A Quality Assessment of Motor Carrier Maintenance Strategies: An Application of Data Envelopment Analysis

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This study seeks to extend the literature examining the relative importance of service and cost as determinants of the transportation choice decision in the motor carrier industry by investigating the quality of maintenance operations. The high replacement cost of equipment and its increasing age contribute to the need for efficient, high quality maintenance operations. Of particular importance in this study is the perception of the safety of the carriers' service measured by the **Quest for Quality***'s equipment quality rating.*

Data envelopment analysis is used to identify the causes of inefficiencies in maintenance strategies and their impact on firms' quality rating performance. A sample of 160 observations is examined over the period 1990-1997. We find that only 8 percent of the observations are classified as efficient with respect to the maintenance operation as it affects the quality of service. We determine that significant reductions and changes in the maintenance cost mix are needed to attain the quality level demanded by shippers.

Introduction

Recent discussions of motor carrier highway safety have included the issue of maintenance policies of individual motor carriers. Disparities in the quality of motor carrier maintenance have motivated several federal safety programs. Roadside inspections as provided by the Motor Carrier Safety Assistance Program (MCSAP) are used to monitor violations of the Federal Motor Carrier Regulations. Audits of

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management compliance with Federal Motor Carrier Regulations are implemented through the Safety and Compliance Review Program.

Testimony before the U.S. House of Representatives Committee on Appropriations, Subcommittee on Transportation, has highlighted the Department of Transportation's continued emphasis on the safety of the nation's transportation system as a top priority.[1] In fiscal year 1999, the federal government through the MCSAP distributed $90 million to the states. About 80 percent of these funds support the salaries of safety inspectors who conduct more than 2 million roadside vehicle inspections each year. The MCSAP allows the Federal Highway Administration (FHWA) to work closely with the states in training personnel to conduct inspections and in sharing information and data. Such information and data facilitates the coordination of roadside inspection efforts and improves safety programs overall. With respect to heavy trucks, the National Highway Traffic Safety Administration investigates any reports of vehicles that are manufactured with safety-related defects.

As new technology promotes further advances in vehicle compliance, agencies will pursue more accurate targeting of motor carriers who persistently pursue strategies that yield poor vehicle maintenance. The FHWA currently uses the Safety Status Measurement System to help investigators target motor carriers who demonstrate high safety-risk strategies. The FHWA also is expanding the Performance and Registration Information System Management program. Under this program, high-risk motor carriers may find their state vehicle registration privileges suspended if no improvement in their behavior is demonstrated.

Something not given the same visibility or emphasis as enforcement policies is the idea that perceptions of the quality of vehicle maintenance affect shippers' choices with regard to motor carriers, specifically less-than-truckload (LTL) carriers. Allen and Liu (1995) explain that LTL carriers "collect, consolidate, and distribute shipments through networks consisting of terminals and breakbulk centers" (p. 499).

This study examines the quality of the maintenance technology of LTL carriers, with an emphasis on safety. Over the eight-year period of this study, total maintenance expenditures as a percentage of total operating revenues ranged from a minimum of 2.6 percent to a maximum of 5.5 percent for the sample. Although this is only a small portion of the carriers' expenses, it is still significant enough to warrant examination because one of the most costly assets of motor carriers and their source of profit is their revenue-generating equipment. Over the period of this study the average gross investment in owned equipment remained constant, while the

[1] Statement of Kenneth R. Wykle, Administrator, Federal Highway Administration, and Ricardo Martinez, Administrator, National Highway Safety Administration, U.S. House of Representatives Committee on Appropriations, Subcommittee on Transportation, February 23, 1999.

average accumulated depreciation on this operating equipment grew 9 percent.[2] The increase in accumulated depreciation indicates that older equipment is not being replaced by newer equipment or that the number of pieces of equipment being replaced is less than the number of pieces being retired due to inherent cost increases. Therefore, the average age of the fleet is increasing. This information is important because as the age of the vehicles increases, so does the cost of maintenance. It is therefore incumbent upon the carriers to improve the quality of the maintenance operation in order to prolong the useful life of its fleet.

Further motivation for this study is evidenced by the continuing emphasis by shippers on the quality of the carriers' performance that relate to the maintenance function. As noted in the *Standard & Poor's Industry Surveys* (1995), "motor carriers must have high on-time performance, ... well-maintained, large capacity trailers, and punctual pickups" (p. 37).

Allen and Liu (1995) argue that LTL carriers are able to provide more frequent and reliable services than their truck-load (TL) counterparts. LTL carriers with these large, integrated networks are able to coordinate shipments and offer faster services to more places at competitive or lower costs than TL carriers. Of particular importance in the current deregulated environment is the fact noted by Allen and Liu (1995) that "the LTL segment of the motor carrier industry has experienced intense rate and service quality competition" (p. 500). A large number of LTL carriers has been driven out of business, and the industry has become more concentrated since deregulation. The rivalrous nature of this industry suggests that LTL carriers should be highly motivated to identify elements of their vehicle maintenance strategies that detract from customer-perceived quality.

Variables used in measuring quality are varied. Parasuraman *et al.* (1985) review the marketing literature and provide some insight into service quality determinants. They find the following determinants of service quality: reliability, responsiveness, competence, access, courtesy, communication, credibility, security, understanding of the customer, and tangible measures. The tangible measures include physical facilities, equipment, and personnel.

