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Cost effectiveness of railroad fuel spill prevention using a new locomotive refueling system

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Abstract

Fuel spillage during locomotive refueling is expensive, as is maintaining spill collection and containment systems, and waste treatment costs. The Association of American Railroads has developed the first standard for a locomotive refueling system for North American railroads. The locomotive fueling interface standard is an open, non-proprietary standard designed to prevent fuel spillage. Prototype equipment was successfully tested at the Transportation Technology Center and field-tested by seven North American railroads and found to operate reliably and prevent spillage. The standard represents a shift from pollution control to pollution prevention regarding environmental protection during refueling. Cost-benefit analyses indicate that the savings due to reduction in energy and environmental costs that railroads can expect to accrue are likely to pay for the new equipment in one to three years, with the principal benefit coming from the reduction in waste treatment expense.

Keywords: Railways; Diesel oil spillage; Cost-benefit analysis; Waste treatment; Pollution prevention

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1. Introduction

The major US and Canadian railroads used approximately 16.5 billion liters (4.3 billion gallons) of diesel fuel in 2001 (Association of American Railroads, 2002a). Efforts to improve locomotive efficiency have potentially large payoffs in terms of fuel savings and reduced emissions, and prevention of fuel spillage is also an important element of environmental protection. Consequently, railroads' refueling facilities have been extensively modified to reduce leakage and to collect spilled fuel.

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In addition to spill collection and containment, railroads adopted automatic shut-off refueling systems. However, no standard for refueling systems was developed. Instead, each railroad used one of several proprietary designs. It became evident in the 1990s that the lack of an industry standard for refueling equipment, and limitations in the designs in use, was contributing to the incidence of spillage (Barkan et al., 1996; Brownlee and Barkan, 2001). Consequently, the major North American railroads acting through the Association of American Railroads (AAR), undertook development of a standard for locomotive refueling. This standard is the first of its kind for any continent-wide rail system.

Relatively little has been published on fuel delivery systems, particularly as a pollution prevention technology. What has been written has focused on safety considerations (Ferrone, 1992; Ford, 1996), special systems for alternative fuels such as liquefied petroleum gas, liquefied natural gas, hydrogen, and methanol (Wetzel, 1998; Jenks, 1998) or on reduction of emissions to the atmosphere during refueling (Cingle and McClement, 1988; Musser and Shannon, 1986; Musser et al., 1990; Schifter et al., 2002). Considering that conventional petroleum hydrocarbons comprise the majority of fuel used in North American transportation, evaluation of options to reduce spillage of these fuels is important.

2. The need for a standard for locomotive refueling

When North American railroads converted to diesel–electric locomotives in the 1930s–1950s, they substantially modified their facilities to deliver the new fuel. The need to use locomotive servicing personnel more efficiently while avoiding spillage due to tank over-filling, led to development of automatic shut-off systems. By the 1950s several systems were available (Dick, 1955), but no industry-standard for the fittings or shut-off technology was developed.

Although automatic fuel shut-off systems helped prevent waste, the low cost of fuel created little incentive to purchase the equipment. Beginning in the 1970s, federal regulations to prevent water pollution were promulgated and protection of the environment became a factor in spill prevention. By the early 1980s the most frequent source of wastewater requiring treatment was associated with refueling activity (Brownlee, 1984). Railroads invested heavily in treatment systems with over 80% of these facilities being modified or newly built during the interval 1970–1982. Automatic fuel shut-off systems were more widely adopted, and by the late 1980s all of the major US and Canadian railroads were using them (Brownlee and Barkan, 2001).

The refueling systems in general use by North American railroads are reliable when properly operated and maintained (Brownlee and Barkan, 2001). However, these systems are subject to malfunction that can lead to overfilling. The systems are also susceptible to premature shut-off leading operators to override the system that can lead to a spill. Since most refueling takes place over spill collection systems, there is generally no release to the environment. However, the expense of the fuel and the cost of treatment and disposal are incurred. If spilled fuel reaches the environment, there is additional risk and potential expense.

The automatic shut-off technology for each of the systems is proprietary and the different designs are incompatible. When a locomotive equipped with one type of system is refueled with another type, an adapter is required that renders the automatic shut-off inoperable. If railroads primarily refuel their own locomotives and use only one automatic shut-off system, the incompatibility is not a problem. However, if a railroad wishes to change suppliers it cannot easily phase out previously deployed equipment through attrition.

