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A SUMMARY OF TRUCK FUEL-SAVING MEASURES
DEVELOPED WITH INDUSTRY PARTICIPATION

by

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CONTENTS

SUMMARY.....	v
ABSTRACT.....	1
1 INTRODUCTION.....	1
1.1 Background.....	1
1.2 Purpose.....	2
2 METHODS.....	3
2.1 Literature Review.....	3
2.2 Development of Draft Matrix.....	3
2.3 Industry Coordination Meeting and Revision of Matrix.....	4
2.4 Press Release and Distribution of Matrix.....	5
2.5 Report Preparation and Distribution.....	5
3 DESCRIPTION OF MATRIX.....	6
3.1 Fuel-Saving Measures.....	6
3.2 Claimed Fuel Savings.....	6
3.3 Assumed Fuel Use.....	7
3.4 Claimed 1983 Fuel Cost Savings.....	7
3.5 Additional 1983 Costs.....	7
3.6 Approximate Payback Period.....	7
3.7 Assumed Market Sectors.....	8
3.8 Remarks.....	8
4 DISCUSSION OF MATRIX REVISIONS.....	36
4.1 Summary of Industry Coordination Meeting Results.....	36
4.2 Addition and Deletion of Matrix Measures.....	37
4.3 Revisions of Fuel-Savings Percentage Estimates.....	38
4.4 Adjustments of Payback Period Estimates.....	39
4.5 Substantive Changes to Remarks Column.....	40
5 CONCLUSIONS.....	42
APPENDIX A: MATRIX REFERENCE LIST.....	45
APPENDIX B: MEETING PARTICIPANTS.....	53
APPENDIX C: ARGONNE PRESS RELEASE.....	55

TABLE

1 Matrix of Truck Energy Efficiency Measures.....	9
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SUMMARY

This report describes the third project undertaken by the Center for Transportation Research, Argonne National Laboratory (ANL), in a U.S. Department of Energy program designed to develop and distribute compendiums of measures for saving transportation fuel. A matrix, or chart, of more than 60 fuel-saving measures was developed by ANL and refined with the assistance of trucking industry operators and researchers at an industry coordination meeting held in August 1982. The first two projects used similar meetings to refine matrices developed for the international maritime and U.S. railroad industries.

The consensus reached by those at the meeting was that the single most important element in a truck fuel-efficiency improvement program is the human element — namely the development of strong motivation among truck drivers to save fuel. The role of the driver is crucial to the successful use of fuel-saving equipment and operating procedures. Identical conclusions were reached in the earlier maritime and rail meetings, thus providing a strong indication of the pervasive importance of the human element in energy-efficient transportation systems.

The number and variety of changes made to the matrix are also delineated, including addition and deletion of various options and revisions of fuel-saving estimates, payback period estimates, and remarks concerning items such as the advantages, disadvantages, and cautions associated with various measures. The quality and quantity of the suggested changes demonstrate the considerable value of using a forum of industry operators and researchers to refine research data that are intended for practical application.

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ABSTRACT

As part of a program sponsored by the U.S. Department of Energy, Argonne National Laboratory (ANL) developed a "matrix" that summarized a wide variety of fuel-saving measures, as well as associated costs and benefits, for the trucking industry. Information was derived primarily from technical documents and manufacturers' literature, but estimates of cost savings were calculated at ANL. The matrix was reviewed by trucking industry representatives at an industry coordination meeting held in 1982; revisions to the matrix were made in response to discussions at the meeting. In its final form, the matrix contained some 60 fuel-saving measures under four principal headings. Participants at the meeting agreed that the single most important factor in any effort to conserve fuel is the human element. Training and incentives are needed to develop strong motivation among drivers to save fuel. More than 2400 copies of the matrix have been distributed free of charge to members of the U.S. trucking industry.

1 INTRODUCTION

1.1 BACKGROUND

This report focuses on the third in a series of matrices, or summary charts, of information on fuel-saving measures for three major transportation industries. The first matrix was prepared for the international maritime industry and the second was for the U.S. railroad industry. The third, which is the subject of this report, was developed for the U.S. trucking industry. These efforts have been part of an information compilation and dissemination program conducted by the Center for Transportation Research at Argonne National Laboratory (ANL) for the Office of Vehicle and Engine Research and Development in the U.S. Department of Energy.

Each of the matrices has been widely distributed. More than 1100 copies of the maritime matrix were mailed to U.S. and foreign shipping

companies engaged in U.S. foreign trade. The rail matrix was sent to more than 120 U.S. railroads and to the Association of American Railroads, while the truck matrix was sent to more than 1800 members of the U.S. trucking industry.

The response to these mailings has been very favorable. More than 100 requests for additional information on the maritime matrix were received from 30 countries, and so far about 100 requests for additional information on the truck matrix have been received. In addition, more than 550 requests for the matrix have been received from members of the trucking industry and its suppliers. International interest in the rail matrix has also been expressed. An important reason for these favorable responses has been the realism brought to the information in the matrices by the involvement of experienced industry operators. This involvement has been through participation in industry coordination meetings with the expressed purpose of refining the appropriate draft matrix as part of the project's research design.

In this report's discussion of the development and distribution of the truck matrix, special emphasis is placed on the extensive refinements made as a result of the industry coordination meeting.

1.2 PURPOSE

Commercial truck transportation in the U.S. consumes approximately 3 quads (1 quad = 10^{15} Btu) annually, or approximately 476 million bbl/yr. This amount, which is 15% of all transportation energy consumed annually in the U.S., is projected to consume 21.5% of annual transport energy by the year 2000. The purpose of the research described in this report is to aid the U.S. trucking industry in its efforts to use fuel more efficiently. The research involved the identification, evaluation, summarization, and distribution of useful information on fuel-saving options in order to provide the industry with a single source of concise, comprehensive data to use in selecting the most appropriate options for specific applications.

2 METHODS

The methods used to conduct this project are as follows (listed in chronological order):

1. Literature review.
2. Development of draft matrix.
3. Industry coordination meeting and revision of matrix.
4. Press release and distribution of matrix.
5. Report preparation and distribution.

Each is described below.

2.1 LITERATURE REVIEW

A review of literature on fuel-saving alternatives in the trucking industry was the starting point for this project. Research reports, journal articles, and conference papers were the primary documents reviewed. Proprietary materials on specific fuel-saving equipment were also consulted. Appendix A lists the final set of sources used to develop and summarize data on fuel-saving measures included in the matrix.

2.2 DEVELOPMENT OF DRAFT MATRIX

The draft matrix of truck energy efficiency measures was developed primarily by extracting and summarizing the following information from the review literature:

- Technical description.
- Energy-savings percentages claimed in demonstrations.
- Estimates of fuel-cost savings and payback periods.
- Estimates of required investment, maintenance, and other costs of implementation.
- Advantages, disadvantages, and related information.

Estimates of cost savings for each option were calculated rather than taken directly from data sources. Two early assumptions in the project were that (1) truck operators engage in energy-saving efforts primarily to reduce costs and (2) a range of potential cost savings for various types of operations would be useful. Therefore, parametric assumptions were made for representative intracity and intercity truck operations to develop low and high diesel fuel use rates, respectively. These rates were then combined with the estimated fuel-savings percentage for each option, factored by an estimated diesel fuel price of \$1/gal. This procedure allowed an estimated range of cost savings to be included in the matrix for most options. For other measures, however, neither percentage- nor a dollar-based fuel cost savings could be included in the matrix because those savings, though known to exist, vary by individual truck and route traveled. In those cases, savings were identified simply as truck-and-route-specific (TRS) so that matrix users could evaluate potential savings for their particular circumstances. The same individualized situations apply to financial payback periods for many options, and the TRS entry was also made in those cases.

Another important assumption made for each fuel-saving measure was the identification of its relevant market sector(s). This was done so that matrix users could focus more easily on alternatives applicable to their types of vehicles and operations.