Crosby (1979) defines quality as conformance to requirements. The problem with this definition as described by Johnston (1986) is that the customer and service provider have different perceptions of quality. Parasuraman *et al.* (1985) explain that perceptions of service quality arise from comparisons of expectations with actual

[2]This information is obtained from *Financial and Operating Statistics*, "Motor Carrier Annual Report," (Alexandria, Virginia: American Trucking Association, Statistical Analysis Department, 1990-1994). This database contains the Interstate Commerce Commission's Annual Report Form M-1 for Class I Motor Carriers of Property and Household Goods. This information is based on the average of all companies included in the database over the eight-year period of the study.

performance. Gale and Buzzell (1989) further assert that quality is whatever the customer perceives it to be.

The next section presents an explanation of the methodology and data used in the analysis. Subsequent sections discuss the results, summarize the findings, and describe their strategic impact on the maintenance function of LTL carriers.

Methodology and Data

This study uses data envelopment analysis (DEA) to examine the quality of the maintenance technology of LTL carriers, with an emphasis on safety. This methodology is used to compare the relative efficiencies of the individual observations. To be efficient, a production plan must result in the same output using fewer inputs or it must use the same inputs to produce more output. Therefore, DEA results in a measure that shows which inputs and outputs can be reduced to result in a minimization of total waste.

In contrast to the traditional parametric production function, where a specific pre-defined functional form is assumed to apply to each observation, DEA makes no assumptions about the form of the production function. The actual, observed inputs and outputs of the specific observations are used to estimate a benchmark production frontier. Efficiency is obtained when comparisons with other units indicate no inefficiency in the utilization of inputs and outputs, as measured by the observation's position relative to the efficient production frontier. DEA is also units-invariant in its efficiency scores.

There are three groups of data used in the analyses: inputs, outputs, and descriptive measures. Input measures represent minimizing goals. The input data variables used in this study are the costs that pertain to maintenance operations. The four inputs are vehicle parts, tires and tubes, outsourced maintenance, and maintenance labor. In order to prevent distortions due to the differing sizes of the companies, all input variables are scaled by total operating revenues.

Table 1, Panel A contains descriptive information about these input variables. Over the eight-year period of the study, the parts and the tires and tubes variables were fairly constant each year. It should be noted that outsourced maintenance cost, on average, increased from $5.58 million in 1990 to $8.95 million in 1997. On the other hand, maintenance labor cost, on average, remained relatively stable, rising from $12.8 million in 1990 to $13.0 million in 1997. This is in spite of industry-wide increased labor costs resulting from a shortage of drivers and the settlement of a Teamsters' strike in early 1994. Control of labor costs is important to carriers because they "are no longer able to automatically pass the cost of higher wages on to shippers (Standard & Poor's, 1994, p. 42)." The dramatic increase in outsourced maintenance cost and the stable maintenance labor cost point to an increased use of outsourced maintenance over the period of the study. Additionally, the minimum labor cost over the eight years of this study was $0.0, while the maximum value

Table 1—Descriptive Statistics For Data

Panel A: Input Variables[a] = Minimizing Goals

Variable	Actual Costs			
	Minimum	Maximum	Average	Median
Vehicle Parts	$464,995	$33,454,048	$7,057,323	$2,667,096
Tires and Tubes	212,907	20,016,086	4,047,121	2,505,072
Outsourced Maintenance	0	46,014,640	6,297,364	1,616,760
Maintenance Labor	0	69,628,668	12,058,849	3,705,963

Variable	Actual Costs Scaled by Revenue			
	Minimum	Maximum	Average	Median
Vehicle Parts	.0052	.0349	.0138	.0128
Tires and Tubes	.0011	.0207	.0093	.0080
Outsourced Maintenance	.0000	.0365	.0099	.0080
Maintenance Labor	.0000	.0476	.0213	.0212

Panel B: Output Variables[b] = Maximizing Goals

Variable	Minimum	Maximum	Average	Median
Equipment Quality	1.8900	2.5500	2.2226	2.2200

Panel C: Descriptive Variables[a]

Variable	Minimum	Maximum	Average	Median
Operating Revenue Change	-27.72%	52.11%	10.10%	8.47%
Maintenance Expenditures Change	-24.55	53.93	8.37	7.50

[a] Data are obtained from the American Trucking Association's financial database, *Financial and Operating Statistics*. These data are accumulated over the eight-year period of the study

[b] Data are obtained from *Distribution* magazine's annual "Quest for Quality Survey." The ratings are based on a three-point scale (3 = outstanding; 2 = average; 1 = poor)

decreased from $68.2 million to $63.2 million, and the maximum value for the outsourced maintenance cost increased from $32.0 million in 1990 to $46.0 million in 1997, further bolstering the argument that carriers increased their outsourced maintenance.

Output measures represent the maximizing goals, such as maximizing the quality of the maintenance function. The output variable used in this study is the equipment performance measure taken from *Distribution* magazine's "Quest for Quality Survey." This survey is conducted annually to evaluate and measure transportation service providers in the logistics industry, as well as to determine the relevant criteria used in selecting a particular type of carrier. One of the five critical areas rated is equipment. This measure captures the following perceptions of customers: equipment availability, its condition, its safety record, and the low incidence of loss and damage claims. The shippers rate their carriers on a three-point scale (3 = outstanding; 2 = average; 1 = poor) that is then averaged and reported in the survey results. Table 1, Panel B contains descriptive information about this output variable. The data are fairly stable over the eight-year period of the study.