Although issues of reliability and compatibility had been in place from the inception of automatic shut-off refueling systems, they had not posed a sufficient problem for the industry to take steps to overcome them. However, in the late 1980s and early 1990s the situation changed.

- North American railroads were increasingly using run-through, pooled and leased motive power, causing more frequent refueling of locomotives at other railroads' facilities. For example, recent figures for one major railroad indicate that nearly 9% of its mainline locomotives were operating off its own lines, and a comparable number of other railroads' locomotives were on its property.
- The US Environmental Protection Agency promulgated new regulations that pertained to storm water runoff at railroad refueling facilities (Barkan et al., 1992).
- Railroads expanded their use of direct truck-to-locomotive (DTL) fueling as compared to fixed facilities (Modern Bulk Transporter, 1995; Barkan et al., 1996; Brownlee and Barkan, 2001).

Most DTL fueling sites are, by their nature, transitory and do not have extensive spill collection and containment equipment. As of the mid 1990s, approximately 75% of the fueling sites were DTL (Brownlee and Barkan, 2001). Although these sites accounted for only about 10% of the fuel issued, the cost of spill collection equipment would be high, and impractical because of their transient nature.

The expense of spilled fuel can be substantial but the cost of collection and treatment of contaminated wastewater is greater. At fixed-site facilities extensive collection and treatment equipment and operating and maintenance personnel employed. When these capital and operating costs are accounted for, they may be as much as 10 times higher per unit spilled than the value of the fuel itself. This is consistent with unpublished AAR data that indicate that the first and third largest items in North American railroads' environmental budgets are cleanup of petroleum-contaminated soil and wastewater treatment. The cost of these items is largely driven by past and present fuel spillage, respectively.

3. Locomotive fueling interface standard

The basic architecture of the LFIS is shown in Fig. 1 (Association of American Railroads, 2002b). The railroads wanted high performance in the new fueling system standard, but they also desired flexibility. Consequently, the standard generally specifies performance rather than design. The principal exception is at the interface between the locomotive and the wayside. In this case, because of the requirement for a physical connection, the geometry of the interface had to be specified to assure that components would be inter-operable, irrespective of manufacturer or model. Also, the range of parameters for the electronic signal used to indicate high fuel level had to be specified.

Prototype LFIS equipment was tested on locomotives operating at the Facility for Accelerated Service Testing at the Transportation Technology Center. Following these tests, the LFIS was revised and new equipment manufactured and tested by seven railroads at nine North American

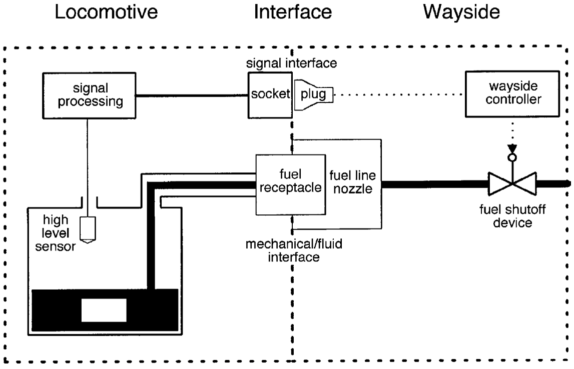

Fig. 1. Schematic diagram of the basic locomotive fueling interface standard design.

locations. The results indicated that the LFIS was effective and reliable for refueling locomotives with almost no spillage.

4. Cost effectiveness

Despite its capability to prevent spills, the LFIS must be more cost-effective than the current technology for fuel delivery, spill collection and treatment, if railroads are to adopt it. The equipment has a higher initial cost than the current technology. The principal benefit is derived from reduced spillage and waste treatment expense. The principal cost is the marginal expense for purchase and installation of the new equipment compared to continued use of current equipment.

The costs and benefits were calculated using Eqs. (1) and (2):

$$C = N_S\left(\sum_{i=1}^{S} c_i + h_S l\right) + N_L\left(2\sum_{j=1}^{L} c_j + h_L l\right) - rN_L c_C, \tag{1}$$

where C is total marginal cost for implementation of LFIS equipment, N_S is number of wayside fueling stanchions, S is number of different components per wayside stanchion, c_i is cost per unit for wayside component i, h_S is hours of labor required to install wayside stanchion components, l is hourly labor cost, N_L is number of locomotives, L is number of different locomotive components, c_i is cost per unit for locomotive component j, h_L is hours of labor required to install locomotive components, r is percentage of locomotives replaced during installation period, and c_C is cost per unit for current locomotive fueling system components,

$$B = V_p(c_f + c_t v)e, \tag{2}$$

where B is annual benefit due to use of LFIS equipment, V is annual volume of fuel issued, p is percentage of fuel spilled, c_f is cost of fuel spilled per unit volume, c_t is cost to treat spilled fuel per unit volume, v is percentage of treatment costs that vary with volume of fuel spilled, and e is effectiveness of LFIS in reducing spillage.