Options were organized in the matrix under the following categories:

- Operations.
- Equipment purchasing and modifying.
- Fuel and lubricant changes.
- Technologies under development.

2.3 INDUSTRY COORDINATION MEETING AND REVISION OF MATRIX

An all-day industry coordination meeting was held on August 26, 1982, in Willowbrook, Illinois (a southwestern suburb of Chicago). A broad cross-section of trucking industry expertise was represented. The participants (listed in Appendix B) included three common-carrier truck operators, three private truck fleet operators, and representatives of the American Trucking Associations, the Canadian TRUCKSAVE Program, and a trucking trade journal, as well as two trucking consultants (one of whom was formerly senior general engineer of the U.S. Voluntary Truck and Bus Fuel Economy Program in the U.S. Department of Transportation) and two ANL program managers. Detailed discussions were held on each measure of the matrix, and all changes and other conclusions were made by consensus, sometimes after lengthy discussions. The results of this meeting are summarized in Sec. 4.

The meeting was tape-recorded and notes were taken by ANL representatives. After the meeting, these records were carefully reviewed and used to revise the matrix, a copy of which was then sent to each participant for final comments. Section 4 contains a detailed discussion of the substantive matrix revisions that were made to incorporate the meeting results.

2.4 PRESS RELEASE AND DISTRIBUTION OF MATRIX

Following revision of the matrix, 1870 copies were mailed to individuals and groups within the U.S. trucking industry, including operators of private truck fleets; appropriate military trucking groups and officials were also among the recipients. Approximately 100 additional copies were mailed to truck industry researchers and consultants who may be able to affect trucking activities directly or indirectly. The addressees were selected from the mailing list of the U.S. Voluntary Truck and Bus Fuel Economy Program. Another 100 copies were sent to the Canadian TRUCKSAVE Program for that group to publicize and distribute upon request. The cover letter for the copies distributed in the U.S. stated that the reference list was a source of additional information concerning fuel-saving measures and was available on request. The resulting requests provided a low-cost indication of industry interest.

In addition, a press release highlighting the truck matrix and industry coordination meeting was sent to various truck- and transportation-industry publications. The release also described the rail and maritime matrices and the results of all three industry coordination meetings. The following publications have printed the release: *Road King*, *Fleet Maintenance and Specifying*, *Transport Topics*, and *Transportation Business*.

The release (reproduced in Appendix C) included an ANL mailing address to which requests for matrix copies could be sent. This was done to distribute the matrix as widely as possible to interested truckers and other parties not included in the original mailing and to provide another low-cost measurement of industry response. Of particular note are the 572 requests for the matrix received through *Road King*, a trade journal for independent truckers.

2.5 REPORT PREPARATION AND DISTRIBUTION

Preparation and distribution of this final report are the final tasks in this research. This document is intended for distribution to (1) appropriate industry organizations such as the American Trucking Association and the Private Truck Council, (2) government agencies such as the U.S. Departments of Energy and Transportation, and (3) truck operators who request additional information about the fuel-savings options in the matrix.

3 DESCRIPTION OF MATRIX

The final version of the matrix developed in this project is included here as Table 1.* The following sections describe the information found in each matrix column.

3.1 FUEL-SAVING MEASURES

The fuel-saving measures listed in the first column of the matrix are divided into four categories:

- Operations.
- Equipment purchasing and modifying.
- Fuel and lubricant changes.
- Technologies under development.

Many fuels-saving measures have several submeasures presented, as for example, in the operations improvement category, where more than 20 separate items are listed under six measures. The list of measures in the matrix, although comprehensive, should not be considered as all-inclusive.

3.2 CLAIMED FUEL SAVINGS

Fuel-savings percentages in the second column, unless indicated otherwise by footnote, are those claimed in the references cited. The word "claimed" is used in the column heading because, for many measures, claims of savings varied among sources. In addition, because each truck and operating route is different, the meeting participants agreed that every user of the matrix should not expect exactly the same result. Even so, for many options, meeting participant and reference estimates of fuel savings were close enough to warrant the use of only one number.

However, some conservation measures were considered to be truck-and-route-specific. This occurred when no estimated range of savings was found or when meeting participants disagreed with the reference claims and yet conceded that some savings potential was likely.

*The matrix in Table 1 is identical to that distributed to the trucking industry except for minor editorial revisions in format and wording.

3.3 ASSUMED FUEL USE

The third column provides a simplified parametric basis for estimating the annual diesel fuel cost savings implied by the claimed fuel-savings percentages in the second column. After discussions with meeting participants, it was assumed that a representative intracity truck would consume 4000 gallons annually (40,000 mi @ 10 miles per gallon [mpg]) and a representative intercity truck would consume 20,000 gallons annually (100,000 mi @ 5 mpg). Even though these assumptions are for diesel-powered trucks, the same assumptions should be applicable to intracity operations using gasoline-powered vehicles.

3.4 CLAIMED 1983 FUEL COST SAVINGS

The savings in this column were derived by multiplying the claimed fuel-savings percentages in the second column by an estimated diesel fuel cost of \$1/gal.

The cost savings estimated in this column are gross, rather than net. They do not take into account (1) the allocations of investment costs necessary to realize the savings or (2) the higher maintenance or other operating costs required by some fuel-saving options (e.g., use of larger trailers). Nevertheless, they do translate energy savings into gross dollar savings, which relate more closely to profit, the primary business motive.

3.5 ADDITIONAL 1983 COSTS

Three columns are included under this heading: investment, maintenance, and other. Information was difficult to obtain for these columns and there are many blank spaces. This lack of information resulted mostly from a primary emphasis in the literature on the energy and cost savings of conservation measures rather than on added costs. In addition, the additional costs varied so widely in some cases that a "TRS" entry was used in the matrix to cover the wide range. Nevertheless, matrix users should realize that added costs do accompany many of the measures and must be determined for individual trucks in order to calculate the payback periods on which investment decisions are usually based.

3.6 APPROXIMATE PAYBACK PERIOD

The payback periods in this column are labeled as approximate because they are based on claimed fuel savings, which often vary by truck and route. Similarly, the investment, maintenance, and other costs required by fuel-savings measures also vary by truck and sometimes by route as well. Nevertheless, the payback periods listed, especially when less than one or two years, should provide truck operators with useful decision-making information.

Payback period calculations were not attempted for the matrix primarily because even when annual fuel savings could be estimated, there were insufficient data on additional costs associated with the conservation measures. In addition, such calculations would be unwieldy and inappropriate for a summary matrix because reviews of relevant payback analyses revealed the need for highly individualized (vehicle-specific) and detailed data, in addition to projections of a wide range of petroleum price escalations and/or reductions.

3.7 ASSUMED MARKET SECTORS

Many of the energy conservation measures are applicable to all trucks, but others are designed for certain truck types (e.g., tractor-trailers, pickup-and-delivery vans), ages, sizes, (e.g., twin trailers), speeds, or engine types (e.g., diesel, gasoline). This column was added to help truck operators focus more easily on the appropriate measures for their vehicles.

3.8 REMARKS

Important information concerning operator experiences and the functions, advantages, disadvantages, and risks of the fuel-saving options is presented in the final column. The column provides qualitative, and in some cases quantitative, information vital to proper evaluation of the measures.

