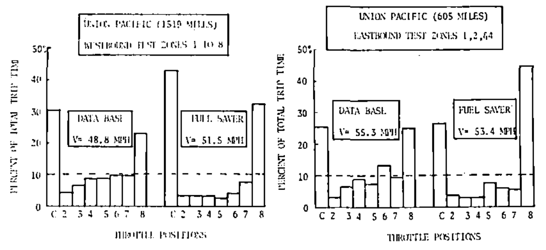

Fig. 6 Histogram of time vs. throttle position

SUMMARY

During the unit train tests performed on the Burlington Northern and Union Pacific railroads, significant fuel savings were realized by using a semi-automatic throttle control device or "fuel saver" system to take one or more units of the locomotive consist off-line when the available power and

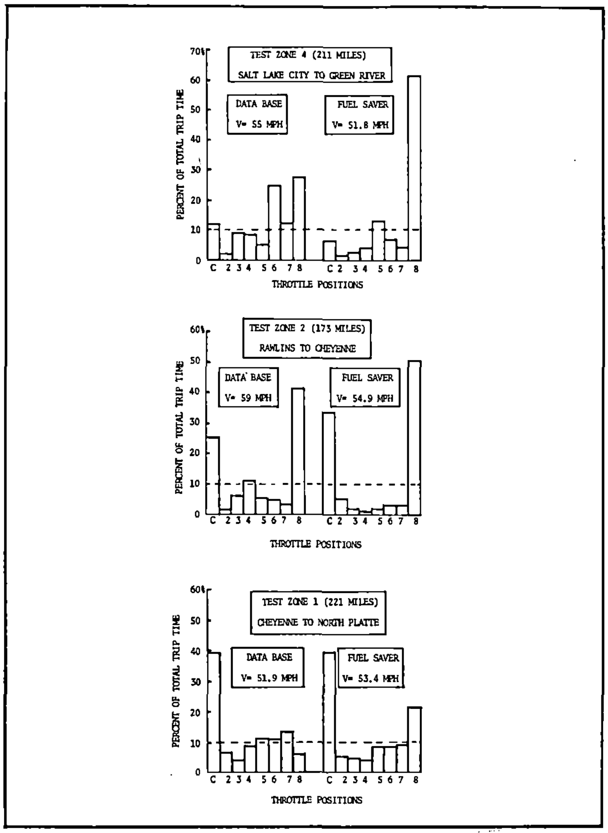

Fig. 7 UP Unit TOFC Train (Eastbound) Histogram of time vs. throttle position per test zone.