Descriptive measures represent variables used to further discriminate between efficient and non-efficient observations. Two descriptive measures are used in this study: the yearly change in revenue and the yearly change in maintenance expenditures. Table 1, Panel C contains descriptive information about these measures. Over the period of this study, the annual changes in operating revenue and total maintenance expenditures range from a decrease of approximates 25 percent to a more than 50 percent increase.

The observations used in this study are those LTL carriers with complete financial information included in the American Trucking Association's financial database for at least five consecutive years during the period 1990 through 1997. Because there are no legal requirements that carriers provide these data, information for all Class I motor carriers for all years of the study is not complete. In addition the carriers must be included in *Distribution* magazine's annual "Quest for Quality Survey." These surveys are mailed in early March and then tabulated and reported in August. The financial data for each year are therefore matched with the quality ratings for the succeeding year. This is done to properly match the financial inputs with the survey results. The final sample used in this study consists 160 observations (21 companies), pooled over eight years.

The DEA approach used in this study is motivated by the Clarke and Gourdin (1991) case study in which DEA was used to evaluate the vehicle maintenance strategy of a large-scale, nonprofit logistics system. Although new vehicles were being added to its fleet, fiscal constraints demanded a lengthening of the productive life of vehicles and an improvement in the quality of maintenance work. The study compared the relative efficiency of 17 separate vehicle maintenance shops over a four-year period. Using the benchmarking information obtained from DEA at the start of the test period, efficiency gains at all 17 facilities were obtained by the end of the four-year period. Other related studies have used the DEA methodology. Odeck and Hjalmarsson (1996) used DEA to evaluate the performance of trucks involved in road maintenance and construction. The inputs used were all costs related to operating a truck with the exception of fixed costs and the output was the annual distance traveled. The study found significant differences in the performance of the trucks and explained ways to eliminate the causes of the inefficiencies noted. Kleinsorge *et al.* (1991) focused on the monitoring process of cost and quality of service using data envelopment analysis (DEA). The study used statistical performance and qualitative measures provided by one Hewlett Packard site. The output for the model tested was the perception of the quality of the carrier. The study found that DEA could be used as a tool to identify problem areas needing corrective action.

Two DEA models are used in this study. The first analysis uses the base DEA model as specified by Ali and Seiford (1993). It is a systems-oriented approach in which total inefficiency in the utilization of inputs and production of outputs is simultaneously determined. The measure of total inefficiency generated is Δ^L; efficient motor carriers obtain a value of zero for Δ^L. In order to compare the different observations, standardization of Δ^L is required. The standardized input measure,

$\Delta^{L}{}_{I}$, represents the total inefficiency, Δ^{L}, in terms of virtual inputs and is calculated by weighting the actual input value by projected prices.

The second model employed is the input-oriented model in which the minimization of inputs takes priority over the maximization of outputs. Although the motor carrier under evaluation seeks to reduce excess input utilization, it must continue to use its current technology mix (reflected in actual input ratios). This efficiency measure also presumes that the current level of output is maintained. The efficiency measure for the input oriented model as defined in Charnes *et al.* (1978) is $\acute{\iota}^{L}$ and equals one for an efficient motor carrier. This model allows a motor carrier to be evaluated with respect to a best practice motor carrier that is most similar to it in terms of input mix because it measures inefficiency in terms of proportional changes of inputs. This model, however, does not capture inefficiency entirely. Therefore, the base model also must be used because it captures inefficiency entirely.

The efficiency measure $\acute{\iota}^{L}$ conveys information with regard to managerial policy. If motor carrier A has an efficiency measure, $\acute{\iota}^{L}$, that is small, then its maintenance strategy needs to be reevaluated and input/production technique needs to be modified. If, on the other hand, $\acute{\iota}^{L}$ is close to 1.0, then the motor carrier could remain with its current production technique and achieve the same levels of output with a small scaling down. Thus, utilization of the input-oriented model in conjunction with the base model allows the researcher to not only develop assessment measures of inefficiency but also to evaluate the efficacy of managerial strategies. The decision to be made by management involves a trade-off between the cost of the maintenance inputs and perceived quality. The company may pursue a low cost strategy of deferring repairs resulting in low maintenance/safety quality. At the other end of the spectrum is the high quality strategy that entails presenting a clean, undamaged vehicle at the customer's premises at the time the customer has requested. In addition the company's vehicles must have a good safety record and the carrier's rates must be comparable to other carriers. The efficient company will pursue a strategy whereby its high quality does not require excessive costs. The use of DEA will assess whether a particular motor carrier, having targeted a particular level of maintenance quality, is doing so in a productively efficient manner. DEA recognizes the fact that there is not a single unique way of pursuing operational efficiency and that a motor carrier, having selected a particular strategy, can be benchmarked against its peer competitors as to the economic effectiveness (in a production efficiency sense) of the components of this strategy.

Results

Table 2 contains a list of all efficiency measures by company. Included in the list are $\acute{\iota}^{L}$, the input-oriented efficiency score, Δ^{L}, the total inefficiency for the base model, and $\Delta^{L}{}_{I}$, the inefficiency per virtual input.