Table 1 Matrix of Truck Energy Efficiency Measures

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
OPERATIONS									
1. Driver improvements:									
a. Development of driver understanding, motivation, cooperation, and participation (preferably through a management program) (Refs. 1-6, 61, 82-86)	----- See Measure 1b below -----			0	0	TRS ^d	<6 months ^e	All trucks	Strong front office and driver support for fuel-savings effort is needed (e.g., a specific top-management-supported fuel conservation manager, positive and negative publicity and peer pressure based on performance; use of an advisory board composed of drivers to select new drivers; monitoring of driver performance). One organization had a team incentive system to add peer pressure to financial incentives in improving fuel efficiency. Setting realistic goals is important. If driver cooperation is not achieved, any measure affected by driver performance will not achieve its potential. References identify several fleets that have successfully used such programs.
				0	0	TRS	<6 months	All trucks	
b. Improve driving practices	Up to 12 ^e (total)	4 20	Up to 480 Up to 2400 (totals)	----- See Remarks -----	----- See Remarks -----		See Remarks See Remarks	All trucks All trucks	Combined savings (only) of 1b(1) through 1b(7) below. Offsetting equipment costs are identified in the investment column. These savings are also offset somewhat by the costs of driver training, which are indicated as truck-and-route-specific in the "other" additional cost column for 1a above.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%)	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
OPERATIONS (Cont'd)									
(1) Eliminate unnecessary idling (Refs. 1-7, 62, 63, 82-86)	-----	See Measure 1b	-----	See Remarks	0	TRS	TRS	All trucks	At stops longer than 2 or 3 min, the engine should be shut down. This saves in certain pickup and delivery operations. Drivers should be persuaded not to use idling at truck stops to help maintain warm or cool cab temperatures. At one truck stop, <i>Fleet Owner</i> magazine in February 1980 (31°F) found 44 of 88 trucks with idling engines. Major engine manufacturers state that engines cool more over lunch breaks while idling than if turned off. Too much idling may lead to premature wear and sludge formation in gasoline engines and to injector problems in diesels. Automatic idling shutdown devices are available.
(2) Never exceed 55 mph speed limit or attempt to defeat purpose of governor equipment (Refs. 1-10, 64, 65, 82-86)	1.5-2.0 for each mph reduced toward 55 mph	20	TRS	0	0	TRS	N/A ^f	All trucks	Driver training, motivation, and monitoring (including tachographs and road patrols) programs are important here, as is governor equipment. Drivers must often be retrained to keep rpm down and not "drive against the governor" as learned in past. Maintenance and tire costs also increase if speed exceeds 55 mph. When headwinds are high, it is especially important not to exceed 55 mph. Today's engines will not be damaged by lower rpm.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
OPERATIONS (Cont'd)									
(3) Use progressive shifting, shift gears only when necessary, and skip-shift where possible (Refs. 1-3, 62, 82-86)	-----	See Measure 1b -----		0	0	TRS	N/A	All trucks	Often requires working with drivers to break old habits. In progressive shifting, drivers use the lowest rpm they need to make their shifts each time to maximize fuel savings with high-torque-rise engines. Excessive shifting is particularly common in heavy traffic and should especially be avoided with high-torque-rise engines. Relating of shifting patterns to the tachometer instead of the speedometer has been found especially effective by one major fleet owner in maximizing savings by fuel-economy engines.
(4) Avoid sudden starts and stops (Refs. 1, 2, 62, 82-86)	-----	See Measure 1b -----		0	0	TRS	N/A	All trucks	Requires careful observation of other vehicles, choosing a lane that will let the truck keep moving, and keeping adequate distance from vehicle in front. Steady acceleration and gradual deceleration save fuel.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
OPERATIONS (Cont'd)									
(5) Maintain constant speed (Refs. 1, 2, 82-86)	-----	See Measure 1b	-----	0	0	TRS	N/A	All trucks	Maintaining constant speed where possible reduces fuel used for acceleration and deceleration. Cruise-control devices are available for trucks for about \$1000 per vehicle and quantity discounts are available. A well-trained driver can be as energy efficient as cruise control, but cruise control prevents mistakes by reducing driver fatigue on long hauls.
(6) Monitor fuel consumption (Ref. 2)	-----	See Measure 1b	-----	1000 (electronic monitoring equipment)	0	TRS	N/A	All trucks	Electronic instruments are available with readout devices to provide data to driver on fuel use during trips. These also provide guidance for tune-up and other maintenance scheduling and are good driver-training devices even where there is not enough capital to equip an entire fleet.
(7) Supervise outside fueling to avoid "overfills" (Ref. 1)	-----	See Measure 1b	-----	0	0	TRS	Immediate ^e	All trucks	Involves training and monitoring of personnel who fill tanks. Also reduces damage to parking areas and reduces fire hazards.
2. Maintenance improvements	1-8 (total)	4 20	40-320 200-1600 (totals)	----- See Remarks -----			See Remarks	All trucks All trucks	Combined savings of 2a through 2c. Costs of training for maintenance personnel and of maintenance equipment should be balanced against fuel savings, longer vehicle life, and trade-in value.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
OPERATIONS (Cont'd)									
a. Maintain proper tire pressure (Ref. 1)	0-6	4 20	0-240 0-1200	0 0	-- See Remarks --	N/A N/A	All trucks All trucks	Maintaining tire pressure at manufacturer's recommended levels saves up to 6% of fuel. Underinflated tires are a safety hazard and wear rapidly.	
b. Improve timeliness of maintenance for air, oil, and fuel cleaning and filtering equipment, oil changes, and tuneups (Ref. 1)	-----	See Measure 2	-----	0	-- See Remarks --	N/A	All trucks	Reduces engine fouling, pollution, and fuel consumption. Also increases tuneup interval. Tests indicate that oil analysis can safely extend oil change interval. Already used by most major fleets.	
c. Assure that spoke or disc wheels run true (Ref. 1)	-----	See Measure 2	-----	TRS	-- See Remarks --	N/A	All trucks	Disc wheels require minimal maintenance, whereas spoke wheels save in cost and weight. When wheels do not run true, excess horsepower is used and tire wear is increased, especially for long-distance-route trailers.	
d. Adjust aerodynamic devices based on trailer height and gap (see Equipment Modifications, Item 1a) (Ref. 66)	-----	See Measure 2	-----	0	-- See Remarks --	N/A	All trucks	As an aid to making adjustments, a 0.5-in. nylon rope attached to the top trailing edge of the deflector can indicate, at road speed, whether air flow is just above the trailer top.	