The cost-benefit analysis includes data for the major US and Canadian freight railroads and Amtrak. These railroads account for a substantial majority of North American railroad infrastructure, operations, and fuel use (Association of American Railroads, 2002a) and thus provide a robust basis for analysis.

5. Computation of industry costs

The costs for LFIS equipment were provided by suppliers and were used in the cost expression to develop low, intermediate and high estimates (Table 1).

Labor costs are based on experience gained during the LFIS testing and AAR data on equipment maintenance personnel wages (Association of American Railroads, 2002a) (plus 30% for fringe benefits) yielding an hourly rate of $28.63. These labor costs are approximate, but sensitivity analysis indicates, that doubling the labor cost would increase cost by 10% or less.

During a transition period from the current fueling equipment to LFIS equipment, some new locomotives would be purchased. These locomotives would have to be equipped with new fueling equipment anyway. Only the difference in the cost of the current equipment compared to the cost of LFIS equipment should be accounted for in the benefit/cost analysis and is accounted for in the last term of the cost expression. The estimated cost for the major North American railroads to install LFIS equipment is presented in Table 2.

5.1. Industry benefits

The principal benefit to railroads is reduction in fuel spillage and its associated costs. Major railroads were surveyed regarding locomotive refueling, spillage and treatment expense. Although all the railroads could not supply all the data requested, a substantial fraction could and the statistics developed were considered to be representative.

Fuel consumption: In 2001 approximately 16.48 billion liters (4.35 billion gallons) were consumed and the average price paid by US railroads was 22.6¢ per liter (85.5¢ per gallon)

Table 1
Estimated cost of LFIS wayside and locomotive components (each locomotive requires two of each component, one for each side)

	Cost estimate		
	Low	Intermediate	High
Wayside expense			
$\sum_{i=1}^{S} c_i$ (wayside components cost)	$3600	$5186	$6983
h_S (installation time in person hours)	8.0	12.0	16.0
$h_S \times l$ (installation labor cost)	$229	$344	$458
Total cost per fueling stanchion	$3829	$5530	$7441
Locomotive expense			
$2\sum_{j=1}^{L} c_j$ (component cost per locomotive)	$876	$1072	$1300
h_L (installation time in person hours)	3.0	4.5	6.0
$h_L \times l$ (installation labor cost)	$86	$129	$172
Total cost per locomotive	$962	$1201	$1472

Table 2
Total estimated cost of LFIS wayside and locomotive components for major North American railroads

	Cost estimate		
	Low	Intermediate	High
Total cost per fueling stanchion	\$3829	\$5530	\$7441
×3300 Stanchions	\$12.6 million	\$18.2 million	\$24.5 million
Total cost per locomotive	\$962	\$1201	\$1472
×23,000 Locomotives	\$22.1 million	\$27.6 million	\$33.8 million
Estimated cost of current equipment over three years transition	\$1.2 million	\$1.2 million	\$1.2 million
Marginal cost of new locomotive equipment	\$20.9 million	\$26.4 million	\$32.6 million

(Association of American Railroads, 2002a) with a resultant estimated total of \$3.7 billion in annual fuel expense.

Fuel spillage: Five major railroads (accounting for 83% of the major railroads' fuel consumption) provided data on the percentage of fuel captured in spill collection systems as a fraction of total issued. Their data indicate an average value for p is 0.117% and the estimated annual volume spilled in 2001 was 19.3 million liters (5.1 million gallons) with an estimated value of \$4.3 million.

Treatment cost for spilled fuel: Collection and treatment related expense is the largest cost of spilled fuel. Three major railroads (accounting for 65% of the major railroads' fuel consumption) estimated that the cost ranges from about \$1.70 to \$2.60 per liter (\$6.50 to \$11.00 per gallon) spilled, with an average of \$2.25 per liter (\$8.51 per gallon). The estimated cost to the major railroads is \$43.3 million per year. Combined with the value of fuel, the annual total is \$47.7 million.