Table 2—Efficiency Measures Obtained from DEA Procedures By Observation[a]

Company	Year	ε^L	Δ^L	Δ^L_I
AAA Cooper Transportation	90	0.6326	2.1314	0.3668
AAA Cooper Transportation	91	0.5878	2.4146	0.4134
AAA Cooper Transportation	92	0.5241	2.6600	0.6630
AAA Cooper Transportation	93	0.5153	2.7305	0.6819
AAA Cooper Transportation	94	0.5620	2.5292	0.4373
AAA Cooper Transportation	95	0.5591	2.3690	0.4417
AAA Cooper Transportation	96	0.6119	2.2286	0.3883
AAA Cooper Transportation	97	0.5835	2.4191	0.4169
ABF Freight	90	0.6502	1.5796	0.3954
ABF Freight	91	0.6249	1.7185	0.4288
ABF Freight	92	0.6319	1.6550	0.4140
ABF Freight	93	0.6419	1.6424	0.4083
ABF Freight	94	0.6950	1.4870	0.3697
ABF Freight	95	0.6441	1.5827	0.3923
ABF Freight	96	0.6768	1.4758	0.3687
ABF Freight	97	0.6648	1.4719	0.3672
American Freightways	90	1.0000	0.0000	0.0000
American Freightways	91	1.0000	0.0000	0.0000
American Freightways	93	1.0000	0.0000	0.0000
American Freightways	94	1.0000	0.0000	0.0000
American Freightways	95	1.0000	0.0000	0.0000
American Freightways	96	0.8988	0.6926	0.1389
American Freightways	97	0.6945	1.7701	0.3573
Consolidated Freightways	90	0.5623	2.1319	0.4544
Consolidated Freightways	91	0.5444	2.2170	0.4722
Consolidated Freightways	92	0.5348	2.2582	0.4819
Consolidated Freightways	93	0.5714	2.0591	0.4497
Consolidated Freightways	94	0.5746	2.1157	0.4527
Consolidated Freightways	95	0.6072	1.8531	0.4224
Consolidated Freightways	96	0.6558	1.5726	0.3733
Consolidated Freightways	97	0.6263	1.6758	0.3990
Crouse Cartage	91	0.3951	3.1631	0.7908
Crouse Cartage	92	0.3866	3.1482	0.7854
Crouse Cartage	93	0.3845	3.1789	0.7952
Crouse Cartage	94	0.4325	2.9545	0.7407
Crouse Cartage	95	0.4407	2.9324	0.7316
Crouse Cartage	96	0.3737	3.0192	0.7540
Crouse Cartage	97	0.4502	2.8477	0.7125
Estes Express	90	0.5984	3.0589	0.7687
Estes Express	91	0.6472	2.8422	0.7078
Estes Express	92	0.5902	2.8438	0.7094
Estes Express	93	0.5829	2.7588	0.6900
Estes Express	94	0.5554	2.4990	0.4449
Estes Express	95	0.5650	2.4846	0.4349
Estes Express	96	0.5938	2.1461	0.4171
Estes Express	97	0.6324	1.8615	0.3853
Fredrickson Motor Express	91	0.4493	3.5065	0.8780
Fredrickson Motor Express	92	0.3991	3.4537	0.8553
Fredrickson Motor Express	93	0.3054	3.4051	0.8512
Fredrickson Motor Express	94	0.3676	3.3616	0.8398
Fredrickson Motor Express	95	0.3902	3.3242	0.8290

Table 2 (cont.)—Efficiency Measures Obtained from DEA Procedures By Observation[a]

Company	Year	ι^L	Δ^L	Δ^L_1
Fredrickson Motor Express	96	0.3889	3.4511	0.8605
G.I. Trucking	90	0.7520	1.3763	0.2804
G.I. Trucking	91	0.8162	1.0801	0.2117
G.I. Trucking	92	0.7664	1.2514	0.2666
G.I. Trucking	93	0.6959	1.5772	0.3452
G.I. Trucking	94	0.9186	0.5028	0.0812
G.I. Trucking	95	0.7947	1.1535	0.2450
G.I. Trucking	96	0.5746	2.0579	0.4601
G.I. Trucking	97	0.6431	1.6954	0.4024
Lynden Transport	90	1.0000	0.0000	0.0000
Lynden Transport	91	0.8469	0.6284	0.2095
Lynden Transport	92	0.8800	0.3845	0.1282
Lynden Transport	93	1.0000	0.0000	0.0000
Lynden Transport	94	1.0000	0.0000	0.0000
Lynden Transport	95	1.0000	0.0000	0.0000
Lynden Transport	96	1.0000	0.0000	0.0000
Lynden Transport	97	1.0000	0.0000	0.0000
Motor Cargo	91	0.7227	1.4140	0.3123
Motor Cargo	92	0.7846	1.1221	0.2393
Motor Cargo	93	0.6729	1.6842	0.3586
Motor Cargo	94	0.7461	1.3851	0.2846
Motor Cargo	95	0.6843	1.6055	0.3497
Motor Cargo	96	0.6017	1.9741	0.4194
Motor Cargo	97	0.7398	1.2384	0.3094
New England Motor Freight	90	0.3100	3.4338	0.8578
New England Motor Freight	91	0.3197	3.4075	0.8520
New England Motor Freight	92	0.3716	3.2468	0.8137
New England Motor Freight	93	0.3854	3.2049	0.8023
New England Motor Freight	94	0.3714	3.0085	0.7525
New England Motor Freight	95	0.3885	3.1264	0.7812
New England Motor Freight	96	0.3822	3.0783	0.7690
New England Motor Freight	97	0.4369	2.8995	0.7243
New Penn Motor Express	90	0.6083	2.2280	0.4022
New Penn Motor Express	91	0.5573	2.2044	0.4718
New Penn Motor Express	92	0.5686	2.2480	0.4699
New Penn Motor Express	93	0.5654	2.1041	0.4586
New Penn Motor Express	94	0.5530	2.0752	0.4589
New Penn Motor Express	95	0.5799	1.9019	0.4481
New Penn Motor Express	96	0.6351	1.7794	0.3903
New Penn Motor Express	97	0.7468	1.3991	0.2608
Old Dominion Freight Line	90	0.6043	2.1203	0.4693
Old Dominion Freight Line	91	0.6284	2.0444	0.4552
Old Dominion Freight Line	92	0.6154	1.8549	0.4279
Old Dominion Freight Line	93	0.6782	1.6698	0.3923
Old Dominion Freight Line	94	0.6625	1.7801	0.4401
Old Dominion Freight Line	95	0.6527	1.8066	0.4514
Old Dominion Freight Line	96	0.6410	1.8288	0.4565
Old Dominion Freight Line	97	0.6662	1.6448	0.4031
Overnite Transportation	90	0.4138	3.1024	0.7761
Overnite Transportation	91	0.4326	3.0614	0.7654
Overnite Transportation	92	0.5438	2.7761	0.6967