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
OPERATIONS (Cont'd)									
e. Maintain coolant temperatures (Ref. 67)	-----	See Measure 2	-----	0	-- See Remarks --		N/A	All trucks	Engine coolant temperature should be about 185°F. Each 9°F drop cuts fuel efficiency by 1%, and many trucks operate at 150°F, burning 4% more fuel than necessary while increasing engine wear. Check temperature gauges periodically.
f. Assure proper alignment of front end, tractor and trailer frames, and axles (Ref. 1)	-----	See Measure 2	-----	0	-- See Remarks --		N/A	All trucks	Improves tire life and fuel economy.
3. Increase load factors									
a. Improve loading practices for current freight mix (no service frequency change) (Refs. 1, 68)	TRS	TRS	TRS	TRS	0	0	N/A	All trucks	Requires analysis to determine if physical loading patterns can be improved (e.g., heavier loading or better sectioning of freight by area and street in proper direction to maximize cube utilization). Increasing payload will lead to an increase in revenue that will more than pay for the extra fuel.
b. Induce shipper to increase shipment sizes and/or accept reduced service frequency where possible (Ref. 12)	TRS	TRS	TRS	0	0	0	N/A	All trucks	Shippers can be induced to consolidate shipments and/or make multiple tenderings per stop with rate incentives. Care must be taken to insure that fuel cost and other savings exceed revenue reductions. Depends upon customer and freight mix.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>OPERATIONS</u> (Cont'd)									
4. Use of satellite, con- solidation, or break-bulk terminals									
a. Use several satel- lite terminals in large cities (Ref. 13)	TRS	TRS	TRS	TRS	0	0	TRS	All trucks	Fuel savings result from reduced stem mileages to each pickup and delivery zone. Also reduces stem times, which are often more important than fuel savings. Fuel-cost savings must be balanced against allocated investment costs.
b. Use single consoli- dation terminal for small-city operations (Ref. 13)	TRS	TRS	TRS	TRS	0	0	TRS	All trucks	Reduces number of pickup and delivery trips by local carriers in small urban areas.
c. Use regional break- bulk terminals	TRS	20	TRS	TRS	0	0	TRS	All intercity trucks	Terminal investment and break-bulk function costs must be more than offset by revenues from higher load factors.
5. Reduction of empty backhauls									
a. Increase inter- corporate backhauls (Ref. 1)	TRS	TRS	TRS	0	TRS	TRS (manage- ment analysis costs)	TRS	Private truck fleets	Motor Carrier Act of 1980 allows intercorporate backhauls, and these should be implemented except where precluded by incompatibilities due to specialized equipment or cargo characteristics.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
OPERATIONS (Cont'd)									
b. Increase trailer matching (Ref. 14)	TRS	20	TRS	TRS	0	TRS (manage- ment analysis costs)	TRS	General- commodity intercity trucks	Trailer matching programs reduce empty backhauls by trading full truckloads of single shipments or less- than-truckload shipments to carriers that have available tractors. One program has 21 carriers affiliated.
c. Increase haulage of backhaul cargoes recently exempted from regulation (Ref. 15)	TRS	TRS	TRS	TRS	TRS	TRS (manage- ment analysis costs)	TRS	All trucks	Motor Carrier Act of 1980 exempts many new commodities from regulations, providing new backhaul cargo opportuni- ties. Exempt and nonexempt commodities now may be hailed at the same time. May require investments in specialized equipment or additional maintenance expenditures.
6. Dispatching-policy improvements (Ref. 1)	TRS	TRS	TRS	0	0	TRS (manage- ment analysis costs)	N/A	All trucks	Careful dispatch times can reduce fuel wasting during rush-hour traffic and can coordinate arrival times with departure times needed to secure backhaul cargoes. Radio communications can aid dispatch procedures and improve vehicle use.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>EQUIPMENT PURCHASING AND MODIFYING</u>									
1. Use of resistance-reducing equipment									
a. Install aerodynamic devices (e.g., wind deflector atop tractor cab, bubble on trailer) and use aerodynamic (smooth, round-cornered) tractors and trailers (Refs. 1-7, 82, 87-89)	4-8	4 20	160-320 800-1600	350-600 350-600 (aero- dynamic devices)	0 0	0 0	1 year 6 months ^e	All trucks All trucks	As truck speed increases, aerodynamic drag increases much more quickly than rolling resistance. Devices reduce aerodynamic drag and are just as useful on straight trucks as on tractor-trailers. Especially good for operations with light-density loads. Results will be a function of vehicle configuration (tractor, trailer, and gap between them). A rig with a large gap will not benefit from present devices. Neither will low-speed local operators or tanker, flat-bed, or bobtail operations. Tractors with high trailerless miles should use fold-down deflectors. Voluntary Truck and Bus Program participants average 6% fuel savings. Keep trailer as low as possible.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
EQUIPMENT PURCHASING AND MODIFYING (Cont'd)									
b. Close-couple tractor and trailer and/or use side panels between trailer and container combinations (Refs. 7, 66, 69, 87-89)	Up to 5 ^e	20	Up to 1000	TRS (may be zero)	0	0	TRS ^e (may be immediate)	All tractor-trailers	Reduces aerodynamic flow-separation drag caused by gaps between equipment. This drag reduction can be added to that achieved with devices in Item 1a above. Trailers with side panels are now available, and seals to close off gaps are also being developed. Can be originally engineered or accomplished with sliding fifth wheel. Closing the gap tends to make the ride rougher.
c. Use radial tires, including super-singles and low-profile (Refs. 1-7, 16-19, 65, 70, 82, 83)	3-10	4 20	120-400 600-2000	TRS (generally 20% higher cost than bias-ply)	Reduces tire maintenance costs	0 0	TRS TRS	All trucks All trucks	Reduce rolling resistance, due to greater circumference. Require driver training and familiarization because of different "feel" and initial negative reactions in some cases. Training should include maximum use of coasting. (Radials coast up to 30% more effectively than bias-ply.) Radials need better alignment programs on all free-rolling axles than bias-ply tires. Maintenance of proper tire air pressures, including those of inside duals, is very important. Trade journal survey found 27 of 35 fleets averaging over 80,000 mi per new radial. Significantly increase recap life on

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>EQUIPMENT PURCHASING</u> <u>AND MODIFYING (Cont'd)</u>									
									tube-type carcasses, 2.5 times on tubeless carcasses. Reduce downtime by 40-80% and maintenance costs for over-the-road operations. Sidewalls can be severely damaged by difficult non-highway operations, but driver training and constant inspections can reduce damaging sidewall scraping. New super-singles provide higher fuel savings than radials and reduce weight and rolling resistance by replacing duals with singles. Caution: super-singles don't handle well on wet roads at high speeds and are more awkward to mount.
2. Power-train modifications	4-20	4	160-800	TRS	TRS	TRS	TRS	All trucks	Use one or more items listed below.
		20	800-4000	TRS	TRS	TRS	TRS	All trucks	
a. Install fan clutch (Ref. 1)	1-7	4	40-280	250-550	0	0	<1 year	All trucks	Operates fan only when needed (% of vehicle operating time). Investment is lower for installation in new vehicles, but still inexpensive for retrofits. Reduces cab noise and is standard equipment on most new trucks. Effective for high- or low-speed operations. Reliability of these fans has improved significantly.
		20	200-1400						