5.2. *Effectiveness of LFIS at reducing cost*

The testing indicated that the LFIS is reliable and would reduce spillage. However, there will continue to be some fixed costs for treatment. Two railroads (accounting for 34% of the major railroads' fuel consumption) estimate that 72–75% of their treatment costs were variable with volume of fuel spilled for an average of 74%. For example, if spillage were eliminated, the reduction in treatment expense would be about 74% and if spillage was reduced by 95% then expense would be reduced 70%. It is useful to calculate a variable, $R = ve$, the cost-reduction effectiveness of implementing the LFIS. The values for the variables in the benefit term are: $V_1 = 16.48$ billion liters per year, $p = 0.117\%$, $c_f = 22.6¢$ per liter, $c_t = \$2.25$ per liter, $v = 74\%$, $e = 95\%$ (assumed), $B_1 = \$34.61$ million per year, and $R = 70\%$ ($= ve$).

Railroads use several methods to assess investment decisions including, payback period, internal rate of return (IRR) and net present value (NPV) and each was calculated. The short payback period, high IRRs and the positive NPV suggest that the LFIS is cost-effective for reducing refueling-related expense (Table 3).

The sensitivity of the results to LFIS equipment cost and to R was calculated (Fig. 2). The results suggest that the LFIS is likely to be acceptable over a broad range of conditions using

Table 3
Comparison of various measures of cost-effectiveness for LFIS implementation (using the parameters presented in the text)

	LFIS equipment and installation cost		
	Low	Intermediate	High
Payback period (years)	1.04	1.38	1.75
Internal rate of return[a]	93.0%	70.0%	54.5%
Net present value[b] ($ millions)	136.8	126.0	114.0

One year implementation, $R = 70\%$.

[a] 20-year period.

[b] 20-year NPV using discount rate = 16%.

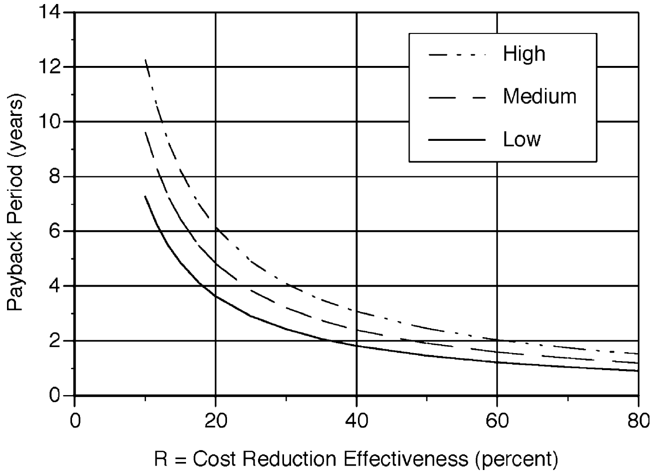

Fig. 2. Sensitivity analysis of the relationship between the effectiveness of the LFIS and payback period.

typical railroad procurement decision criteria. Even values of R as low as 40% combined with the highest estimated cost of the LFIS equipment, yields a payback period of about three years.

The figures presented are based on industry averages, but the cost-effectiveness for a particular railroad will vary depending on its own parameter values. One example is spillage rate. Although the average value for p was 0.117%, there was considerable variation. The lower the value of p the lower the benefit due to spill prevention. Conversely, a railroad with a higher-than-average value for p will experience a larger benefit.

A relative spill ratio was calculated, $p' = p_x/p$, where p_x is the spill rate for railroad x, and p is the industry average. The effect of R and the relative value of p' on payback period were simultaneously varied in a sensitivity analysis (Fig. 3). At $R = 0.7$, the payback period varied from 0.78 years for $p' = 1.5$ to 2.67 years for $p' = 0.5$. For $p' = 1.5$, even a value of R as low as 0.2 yielded a payback period just over three years and for $p' = 0.5$, an $R = 0.6$ yielded a similar payback period. Not surprisingly, combinations of low R and low p' result in considerably longer payback periods and under these conditions the choice to adopt the LFIS would be less attractive.