Table 2 (cont.)—Efficiency Measures Obtained from DEA Procedures By Observation[a]

Company	Year	ϵ^L	Λ^L	Δ^L_1
Overnite Transportation	93	0.5556	2.7412	0.6851
Overnite Transportation	94	0.5948	2.5923	0.4152
Overnite Transportation	95	0.5433	2.7994	0.6990
Overnite Transportation	96	0.5202	2.8577	0.7136
Overnite Transportation	97	0.6053	2.6843	0.6702
Roadway Express	90	0.5528	2.2616	0.5102
Roadway Express	91	0.5490	2.2078	0.4996
Roadway Express	92	0.5679	2.1290	0.4866
Roadway Express	93	0.5916	2.0693	0.4687
Roadway Express	94	0.6369	1.8639	0.4304
Roadway Express	95	0.6032	1.7837	0.4278
Roadway Express	96	0.6355	1.8943	0.4457
Roadway Express	97	0.6698	1.7493	0.4142
Saia Motor Freight	91	0.6901	1.6057	0.3100
Saia Motor Freight	92	0.6685	1.6060	0.3320
Saia Motor Freight	93	0.6426	1.7872	0.3572
Saia Motor Freight	94	0.6047	2.1102	0.3945
Saia Motor Freight	95	0.5368	2.3110	0.4854
Saia Motor Freight	96	0.5518	2.1023	0.4809
Saia Motor Freight	97	0.5577	2.2344	0.4596
Southeastern Freight Lines	90	0.3509	3.1165	0.7785
Southeastern Freight Lines	91	0.3792	3.0331	0.7587
Southeastern Freight Lines	92	0.4209	2.9185	0.7309
Southeastern Freight Lines	93	0.4886	2.6599	0.5183
Southeastern Freight Lines	94	0.5386	2.4062	0.4647
Southeastern Freight Lines	95	0.5035	2.5629	0.4973
Southeastern Freight Lines	96	0.4764	2.5278	0.5466
Southeastern Freight Lines	97	0.4716	2.4264	0.5489
TNT Holland	90	0.6243	1.8522	0.4639
TNT Holland	91	0.6758	1.7459	0.4368
TNT Holland	92	1.0000	0.0000	0.0000
TNT Holland	93	0.6901	1.7405	0.4342
TNT Holland	94	0.6977	1.7274	0.3464
TNT Holland	96	0.6564	1.8064	0.3831
TNT Holland	97	0.7039	1.7398	0.3655
Ward Trucking	90	0.6682	2.0032	0.3315
Ward Trucking	91	0.7444	1.5061	0.2623
Ward Trucking	92	0.6510	1.8169	0.3561
Ward Trucking	93	0.6312	1.9741	0.3686
Ward Trucking	95	0.6142	2.0401	0.3843
Ward Trucking	96	0.7551	1.3110	0.2693
Ward Trucking	97	0.5962	2.2492	0.4283
Watkins Motor Lines	90	1.0000	0.0000	0.0000
Watkins Motor Lines	91	0.9031	0.6679	0.1162
Watkins Motor Lines	92	0.9079	0.6670	0.1269
Watkins Motor Lines	93	0.8641	0.8099	0.1521
Watkins Motor Lines	94	0.9758	0.2212	0.0336
Watkins Motor Lines	95	0.8203	1.0997	0.1917
Watkins Motor Lines	96	0.8005	1.2168	0.2086
Watkins Motor Lines	97	0.8822	0.7471	0.1247
Yellow Freight System	90	0.5834	2.1583	0.4318

Table 2 (cont.)—Efficiency Measures Obtained from DEA Procedures By Observation[a]