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>EQUIPMENT PURCHASING AND MODIFYING (Cont'd)</u>									
b. Install and/or adjust governors for maximum fuel efficiency (Refs. 1, 7)									
(1) Adjust engine-rpm governor for maximum efficiency (Refs. 1, 7, 69)	TRS	TRS	TRS	50-100	TRS	TRS	TRS	All trucks	Installation establishes maximum engine speed, thus reducing fuel use. For example, governed engine speed can be reduced by 200-300, while the truck still has a maximum speed of 60 mph and saves considerable fuel.
(2) Adjust road-speed governor for maximum fuel efficiency (Refs. 1, 7, 69, 71)	TRS	TRS	TRS	TRS	TRS	TRS	TRS	All trucks	Limits road speed below the geared road speed. More expensive and complex than engine governor, as well as making the truck harder to drive and requiring more shifting, but allows efficient engine operation. Computer simulation indicated a 5% mpg improvement.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
EQUIPMENT PURCHASING AND MODIFYING (Cont'd)									
c. Install lowest rear axle ratio appropriate for desired road and engine speed (Refs. 1, 7, 19, 65)	Up to 5	4 20	Up to 200 Up to 1000	0 0 (new tractors)	0 0	0 0	TRS TRS	All trucks All trucks	Primarily for new tractor purchases because retrofit is expensive. Ratios such as 3.55 to 3.7 are being used for over-the-road tractors. Caution: Truck must have a transmission and rear axle combination to meet steepest-grade starting conditions for the particular operations. Also, trucks with low-rpm cruise capability of 55 mph are still capable of reaching quite high, fuel-inefficient speeds. This can be controlled with a road-speed governor.
d. Install transmission with fewer fixed gear ratios and overdrive	TRS	TRS	TRS	TRS	TRS	TRS	TRS	All trucks	Fewer gears to shift enable better driver training and control. Gear friction is also reduced. Overdrive is preferred for on/off highway applications.
e. Substitute diesel for gasoline engine									
(1) Large or medium trucks (Ref. 19)	Up to 40	4 20	Up to 1600 Up to 8000	3000 3000	0 0	0 0	1 year <1 year	New, long-distance trucks	Best application is for large, long-distance trucks. Operations that have traded up from small to medium trucks have realized substantial savings. Engine life is 100-200% longer for diesels. Need 15,000-20,000 miles to reach payoff for diesel vs. gasoline.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>EQUIPMENT PURCHASING AND MODIFYING (Cont'd)</u>									
(2) Small trucks (Refs. 19-23)	20-50	4	800-2000	2000	See Remarks	40% decrease to 90% increase in oper- ating costs	TRS	New, short-, medium- distance trucks	Results of fleets of small diesels have been mixed. Smaller diesels appear to need at least 15,000-20,000 mi/yr to reduce overall costs due to significantly higher investment costs. Engine life is 100-200% longer for diesels. Particularly effective when operations require much idling time.
f. Use tag (dead) axle Refs. 1, 7, 19, 24)	2-5	4 20	80-200 400-1000	0 0	0 0	0 0	TRS TRS	See Remarks	Retrofit not feasible due to cost. Fuel savings result from fewer moving parts. Use on rear axle of new vehicle as part of tandem axle is usually less costly than live drive axle. Although it causes loss of maximum tractive effort, a single driven axle is sufficient except for poor road surfaces and extreme grades. Nevertheless, higher operating costs due to loss of traction must be balanced against lower purchase cost. Recent tests have demonstrated a new tandem-drive axle with a fuel economy almost equal to that of tag axles.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
EQUIPMENT PURCHASING AND MODIFYING (Cont'd)									
g. Use high-torque, low-rpm diesel engine (Refs. 1, 25, 26)	5-15 ^d	4 20	200-600 ^g 1000-3000 ^g	500-600 ^g 500-600 ^g	0 0	0 0	TRS TRS	All new trucks	These engines are direct- injection, turbocharged diesels with high torque at low engine speeds (1600 rpm and lower) and low governed engine speeds. Noise is reduced. Manufacturers have programs to educate owners and drivers for maximization of fuel savings from these engines.
h. Use diesel turbo- charged/aftercooled engine (Ref. 65)	TRS	TRS	TRS	TRS	TRS	TRS	TRS	All new trucks	The aftercooler lowers intake temperature, which in turn reduces peak cylinder and exhaust temperatures and reduces compression work requirements.
3. Install monitoring equipment									
a. Tachometer (Ref. 3)	TRS	TRS	TRS	130 (Frequently standard equipment)	0	TRS	<1 year ^e	All trucks	Training drivers to tie shifting patterns to tach- ometer instead of speed- ometer is important to the effective use of fuel- economy engines.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
EQUIPMENT PURCHASING AND MODIFYING (Cont'd)									
b. Tachograph (Refs. 1-6, 10)	TRS	TRS	TRS	290-370 (mechanical) 670 (electronic)	0	TRS (manage- ment analysis costs)	<1 year ^e	All trucks	References cite several cases of use of tach charts on every trip to monitor driver performance regarding speed and idling. The tachograph can also be combined with computer equipment to produce daily fleetwide reports that should be used for follow-up analyses. Also is a good driver-training device and has driver protection and insurance benefits as accident evidence.
4. Install improved air intake and exhaust system equipment (Refs. 27, 73)	Up to 2.5 ^e	4 20	Up to 100 Up to 500	5-13 (air filter indicators)	0	0	TRS	All diesel trucks	Some air filters have a special indicator that identifies the exact level of air restriction. This avoids excessive air filter changes and the excessive dirt that enters the engine side of the filter with these changes. Air filter should be mounted as close to the engine air intake as possible. Improved air intake hoods avoid intake of road dust and carbon and remove 90% of water brought in with air before it can block filter element. Improved mufflers with straight-through design reduce back pressure by as much as 70% while retaining noise control. Cost of these mufflers is comparable to that of conventional mufflers.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			

EQUIPMENT PURCHASING AND MODIFYING (Cont'd)									
5. Use of larger or multiple trailers									
a. Use 45-ft trailers instead of 40-ft trailer (Refs. 28, 29, 74)	Up to 10 (per ton-mile)	20	Up to 2000	800	0	-	TRS intercity trucks	All	Increased capacity per rig enables savings in all cases, but lower-density cargoes enable higher savings. Terrain, highway type, and type of service also affect savings. Only six states permit operation of triples (Nev., Idaho, Ore., Vt., Ariz., and Kans.) The U.S. Department of Transportation's truck-size-and-weight study found no consensus on whether multiple trailer trucks have higher accident and fatality rates than do tractor-semi-trailer rigs. Need to be more careful in icy or wet weather. Fifty-seven-foot trailer units are available. Tests in South Dakota with twin 45-ft trailers and maximum weights of 129,000 lb found 41% fuel savings over singles operation.
b. Use twin 27-ft trailers instead of single 40-ft trailer (Refs. 28, 29)	Up to 22 (per ton-mile)	20	Up to 4400	9000-11,000 (includes single-axle dolly)	TRS	-	TRS intercity trucks where allowed by state law	All	
c. Use triple 27-ft trailers instead of single 45-ft trailer (Refs. 28-32)	Up to 15 (per ton-mile)	20	Up to 3000	21,000-25,000 (includes two dollies)	TRS	-	TRS intercity trucks where allowed by state law	All	
d. Use triple 27-ft trailers instead of twin 27-ft trailers (Refs. 33, 34)	Up to 27 (per ton-mile)	20	Up to 5400	15,000	TRS	-	TRS intercity trucks where allowed by state law	All	
e. Use longer trucks, or drop trailers, swap bodies, or drom vans with trailers (Refs. 1, 35)	TRS	TRS	TRS	TRS	TRS	-	TRS	All trucks	

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck							Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)						
				Investment	Main- tenance	Other				
EQUIPMENT PURCHASING AND MODIFYING (Cont'd)										
6. Use of dedicated piggy- back (trailer-on-flatcar or container-on-flatcar) trains (Refs. 36-38)	Up to 50 (est.)	20	TRS (Revenue sharing with rail- road will also occur)	TRS (see Remarks)	0	-	N/A	Intercity trucks moving over 200 mile	Limited and nondefinitive federally sponsored research has found that dedicated piggyback trains use approx- imately one-half the fuel per revenue ton-mile that intercity trucks do on flat terrain. However, this advantage is often reduced considerably by circuitry, grade factors, and curves. Piggyback is an option for volume expansion that requires investment in addi- tional trailers but not necessarily in tractors. Piggyback is most applica- ble for long-distance move- ments, but is less effective for shorter movements.	
7. Use of vehicles with reduced tare weight (Ref. 72)	Up to 5.5	4 20	Up to 220 Up to 1100	TRS TRS	TRS TRS	TRS TRS	TRS TRS	All trucks All trucks	Weight reduction of up to 10% is possible, resulting in increased payloads and up to a 5.5% fuel savings according to one study.	