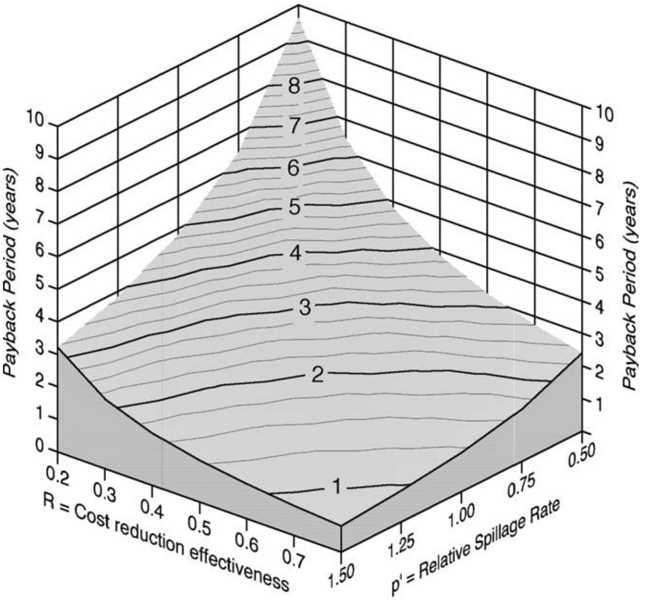

Fig. 3. Sensitivity analysis showing the effect of R (LFIS cost-reduction effectiveness), and p' (relative spillage rate) on payback period (intermediate LFIS cost assumed).

Although the result suggests that railroads with lower spillage rates will experience a longer payback period, it bears closer scrutiny. It is difficult to know how much it costs to maintain a lower spill rate using current technology. Presumably the improved performance is due to some combination of better maintenance of refueling equipment, better operating procedures, and/or a greater number of personnel employed in refueling activities. Railroads do not generally record these costs separately but without them it cannot be concluded that adoption of the LFIS when spillage rate is already relatively low is more or less cost effective than current practices.

5.3. Net present value calculation

The NPV was calculated using:

$$\mathrm{NPV} = \sum_{i=0}^{Y} \frac{B_i - C_i}{(1+d)^i} \tag{3}$$

where Y is time span over which NPV is calculated in years, B_i is benefit from LFIS in year I, C_i is cost of LFIS in year I, and $d =$ discount rate.

It is assumed that implementation of LFIS equipment occurs in year 0 and that benefits do not accrue until the following year, i.e. $B_0 = 0$. It is also assumed that the principal cost in successive years is the marginal cost of equipping new locomotives with LFIS equipment compared to the cost for the current equipment is about \$500 per locomotive—this is subtracted from the annual LFIS figure to obtain the difference used in the cost benefit analysis. Differences in maintenance cost between the LFIS and current equipment should also be accounted for but they would comprise only a small fraction of the total and the data are not available. Because the LFIS was engineered for low maintenance it is likely that LFIS costs would be somewhat lower in this regard, but for the purpose of this analysis, they are assumed to be equal.

Assuming R is 70%, the estimated annual benefit (B_i) is \$33.06 million. The estimated costs in year 0 (C_0) for the Low, Intermediate and High component costs are \$35.13, \$46.43 and \$59.19 million, respectively. After the initial installation, the annual net cost (C_i) of the LFIS equipment using the Low, Intermediate and High estimates is \$0.37 million, \$0.56 million and \$0.78 million, respectively.

Railroads typically depreciate locomotives based on a 20-year life so this value was used. Current North American locomotive replacement rate suggests a 30-year life may be more typical. The NPV for the LFIS was calculated over different time scales ranging from 1 to 30 years (Fig. 4). The NPV increases rapidly and, consistent with the results of the payback time analysis, is positive within two to three years after implementation. The increase in NPV begins to reach an asymptote after about 20 years.

Simultaneous operation of two systems is likely to be troublesome, but constraints on capital budgets may constrain railroads' ability to change out all their equipment in a single year. The NPV calculations assumed a one-year implementation but sensitivity analysis was conducted in which the rate of implementation varied (Fig. 5). It was assumed LFIS installation was uniformly distributed over the implementation period and the benefit due to the installation that occurred in a given year was not accrued until the following year. For example, in a three-year implementation schedule, one third of the equipment would be installed per year and the commensurate cost incurred, in years 0, 1, and 2 with benefits spread evenly across them. It is evident that the shorter the implementation period, the higher the NPV.