Company	Year	i^L	Δ^L	Δ^L_I
Yellow Freight System	91	0.5671	2.2126	0.4513
Yellow Freight System	92	0.5768	2.2094	0.4389
Yellow Freight System	93	0.5377	2.3405	0.4846
Yellow Freight System	94	0.4777	2.5562	0.5423
Yellow Freight System	95	0.4721	2.5399	0.5510
Yellow Freight System	96	0.4008	2.7159	0.6243
Yellow Freight System	97	0.5063	2.2481	0.5160

[a] i^L is the input-oriented efficiency score. A score of 1.000 means that the observation has no inefficiency
Δ^L is the total inefficiency for the base model. A score of 0.0 means that the observation is efficient
Δ^L_I is the inefficiency per virtual input. The value of this measure shows the units of total excess inputs plus foregone outputs generated for each unit of virtual input

The input-oriented efficiency score, i^L, presumes that no change can be made in output efficiency. It shows the proportionate amount of input reduction needed to achieve efficiency while continuing production at the current output level. Over the eight-year period of the study, the values for i^L range from 0.3054 (Fredrickson-93) to 1.0000 (no inefficiency). A value of 0.3054 implies that the carrier could have produced its current level of maintenance quality and, at the same time, proportionally reduced all inputs in the maintenance process 69.46 percent.

There are 13 observations (8 percent of the observations) with an i^L efficiency score of 1.0000. Only four companies (of 21) have at least one efficient observation, and none is considered efficient over the whole eight-year period of the study. The number of efficient observations is three in 1990; two in 1993, 1994, and 1995; and 1 in 1991, 1992, 1996, and 1997. This indicates a gradual decline in the efficiency of the maintenance function.

An examination of only the inefficient observations reveals that the range of values for i^L is 0.3054 (Fredrickson-93) to 0.9758 (Watkins-94). Of these, the average value for i^L is 0.5949. Five companies (of 21) have i^L values below the average value for all years of the study. Table 3 lists descriptive statistics for i^L for the inefficient observations on an overall and a year by year basis. The range of values on a yearly basis mimics that of the overall eight-year period. These data suggest that few companies correctly perceived and implemented efficient maintenance quality strategies.

The base model efficiency scores, Δ^L, and Δ^L_I, all presume that both the inputs and outputs can change in order to reach the efficient frontier. The values for Δ^L, the total inefficiency, range from 0.000 to 3.5065 (Fredrickson-91) with an average value of 1.955. The values for Δ^L only assist in the classification of observations as efficient or inefficient. In this study, the classification using Δ^L is the same as that for i^L. Of greater importance is the value of Δ^L_I. The value of Δ^L_I ranges from 0.0000 to 0.8780 over the eight-year period. The maximum is attributable to Fredrickson-91. A value of 0.8780 for Δ^L_I implies that 0.878 units of total excess inputs plus foregone outputs were generated for each unit of virtual input.

Table 3—Descriptive Statistics for ΐl - Inefficient Observations Only[a]

Year	Minimum	Maximum	Average	Median
OVERALL	0.3054	0.9758	0.5949	0.5962
1990	0.3100	0.7519	0.5651	0.6083
1991	0.3197	0.9031	0.6041	0.6249
1992	0.3714	0.9079	0.5995	0.5835
1993	0.3054	0.8641	0.5790	0.5916
1994	0.3675	0.9758	0.6092	0.5988
1995	0.3885	0.8203	0.5778	0.5916
1996	0.3737	0.8988	0.5915	0.6119
1997	0.4369	0.8821	0.6251	0.6377

[a] i^L represents the input-oriented efficiency score. A score of 1.000 means that the observation has no inefficiency. It shows the proportionate amount of input reduction needed to achieve efficiency while continuing production at the current output level. The number of inefficient observations is 147

Table 4 shows the descriptive statistics for $\Delta^L{}_1$ over the eight-year period for the inefficient observations only. The values range from 0.0335 (Watkins-94) to 0.8780 (Fredrickson-91) with an average value of 0.4806. A review of the values of this measure on a yearly basis reveals no startling variations in value. The averages are rather low, ranging from 0.4350 to 0.5205. For six of the eight years, Watkins has the lowest $\Delta^L{}_1$ value, (G.I. in 1990 and American in 1996). Fredrickson attains the highest values for $\Delta^L{}_1$ from 1991 through 1996 with New England Motor Freight having the highest values in 1990 and 1997. In order to provide a clearer understanding of what causes the overall input inefficiency, an analysis of the amount of inefficiency for each input is performed.

Table 4—Descriptive Statistics For Δ_I^L - Inefficient Observations Only[a]

Year	Minimum	Maximum	Average	Median
OVERALL	0.0335	0.8780	0.4806	0.4330
1990	0.2804	0.8578	0.5205	0.5205
1991	0.1162	0.8780	0.4902	0.4533
1992	0.1269	0.8553	0.4959	0.4699
1993	0.1521	0.8512	0.5106	0.4586
1994	0.0335	0.8398	0.4405	0.4387
1995	0.1917	0.8290	0.4869	0.4449
1996	0.1388	0.8605	0.4734	0.4325
1997	0.1247	0.7243	0.4350	0.4031

[a] Δ_I^L represents the inefficiency per virtual input. The value of this measure shows the units of total excess inputs plus foregone outputs generated for each unit of virtual input. The number of inefficient observations is 147