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
FUEL AND LUBRICANT CHANGES									
1. Use of gaseous fuel instead of gasoline									
a. Propane (liquefied petroleum gas, or LPG) - total substitution (Refs. 39-41, 75, 76)	Substi- tutes for gasoline	4	600-800 ^h	1000-1600 (conver- sion)	0 (see cautions in Remarks)	0	TRS (18 months claimed in in some cases)	Local pickup and delivery and route delivery fleets (<u>></u> 15 gasoline- powered trucks in fleet)	Not applicable for diesel-trucks. Gas tank is re- placed by pressure vessel. Requires bulk storage tank at each fueling location or use of 8,000-10,000 propane stations (vs. 160,000 gaso- line stations), resulting in limited range. Mileage (mpg) is approximately 5% less, but lower propane costs result in net savings of 15-20¢/gal (some fleets claim higher savings). Driver must follow slightly different operating pro- cedures. <i>Caution:</i> Not allowed in tunnels and certain bridges and should always be parked outdoors due to possible leakage of volatile fumes. Extreme care should be taken not to overfill tanks, because normal expansion can acti- vate the emergency pressure release valve and create a fire hazard. Fleet demon- strations have shown inac- curacies with propane fuel gauges. Maintenance of spark plugs, ignition, cooling, and aeration sys- tems must be superior to prevent detonation. How- ever, less maintenance is required; for example, spark plugs and lubricating oil last 2 to 3 times longer.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
FUEL AND LUBRICANT CHANGES (Cont'd)									
b. Compressed natural gas (CNG) - total substitution (Refs. 39-41)	Substi- tutes for gasoline	4	600-800 ¹	1600-2600 per truck - parts only; >24,000 for time- fill station; >31,000 for quick- fill station	TRS (see cautions in Remarks)	0	TRS	Local pickup and delivery and route delivery fleets (>15 gasoline- powered trucks in fleet)	Not applicable for diesel- powered trucks. Requires either a time-fill (10-14 hr per vehicle) or quick-fill (2-5 min per vehicle) compression station (see investment costs column), resulting in limited range. Gas tank is replaced by one or more CNG cylinders. All cited uses of CNG were in dual-fuel (with gasoline) systems (see Measure 1c). One operator reports CNG costs were 80¢/gal cheaper than gasoline. Caution: Same as in 1a.
c. Dual-fuel system - gasoline with LPG or CNG (Refs. 39-41)	Up to 50% ¹ Substi- tution for gasoline	4	Up to 400 ¹	Same as 1 a for LPG, 1b for CNG	TRS (see cautions in Re- marks)	0	TRS (2 to 5 years claimed in various cases)	Local pickup and delivery and route delivery fleets (>15 gasoline- powered trucks in fleet)	Same as 1a for LPG, same as 1b for CNG. More mainten- ance required and less effi- cient, but offers greater flexibility during fuel shortages and for local operations with occasional long-distance hauls.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
FUEL AND LUBRICANT CHANGES (Cont'd)									
2. Use of extended-life engine lubricants									
a. Synthetic (Refs. 42-44)	Up to 3 ^e	4 20	Up to 120 Up to 600	0	0	0 (higher oil cost offset by fewer oil changes)	TRS ^e	All trucks	More expensive (\$12/gal) but claimed to last 100,000 miles (with addition of some make-up oil) vs. 25,000 miles for conventional lubricants. Most beneficial in colder climates; has improved low-temperature fluidity for cold weather starting and engine protection. High-temperature stability results in reduced oil degradation during service. Widely used in U.S. and Canadian highway and off-highway fleets. Generalizations should not be made among brands of synthetic lubricants.
b. Multiviscosity petroleum-based (Ref. 45)	TRS	TRS	TRS	0	0	0	TRS ^e	All diesel trucks	Contains agents to reduce internal engine friction and additives to resist viscosity changes and inhibit oxidation and corrosion.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
FUEL AND LUBRICANT CHANGES (Cont'd)									
3. Use of improved gear oils (Refs. 42, 46)	Up to 1.5 ^e	4	Up to 60	0	0	15-30/yr (higher oil cost)	6 months	All trucks	Savings of 1-1.5% are claimed for one synthetic gear oil, 3 to 5% for an improved conventional gear oil. At 212°F, synthetic oil has same viscosity as conventional oil, but has significantly better low- temperature fluidity. Improved conventional oil has a sheer-stable, multi- function viscosity within acceptable limits at high and low temperature over extended periods of severe service. Costs between \$15 and \$30 more annually per tractor but an annual savings of up to \$360/yr per tractor has been claimed. Provides extra protection at temperatures up to 325°F. Both oils reduce friction and power losses in gear- boxes.
		20	Up to 300	0	0	15-30/yr (higher oil cost)	2 months	All trucks	
4. Re-use of used crankcase oil in diesel fuel (after processing through filter/separator and blending devices) (Refs. 47-49)	Up to 5 (per oil change)	TRS (Depends upon number of annual oil changes)	TRS	1500 (filter separator device) 10-15 (each filter good for 50-60 oil changes)	0	TRS	TRS	All diesel trucks	After extensive monitoring of fleets, one major engine manufacturer has approved use of up to 5% filtered crankcase oil in blend with diesel oil. Performance of engines after 100,000 miles was found to be unaffected.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>FUEL AND LUBRICANT CHANGES</u> (Cont'd)									
5. Use of alcohol fuels as extenders of petroleum-based fuels									
a. With gasoline - 10% blend (gasohol) (Refs. 41, 50, 51)	Fuel economy 1% (Substitution for gasoline 10%)	TPS	TRS	0	0	0	N/A	All gasoline-powered trucks	Fuel efficiency is equal to or slightly better than straight gasoline because of octane increase. Does not cause engine damage. One study found that if gasohol is purchased for less than 10¢/gal more than the cheapest gasoline a truck can use, cost savings will be obtained. Ethanol blends are more fuel efficient than those using methanol because ethanol has a higher energy content.
b. With diesel fuel (dieselhol) (Ref. 50)	TRS	TRS	TRS	0	0	0	N/A	All diesel-powered trucks	No definitive findings exist on net petroleum savings, but diesel fuel-alcohol blends are known to be less fuel efficient than gasohol, because the lower energy content of alcohol is not counter-balanced by improved combustibility in diesel fuel-alcohol blend. Alcohol is not a cetane improver.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
TECHNOLOGIES UNDER DEVELOPMENT									
1. Organic Rankine bottoming-cycle waste heat recovery system (Refs. 52-54, 77)	Up to 15	20	Up to 3000	\$10,000 increase in cost of \$60,000 tractor	0	0	2 years (est.)	All new heavy-duty intercity trucks	Road tests with 70,000-lb-gross tractor-trailer have achieved 12.5% fuel savings, but six more years of testing and demonstration are projected. Up to 40 additional horsepower are estimated to be achievable through recovery of waste heat (exhaust gas) in a 290-horsepower engine. It is anticipated that a few standard designs will be adaptable to many different engines. Major components include turbine, gearbox, feed pump, vapor generator, condenser, and regenerator. Could be commercially available in a few years.
2. Gas turbine engine (Refs. 54-56, 78)	Up to 100 (potential oil savings through alternate fuel use)	TRS	TRS	Unknown	Unknown	Unknown	Unknown	All new long-distance trucks	Twenty-four trucks have been used for operational tests in widely divergent locations throughout U.S. Fuel consumption rate was once higher than diesel due to high fuel-flow rates at idle. Main energy savings potential lies in combustion efficiency improvements (e.g., through development and use of high-temperature ceramics) that enable use of alternate fuels (i.e., coal-derived synfuel, methanol) in place of petroleum-based fuels. Most applicable for

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>TECHNOLOGIES UNDER DEVELOPMENT (Cont'd)</u>									
3. Other energy recovery and fuel tolerance technologies (turbocompound diesel; uncooled engine; minimum-friction adiabatic engine; fully adiabatic turbocompound diesel; adiabatic engine plus bottoming cycle; spark ignited/assisted stratified-charge gasoline and diesel engines) (Refs. 54, 57, 58, 79)	TRS	TRS	TRS	Unknown	Unknown	Unknown	Unknown	All trucks	<p>long-distance operations at full power most of the time. It is estimated that successful application in quantity will not occur until 1990-2005.</p> <p>In various stages of research and development and projected for commercialization between 1985 and 2000. Turbocompound diesels have been under development since 1972 and use turbine power generated by exhaust gas expansion by transferring the power to the drivetrain by gearing the turbine to the engine crankshaft. A 50,000-mi field test of a turbocompound, turbocharged, and aftercooled engine on a heavy-duty truck found fuel savings of about 15% (6% was determined to be due to turbocompounding alone). Driver reaction was favorable to the quiet and smooth operation and strong performance on long grades. Turbocharger efficiency has been found to be critical due to degree of conversion of exhaust gas energy. Adiabatic engines are based on concept of insulating diesel combustion chamber with high-temperature</p>

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>TECHNOLOGIES UNDER DEVELOPMENT</u> (Cont'd)									
									materials (usually ceramic) to allow "hot" operation near an adiabatic condition. One major package-delivery firm is currently testing a stratified-charge engine in its fleet using multiple fuel types and has found up to 35% fuel savings.
4. Undercarriage wind deflectors and improvements in aerodynamic design (Ref. 69)	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	All trucks	Undercarriage wind deflectors are being tested, but may cause maintenance problems. Improved aerodynamic designs of tractors are also being developed.
5. Injection of water and alcohol blend in diesel engines (Refs. 79, 80, 81)	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	All trucks	Maritime industry is conducting extensive tests of water-fuel emulsions. Farm tractors show 6% fuel savings in selected tests.