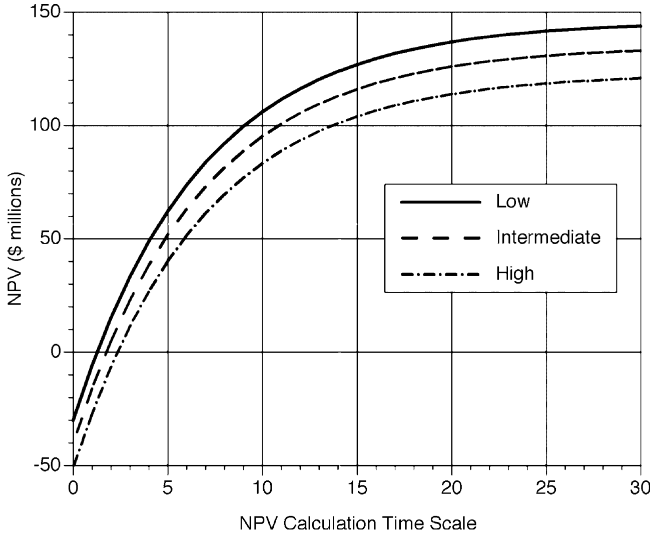

Fig. 4. Relationship between time scale over which NPV is calculated and NPV for three different cost estimates for LFIS equipment ($R = 0.7$ assumed).

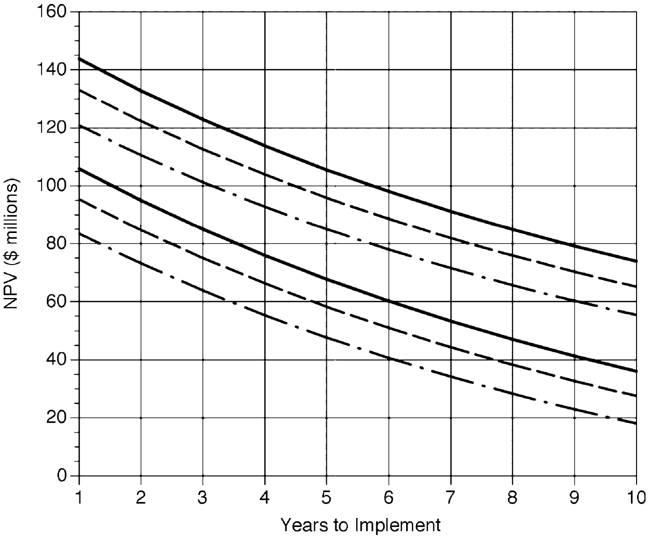

Fig. 5. Relationship between implementation time and 10-year and 30-year NPV, for low, intermediate and high cost LFIS equipment ($R = 0.7$ assumed).

5.4. Other benefits of the LFIS

The cost-benefit analysis uses avoided costs due to reduction in fuel waste and treatment expense, because these are quantifiable and considered to be the largest; however, there are other benefits.

The LFIS is an open standard so competitive pressure on price and quality should improve value. Investment in one manufacturer's system will not create 'inertia' to continue using that product if the equipment does not meet performance or price requirements. Procurements of new refueling equipment can be bid competitively with assurance that it will be compatible with other equipment already in place.

Adoption of the LFIS should improve railroads' flexibility in when and where they use DTL refueling. It can be considered a 'best available technology' for fuel-spill prevention instead of spill collection and treatment systems. The LFIS nozzle is, by specification, light weight and more easily used under a variety of conditions. The LFIS will prevent fuel 'blowback', a potential source of worker injury that occurs when a refueling nozzle is disconnected from a fuel tank that has inadvertently become pressurized due to a clogged vent during refueling.

During testing the LFIS equipment permitted higher refueling rates than current equipment (<50% increase). This enables faster refueling, higher productivity at refueling facilities and more rapid turnaround of locomotives. The LFIS was designed to be reliable with minimal maintenance, thus spare nozzle inventory and periodic rebuilding costs should also be reduced.

The LFIS electrical connector was designed to support the transfer of information for fuel management if railroads want to employ this technology. The extra electrical pins can also be used to electronically transfer locomotive health information if desired.

6. Conclusion

The LFIS is an open, non-proprietary performance and design standard for a locomotive refueling system developed in response to changes in railroad refueling requirements over the past 10–15 years. It represents a shift in railroad environmental protection philosophy from pollution control to pollution prevention during refueling. Railroads and refueling equipment manufacturers evaluated current problems and future demands for locomotive refueling and developed the standard to address known causes of spillage. Testing showed that the system was practical, robust and reliable in field operation.

Cost-benefit analyses indicate that adoption of the LFIS is a cost-effective means for major North American railroads to reduce fuel waste and treatment expense and sensitivity analyses indicate the robustness of the result. The value of the unspilled fuel is a relatively small fraction of the benefit. The principal savings are due to the reduction in waste treatment and disposal related expense.

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