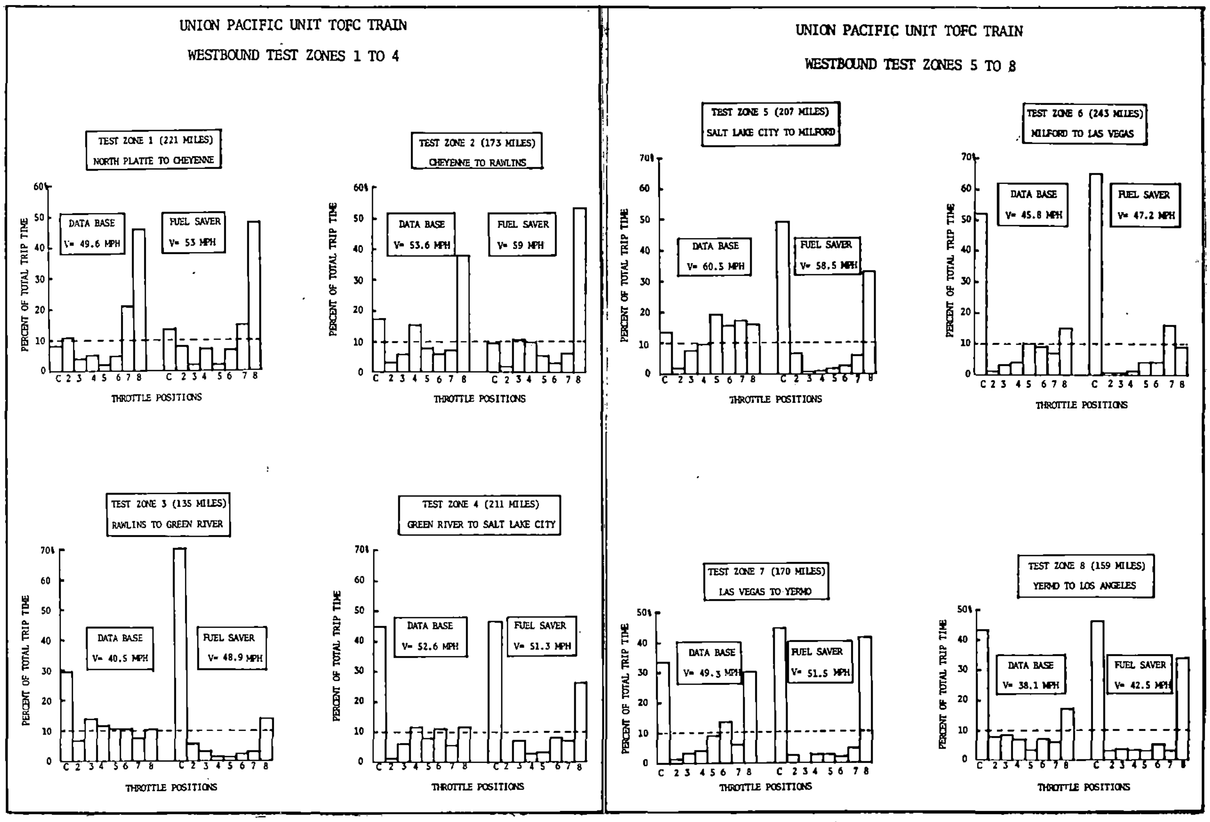

Fig. 8 Westbound-Histogram of time vs. throttle position per test zone

Table 7 UP Unit TOFC Train
Return Fuel Oil Temperatures

TEST ZONE	TYPE OF TEST	RETURN FUEL TEMPERATURE, °F: PERCENT OF TRIP TIME COMPLETED 0	10	20	30	40	50	60	70	80	90	100	MIN. TEMP. °F	MAX. TEMP. °F	DIFF. °F
(WEST) 1	DB	110	129	130	132	125	127	131	130	114	104	115	104	132	28
	FS	112	132	130	132	130	129	132	115 STOP	127	129	119	112	132	20
2	DB	111	129	129	122	114	121	121	122	115	118	108	108	129	21
	FS	108	128	129	118	112	123	118	125	123	115	115	108	129	21
3	DB	99	118	114	114	102	100	111	99	109	106	103	99	118	19
	FS	97	117	109	114	95	96	91	88	86	83	88	83	117	34
4	DB	NONE	114	115	118	107	106	106	106	105	105	109	105	118	13
	FS	88	119	121	121	101	99	95	98	101	105	100	88	121	33
5	DB	102	115	123	120	122	113	115	117	123	125	114	102	125	23
	FS	101	105	123	111	127	107	109	115	119	106	110	101	127	26
6	DB	111	123	125	119	120	117	124	119	133	124	119	111	133	22
	FS	110	125	127	114	111	112	113	114	116	115	123	110	127	17
7	DB	114	132	128	136	135	122	126	128	128	137	128	114	137	23
	FS	114	132	122	122	136	121	115	115	133	137	125	114	137	23
8	DB	124	123	134	127	128	122	122	123	122	123	122	122	134	12
	FS	117	138	137	137	120	116	119	134	121	121	121	116	138	22
(EAST) 1	DB	105	110	116	117	108	119	123	123	126	129	113	105	129	24
	FS	109	111	112	120	109	119	129	131	129	127	115	109	131	22
2	DB	103	109	122	111	118	122	124	116	109	109	109	103	124	21
	FS	96	113	108	103	123	123	117	132	116	111	110 STOP	96	132	36
4	DB	110	125	127	127	132	131	131	117	120	122	115	110	132	22
	FS	116	134	121	138	137	138	137	135	128	132	121	116	138	22