Table 1 (Cont'd)

Fuel-Savings Measure	Per Truck						Approx. Payback Period (if available)	Assumed Market Sectors	Remarks
	Claimed Fuel Savings (%) ^a	Assumed Fuel Use ^b (10 ³ gal/yr)	Claimed 1983 Annual Fuel Cost Savings ^c (\$)	Additional 1983 Costs (\$)					
				Investment	Main- tenance	Other			
<u>TECHNOLOGIES UNDER DEVELOPMENT (Cont'd)</u>									
6. Electronic controls									
a. Fuel (Ref. 59)	Up to 7	4 20	Up to 280 Up to 1400	Unknown	Unknown	Unknown	Unknown	All diesel trucks	Controls being bench-tested include a family of pumps, sensors, and microprocessors to govern delivery of fuel to injectors and select optimum injection timing.
b. Transmission (Ref. 60)	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	All diesel trucks	Controls are expected to reduce shift-point variations from optimum from ±75 rpm down to ±15 rpm. First applications planned for 1983-84.

^aFuel savings of the various measures are not directly additive because each new savings will diminish the annual base of fuel consumption that can be further reduced.

^bWhen two sets of numbers are given, top number is for local, intracity fleets and assumes 40,000 miles annually @ 10 mpg; bottom number is for intercity fleets and assumes 100,000 miles annually @ 5 mpg. Both estimates assume diesel operations.

^cAssumes baseline annual fuel use and \$1.00/gal fuel price.

^dTRK = Truck- and route-specific. Costs can include management program and driver training and monitoring costs. This entry was used where no estimate could be found for a data item.

^eReference estimates adjusted by industry coordination meeting consensus.

^fN/A = Not applicable.

^gUses comparison of two engine types of a major manufacturer.

^hBased on a gas company's estimated 15-20¢/gal net savings after 5% loss in mpg.

ⁱBased on estimated use of LPG or CNG as substitute for gasoline daily (total substitution) or every other day (dual-fuel system), and on a gas company's estimate of net potential savings of 15 to 20¢/gal after 5% loss in mpg.

4 DISCUSSION OF MATRIX REVISIONS

This section demonstrates the usefulness of the industry coordination meeting as a research tool for use in (1) developing and evaluating summary information and (2) identifying and discussing the specific revisions that improved the matrix.

4.1 SUMMARY OF INDUSTRY COORDINATION MEETING RESULTS

One important result of the meeting was the unanimous agreement by the participants that the first measure in the matrix (i.e., development of driver understanding, motivation, cooperation, and participation, preferably through a management program) is the single most important part of any truck fuel savings program. The human element, namely the driver, was considered crucial to the success of fuel-saving equipment and procedures. It is not coincidental that the same generic consensus regarding operating personnel was reached in the earlier industry coordination meetings conducted by ANL during the last two years for the maritime and railroad industries. At all these meetings, roughly the same percentage of participants agreed unanimously that this measure offers the greatest savings potential. These results testify to the pervasive importance of the human element in energy efficient transportation systems.

Discussions during this meeting resulted in the following changes to the matrix:

- There were 55 fuel-saving measures in the draft matrix; one was deleted and eight were added for a final total of 62.
- The fuel-savings percentage estimates for five measures were revised.
- The payback period estimates for eight measures were changed.
- There were 17 substantive changes and/or additions to the remarks (e.g., advantages, disadvantages) columns of 14 measures. The meeting also resulted in the addition of 29 publications to the matrix reference list, increasing the total from 60 to 89.

4.2 ADDITION AND DELETION OF MATRIX MEASURES

The measures listed below were added to the matrix as a result of participant recommendations made during the coordination meeting. The participants also provided appropriate reference sources for use in developing both the summary data for the matrix and the reference list to provide a source of more detailed and extensive information. The added measures were:

- Maintain coolant temperatures.
- Adjust aerodynamic devices based on trailer height and gap.
- Install transmission with fewer fixed gear ratios and an overdrive for on-off highway, fixed-speed cruise operation.
- Use diesel turbocharged/aftercooled engine.
- Use regional break-bulk terminals.
- Use vehicles with reduced tare weight.
- Use undercarriage wind deflectors and improvements in aerodynamic design; injection of water-and-alcohol blend in diesel engines.

In the making of six of these eight matrix changes, unlike those discussed in the subsequent sections, truck operators generally allowed the research community to take the lead. This is consistent with the approach generally taken by truck operators in considering changes to their operations and equipment, i.e., allowing the research and equipment-manufacturing communities to offer fuel-savings alternatives. Although not as familiar with these measures as with the other 56, the industry participants saw sufficient merit in the information provided orally by the research community members to accept them as additions to the matrix pending ANL review of the cited references. This review verified the oral information presented at the meeting. Significantly, however, no specific fuel-savings percentage estimates were agreed on for any of the added measures, although the results of some studies and tests were included in the "Remarks" column of the matrix.

Two of the first six added measures were proposed by Raymond Camball, project manager of the Canadian TRUCKSAVE Program, which operates in Ontario. This resulted not only in these two new measures (which were not found in U.S. truck research literature by ANL), but also in nine new references that are included in Appendix A.

John Burke, a former official of the U.S. Voluntary Truck and Bus Fuel Economy Program, proposed the transmission options and diesel

turbocharged/aftercooled engine measure, as well as the undercarriage wind deflectors and improved aerodynamic tractor designs. He also supplied 18 new references that were added to the list in Appendix A.

Professor McNally proposed adding to the list of technologies under development the research and testing being done on injecting a water-and-alcohol blend into diesel engines. This proposal was also accepted, with particular reference made in the matrix to similar research and development in the maritime industry.

Finally, two new measures in the above list were suggested by truck industry representatives. One measure was added when truck operators pointed out that regional break-bulk terminals en route for intercity movements are analogous to city consolidation terminals and are already being used to increase cargo ton-miles per mile driven. The second measure was added when the operators cited examples of vehicles with reduced tare weight that are already available and being used to increase load factors.

4.3 REVISIONS OF FUEL-SAVINGS PERCENTAGE ESTIMATES

All recommendations for revisions in fuel-savings percentage estimates at the meeting were initiated by truck operators, based on their operating experiences. These recommendations, combined with the operators' agreement with the rest of estimated percentages in the matrix, were among the most important contributions made by industry. The revisions were made to include a perspective based on a wider cross-section of real-world truck operations to the fuel-savings estimates that were based on research and/or limited tests. The five revisions of fuel-savings percentage estimates are as follows:

- Improve driving practices: 1 to 10% changed to Up to 12% for both intercity and intracity operations.
- Close-couple tractor and trailer and/or use side panels between trailer and container combinations: *Truck- and route-specific* changed to Up to 5% for intercity operations.
- Install improved air intake and exhaust system equipment: Up to 3.7% changed to Up to 2.5% for both intercity and intracity operations.
- Use of synthetic extended-life engine lubricants: Item 2a; Up to 6% changed to Up to 3% for both intercity and intracity operations.
- Use of improved gear oils: 1 to 5% changed to Up to 1.5% for both intercity and intracity operations.

The downward adjustment of three estimates and upward adjustment of two reflected the levels of success encountered by industry participants in employing the various measures.