The amount of inefficiency compares the actual input value with a projected efficient value for the specific observation. The number of observations with an amount of inefficiency equal to zero is 106 (66 percent of the observations) for the parts variable, 25 (16 percent) for the maintenance labor variable, 14 (9 percent) for the outsourced maintenance variable, and 13 (8 percent) for the tires and tubes variable. For all variables, only 13 (8 percent) of these zero amounts of inefficiency

Table 5—Percent Inefficiency, Inefficient Observations Only*

Company	Year	Parts	Tires and Tubes	Labor	Outsourced Maintenance
AAA Cooper Transportation	90	0.0000	0.8797	0.5256	0.6343
AAA Cooper Transportation	91	0.0000	0.9174	0.5845	0.8393
AAA Cooper Transportation	92	0.0442	0.9195	0.5936	0.9908
AAA Cooper Transportation	93	0.1196	0.9168	0.6015	0.9976
AAA Cooper Transportation	94	0.0000	0.9166	0.5776	0.9315
AAA Cooper Transportation	95	0.0000	0.9086	0.5986	0.7846
AAA Cooper Transportation	96	0.0000	0.8698	0.5803	0.7132
AAA Cooper Transportation	97	0.0000	0.8815	0.5840	0.8756
ABF Freight	90	0.3465	0.3808	0.3316	0.4294
ABF Freight	91	0.4014	0.3955	0.3411	0.4689
ABF Freight	92	0.4074	0.3809	0.3323	0.4416
ABF Freight	93	0.0000	0.4997	0.3804	0.6356
ABF Freight	94	0.0000	0.4321	0.3132	0.6200
ABF Freight	95	0.0000	0.4294	0.3920	0.6182
ABF Freight	96	0.3323	0.2053	0.3697	0.4295
ABF Freight	97	0.3243	0.2718	0.3024	0.4153
American Freightways	96	0.0000	0.0986	0.1802	0.3524
American Freightways	97	0.0000	0.6001	0.3274	0.7753
Consolidated Freightways	90	0.0000	0.7330	0.5636	0.7844
Consolidated Freightways	91	0.0000	0.7494	0.5904	0.8277
Consolidated Freightways	92	0.0000	0.7476	0.5997	0.8371
Consolidated Freightways	93	0.0000	0.6446	0.5793	0.7142
Consolidated Freightways	94	0.0000	0.6505	0.5906	0.7580
Consolidated Freightways	95	0.0000	0.6120	0.5250	0.5906
Consolidated Freightways	96	0.0000	0.4725	0.4623	0.4809
Consolidated Freightways	97	0.0000	0.5084	0.4275	0.5892
Crouse Cartage	91	0.3233	0.8772	0.8181	0.9983
Crouse Cartage	92	0.2520	0.8907	0.8145	0.9936
Crouse Cartage	93	0.3127	0.8697	0.8068	0.9954
Crouse Cartage	94	0.1936	0.8491	0.7778	1.0018
Crouse Cartage	95	0.1780	0.8380	0.7780	0.9958
Crouse Cartage	96	0.2427	0.8825	0.7410	0.9974
Crouse Cartage	97	0.1701	0.8250	0.7126	1.0023
Estes Express	90	0.2010	0.9138	0.7327	1.0188
Estes Express	91	0.0070	0.9237	0.6788	0.9890
Estes Express	92	0.0590	0.9270	0.6494	0.9911
Estes Express	93	0.0235	0.9428	0.6171	0.9956
Estes Express	94	0.0000	0.9280	0.5381	0.8937
Estes Express	95	0.0000	0.9224	0.5372	0.8704
Estes Express	96	0.0000	0.8827	0.4815	0.6826
Estes Express	97	0.0000	0.8477	0.4380	0.4791
Fredrickson Motor Express	91	0.4949	0.9502	0.7693	1.0044
Fredrickson Motor Express	92	0.5484	0.9395	0.7810	0.9645
Fredrickson Motor Express	93	0.5106	0.9337	0.7566	0.9965
Fredrickson Motor Express	94	0.4507	0.9220	0.7347	0.9953
Fredrickson Motor Express	95	0.4278	0.9244	0.7265	0.9936
Fredrickson Motor Express	96	0.4395	0.9376	0.7476	0.9874
G.I. Trucking	90	0.0000	0.4734	0.4219	0.2996
G.I. Trucking	91	0.0000	0.2146	0.4431	0.2255
G.I. Trucking	92	0.0000	0.4926	0.4558	0.1613

Table 5 (cont.)—Percent Inefficiency, Inefficient Observations Only[a]