Table 8 UP Unit TOFC Train
Lube Oil Temperatures

TEST ZONE	TYPE OF TEST	LUBE OIL TEMPERATURE, °F: PERCENT OF TRIP TIME COMPLETED 0	10	20	30	40	50	60	70	80	90	100	MIN. TEMP. °F	MAX. TEMP °F	DIFF °F
(WEST) 1	DB	158	184	180	184	180	180	-	-	-	-	-	158	184	26
	FS	157	180	180	178	173	173	174	155 STOP	172	179	-	155	180	25
2	DB														
	FS	-	-	-	-	154	173	165	161	172	-	143	143	173	30
3	DB														
	FS	133	177	163	172	155	150	142	137	135	134	139	133	177	44*
4	DB														
	FS	140	176	175	175	156	154	148	156	161	166	155	140	176	36
5	DB														
	FS	162	163	182	169	177	160	164	164	173	156	160	156	182	26
6	DB														
	FS	160	176	-	-	-	-	-	-	-	-	-			
7	DB														
	FS														
8	DB														
	FS														
(EAST) 1	DB	-	156	167	171	158	168	169	174	173	176	157	156	176	20
	FS														
2	DB														
	FS														
4	DB														
	FS														

tractive effort exceeded the demand. This procedure effectively lowered the horsepower per ton ratio of the train and decreased the rate of fuel consumption. For the particular set of operating conditions tested, the average fuel savings in percent reached 9.8% for the unit coal train tests and 12.4% for the unit TOFC train tests. A prime ingredient for the effective use of such a device was the operating locomotive engineer.

On a per test zone basis within each of the two test series, the fuel savings ranged from zero to considerably more than 15%. However, for three out of six test zones on the BN loaded coal train tests, the fuel consumed actually increased. In this particular situation the 0.8 horsepower per ton power assignment was below the threshold at which the fuel saver concept could be effectively employed.

In both test series there were significant pattern changes in the average percent time spent per throttle position between the data base and fuel saver tests. As might be expected, operating in fuel save dramatically increased the total time accumulated in the eighth throttle position. As a result, there were significant reductions recorded for the average percent time spent in throttle positions #2 through #5.

In the TOFC tests and in the unloaded coal train tests, several of the individual test zones exhibited higher operating speeds for the fuel saver tests but lower fuel consumptions when compared to the data base tests. Combining this fact with higher ratios of ton miles per gallon and extensive shifts in throttle usage patterns indicated a possible trend toward greater fuel savings when using the fuel saver system at increased operating speeds for the 3.5 and 6.5 horsepower per ton power assignments.

For the ambient conditions tested, the fuel and lube oil temperatures changed very little per round trip after 30 and 50 hours in motion with the same number of crew changes and a similar number of stops. At the lower 25 MPH operating speed of the unit coal train, the average temperatures were slightly elevated for the fuel saver tests. Such was not the case for the 50 MPH unit TOFC train where the fuel and lube oil temperatures were consistently similar to the data base comparison levels.

For the conditions encountered, testing of the fuel saver system did not affect the total test times or the average operating speeds. Although there were no difficulties experienced in either the lead or trailing units of the locomotive consists tested, any maintenance or mechanical problems which might develop can only be evaluated after extensive usage of the system combined with continual monitoring of the results.

ACKNOWLEDGMENTS

The cooperative efforts of the Burlington Northern and Union Pacific railroads were sincerely appreciated during the planning and execution phases of the fuel saver test series. Test coordination and equipment installation expertise were provided through the staff of the Transportation Systems Center at Cambridge, MA. At the completion of the BN test series, the tedious reduction and evaluation of all test data were accomplished through the diligent efforts of the OAO Corporation.

OVERVIEW OF FREIGHT SYSTEMS
R&D REPORT NO FRA/ORD-77/58
OCTOBER 1977

ERRATA

"Rail Dynamics Laboratory Requirements and Hardware Configurations"

Page 90 first sentence under Fig. 6, Vibration Test Unit should read as follows:

"The vertical excitation modules (each under independent servo control) are designed around a 60,000 lb (27,216 kg) hydraulic actuator, equipped with a 200 gpm (.0126 m^3/s) high performance servo-valve."

Page 90 first sentence of second major paragraph from bottom starting "The hydraulic flow demands ..." should be changed to read as follows:

"The hydraulic flow demands of the various excitation modules and hydrostatic bearing elements at peak excitation levels can be as high as 1000 gpm (.0631 m^3/s) @ 3,000 psi (20,684,271 N/m^2). This has been provided for via three 360 gpm (.0227 m^3/s) variable volume pumping systems each capable of delivering the rated flow at 3,000 psi (20,684,271 N/m^2)."