4.4 ADJUSTMENTS OF PAYBACK PERIOD ESTIMATES

The payback period, or length of time required for an investment to save a company enough money to pay for itself, is an important criterion to a business contemplating that investment. The adjustments made to payback-period column for eight measures at the suggestion of industry participants were valuable contributions. Six of the eight adjustments were favorable, indicating that industry participants have had very positive experiences with several measures. The eight adjustments were as follows:

- Development of driver understanding, motivation, cooperation, and participation (preferably through a management program): *Truck- and route-specific* changed to *Less than six months* for both intercity and intracity operations.
- Supervise outside fuelings to avoid "overfills": Changed from *Not Applicable* to *Immediate* for both intercity and intracity operations.
- Install aerodynamic devices (e.g., wind deflector tractor cab, bubble on trailer): *Less than one year* changed to *Six months* for intercity operations.
- Close-couple tractor and trailer and/or use side panels with trailer and container combinations: *Truck- and route-specific* changed to include *May be immediate* in parentheses for intercity operations.
- Install tachometers: *No estimate* changed to *Less than one year* for both intercity and intracity operations.
- Install tachographs: *No estimate* changed to *Less than one year* for both intercity and intracity operations.
- Use of synthetic extended-life engine lubricants: *No payback period* changed to *Truck- and route-specific* for both intercity and intracity operations.
- Use of extended-life engine lubricants that are multi-viscosity, petroleum-based: *Less than six months* changed to *Truck- and route-specific* for both intercity and intracity operations of diesel trucks.

4.5 SUBSTANTIVE CHANGES TO REMARKS COLUMN

Because of the many (17) substantive changes to the "Remarks" column (e.g., advantages, disadvantages, technical explanations of measures) for 14 matrix measures, this section concentrates only on eight selected changes in the interest of brevity. The changes discussed are individual comments or sets of comments regarding a fuel-savings measure. They are among the most important changes made to this column in terms of new and/or clarifying information provided.

The first set of changes in the "Remarks" column was for the measure calling for development of driver understanding and support of a fuel savings program. Whether or not a formal management program is used, meeting participants agreed that the setting of realistic goals (e.g., achievable improvements in mpg) is important to successful fuel-savings efforts. Realistic goals aid these efforts by not only providing sufficient opportunities for positive reinforcement through the reaching of goals, but also help prevent the cheating that has been known to occur, according to meeting participants. The participants also recommended adding two examples of successful program elements for fleet operations based upon their experiences, i.e., (1) use of an advisory board composed of drivers to select new drivers and (2) use of a team incentive program to add peer pressure to financial incentives in improving fuel efficiency. Such driver group activities were considered to be useful in building teamwork and sharing information among drivers.

The second important change to the "Remarks" column was made for the 55-mph maximum speed measure. A consensus statement was added to note the particular importance of not exceeding 55 mph when headwinds are high, because disproportionately high power increases are required.

A statement was added for the measure calling for avoidance of sudden stops and starts. It was noted that this measure requires careful observation of other vehicles and choosing of a lane that will let the truck keep moving while maintaining an adequate distance from the vehicle ahead. This element of driving strategy is necessary, particularly on heavy traffic routes, if the measure is to be accomplished.

The fourth added remark was for the measure that calls for monitoring of fuel consumption. Meeting participants pointed out that electronic monitoring instruments are good driver-training devices even if there is not enough capital to equip the entire fleet.

The fifth comment added an operational (i.e., service) incentive for the use of satellite terminals in large cities. The reminder placed in the remarks column (noting that the reduction in stem times effected by the terminals is often more valuable than the fuel savings achieved) provides trucking firms with an even greater reason to use satellite terminals.

The sixth set of changes was related to radial tires and their safe and proper use. A caution was added for the recently developed "super-single" radials (i.e., single tires that replace dual radials, reducing weight and rolling resistance). It was noted that they do not handle well on wet roads at high speeds. In addition, recommendations were made for better alignment programs for radial tires than for bias ply tires on all free-rolling axles and for maximization of coasting. The latter was recommended because radials coast up to 30% more effectively than bias-ply tires and this fact should be demonstrated to drivers during training. These inclusions in the "Remarks" column provide to the novice user of highly popular radials valuable information not found in the many references that describe radials and that were used to develop the draft matrix.

The seventh added remark concerned installation of fan clutches. While some early users may have found these devices to be unreliable, the recent experiences of the meeting participants resulted in the addition of a remark indicating that fan-clutch reliability has improved significantly in recent years.

The eighth set of changes significantly altered the remarks concerning the use of propane (liquefied petroleum gas, or LPG) rather than gasoline. The meeting consensus was that the draft matrix remarks taken from the literature unduly emphasized the dangers of using propane. Noting, for example, the extreme combustibility of gasoline and its harmfulness to the skin, participants removed statements cautioning that the "engine must not be started and then shut down without giving the coolant a chance to attain 55°F" and that "propane contact with the skin causes serious freeze burns." These were replaced with a statement that the "Driver must follow slightly different operating procedures." Regarding maintenance, the participants retained a draft matrix comment on the need for careful attention to spark plugs, ignition, cooling, and aeration systems to prevent detonation. However, to give proper credit to the maintenance advantages of propane, the participants agreed to add a statement that "...less maintenance is required; for example, spark plugs and lubricating oil last two to three times longer." Finally, participants' respects for the dangers of using propane is demonstrated by the comment added to the remarks that "extreme care should be taken not to overfill tanks, because normal expansion can activate the emergency pressure release valve and create a fire hazard." These changes, although not related to fuel efficiency, provide operators who contemplate the use of propane with balanced information on its advantages and disadvantages. The changes downplaying the dangers of propane were included in the matrix because they came from truck operators, not from propane manufacturers.

5 CONCLUSIONS

This report contains a compendium of information developed for the trucking industry on options available for saving fuel. The considerable research value of an industry coordination meeting in revising the matrix was focused upon and clearly demonstrated. Moreover, the credibility of this information dissemination program with its intended audience was greatly enhanced by describing participants' input and providing a list of the participants as part of a mailing list sent to members of the trucking industry. An important result of this program was the consensus reached at the meeting, as at the maritime and railroad industry meetings, that the vehicle operator is the single most important ingredient in a successful fuel-saving program.

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APPENDIX A: MATRIX REFERENCE LIST

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APPENDIX B: MEETING PARTICIPANTS

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APPENDIX C: ARGONNE PRESS RELEASE

December 15, 1983

83-92
FOR IMMEDIATE RELEASE
Media contact: David Baurac

ARGONNE, ILL. ... The individual truck driver is the key to saving energy in the trucking industry. This is the conclusion of a recent study by the Department of Energy's Argonne National Laboratory and reflects the consensus reached at a trucking-industry meeting sponsored by Argonne during the study.

The study gathered and summarized information on more than 60 different energy-saving measures suitable for all truck operators. Measures included changes in operating procedures, add-on equipment, purchase of new vehicles with new fuel-saving features, fuel and lubricant changes, and new technologies under development.

"The role of the driver is crucial to the success of fuel-saving programs," said Ken Bertram of Argonne. Bertram is head of the study group. "New equipment and procedures to save fuel are most effective when individual drivers understand them and how they work and are strongly motivated to use them properly."

Specific fuel-saving measures included:

- o Substituting propane for gasoline fuel.
- o Installing aerodynamic wind deflectors on top of tractor cabs.
- o Buying new vehicles with high-torque, low-rpm diesel engines.

- o Using organic Rankine engines that reclaim exhaust heat and convert it into more horsepower.

- o Better and more timely maintenance.

Representatives of six firms with ongoing truck fuel efficiency programs and eight members of the private, academic and government truck research community attended an Argonne-sponsored, industry-coordination meeting in late 1982. The participants reached the same conclusions, while helping to refine Argonne's summary information. Organizations represented at the meeting were the American Trucking Associations, Beatrice Foods Co., CFS Continental Inc., W. W. Grainger Inc., Growmark Inc., Preston Trucking Co. Inc. and Ruan Trucking Inc.

The study's conclusion echoes the results of earlier Argonne studies of the maritime and railroad industries. These studies held similar industry-coordination meetings that concluded that the key to successful energy-saving programs in those industries was the understanding and motivation of individual ship and railroad operating crews.

Argonne has prepared a chart summarizing the information available on more than 60 energy-saving measures that can be applied to local and long-haul trucking. Similar charts are available for the maritime and railroad industries.

Anyone interested in copies of the charts may contact Ken Bertram at the Center for Transportation Research, Building 362, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439.

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