Company	Year	Parts	Tires and Tubes	Labor	Outsourced Maintenance
G.I. Trucking	93	0.0000	0.4989	0.4462	0.3849
G.I. Trucking	94	0.0000	0.0565	0.2808	0.0000
G.I. Trucking	95	0.0000	0.3583	0.4631	0.0795
G.I. Trucking	96	0.0000	0.6770	0.5459	0.6419
G.I. Trucking	97	0.0000	0.6109	0.4137	0.4476
Lynden Transport	91	0.1894	0.3111	0.0000	0.1231
Lynden Transport	92	0.2883	0.0388	0.0000	0.0569
Motor Cargo	91	0.0000	0.4570	0.5215	0.3010
Motor Cargo	92	0.0000	0.2580	0.4920	0.2962
Motor Cargo	93	0.0000	0.5890	0.5505	0.3381
Motor Cargo	94	0.0000	0.4918	0.4904	0.1889
Motor Cargo	95	0.0000	0.5238	0.5645	0.3701
Motor Cargo	96	0.0000	0.6016	0.5608	0.6754
Motor Cargo	97	0.0000	0.3738	0.5344	0.1805
New England Motor Freight	90	0.4781	0.9050	0.7564	0.9975
New England Motor Freight	91	0.4939	0.8927	0.7699	1.0030
New England Motor Freight	92	0.4265	0.8394	0.7558	1.0025
New England Motor Freight	93	0.3708	0.8879	0.7091	1.0058
New England Motor Freight	94	0.1589	0.9018	0.6838	1.0036
New England Motor Freight	95	0.2938	0.9229	0.7063	0.9940
New England Motor Freight	96	0.3273	0.9290	0.6926	0.9976
New England Motor Freight	97	0.2058	0.9010	0.6649	0.9947
New Penn Motor Express	90	0.0000	0.7714	0.6236	0.7437
New Penn Motor Express	91	0.0000	0.6856	0.6200	0.8166
New Penn Motor Express	92	0.0000	0.6703	0.6132	0.8448
New Penn Motor Express	93	0.0000	0.6735	0.5728	0.8036
New Penn Motor Express	94	0.0000	0.7068	0.5575	0.7783
New Penn Motor Express	95	0.0000	0.6928	0.5129	0.6374
New Penn Motor Express	96	0.0000	0.6655	0.4560	0.5904
New Penn Motor Express	97	0.0000	0.6053	0.5088	0.2232
Old Dominion Freight Line	90	0.0000	0.8148	0.3916	0.7208
Old Dominion Freight Line	91	0.0000	0.7949	0.3551	0.6976
Old Dominion Freight Line	92	0.0000	0.7649	0.3568	0.5280
Old Dominion Freight Line	93	0.0000	0.6544	0.3179	0.5244
Old Dominion Freight Line	94	0.0000	0.7222	0.2873	0.5713
Old Dominion Freight Line	95	0.3862	0.6171	0.2448	0.3788
Old Dominion Freight Line	96	0.3940	0.5733	0.2602	0.4586
Old Dominion Freight Line	97	0.0000	0.5553	0.3285	0.5671
Overnite Transportation	90	0.3369	0.8388	0.7841	0.9971
Overnite Transportation	91	0.2699	0.8623	0.7637	1.0049
Overnite Transportation	92	0.0914	0.8565	0.7018	1.0082
Overnite Transportation	93	0.0457	0.8215	0.6954	1.0051
Overnite Transportation	94	0.0000	0.7878	0.6719	0.9596
Overnite Transportation	95	0.1094	0.7844	0.7274	0.9951
Overnite Transportation	96	0.1551	0.7848	0.7200	0.9964
Overnite Transportation	97	0.0103	0.7683	0.7087	1.0030
Roadway Express	90	0.0000	0.7971	0.4587	0.9355
Roadway Express	91	0.0000	0.7642	0.4820	0.8976
Roadway Express	92	0.0000	0.7295	0.4559	0.8795
Roadway Express	93	0.0000	0.6774	0.4411	0.8721

Table 5 (cont.)—Percent Inefficiency, Inefficient Observations Only[a]

Company	Year	Parts	Tires and Tubes	Labor	Outsourced Maintenance
Roadway Express	94	0.0000	0.5780	0.3838	0.8118
Roadway Express	95	0.0000	0.5089	0.3715	0.8005
Roadway Express	96	0.0000	0.5942	0.3650	0.8268
Roadway Express	97	0.0000	0.5133	0.3228	0.8018
Saia Motor Freight	91	0.0000	0.7673	0.5442	0.2421
Saia Motor Freight	92	0.0000	0.7465	0.5003	0.3098
Saia Motor Freight	93	0.0000	0.7704	0.5601	0.3642
Saia Motor Freight	94	0.0000	0.7977	0.5963	0.5677
Saia Motor Freight	95	0.0000	0.8375	0.6108	0.7073
Saia Motor Freight	96	0.0000	0.7990	0.5874	0.5960
Saia Motor Freight	97	0.0000	0.8369	0.5855	0.6770
Southeastern Freight Lines	90	0.4133	0.9269	0.7680	0.9964
Southeastern Freight Lines	91	0.2494	0.9306	0.7791	1.0042
Southeastern Freight Lines	92	0.1491	0.9278	0.7669	1.0034
Southeastern Freight Lines	93	0.0000	0.9095	0.7215	0.9793
Southeastern Freight Lines	94	0.0000	0.8675	0.6663	0.8104
Southeastern Freight Lines	95	0.0000	0.9182	0.6736	0.9318
Southeastern Freight Lines	96	0.0000	0.9086	0.6359	0.9457
Southeastern Freight Lines	97	0.0000	0.8666	0.5957	0.9035
TNT Holland	90	0.4706	0.5624	0.2633	0.5555
TNT Holland	91	0.3854	0.6159	0.1614	0.5630
TNT Holland	93	0.3881	0.5900	0.0785	0.6515
TNT Holland	94	0.3970	0.6062	0.0000	0.6711
TNT Holland	96	0.4733	0.5784	0.0000	0.7191
TNT Holland	97	0.3533	0.5883	0.0000	0.7443
Ward Trucking	90	0.0000	0.6216	0.6437	0.5771
Ward Trucking	91	0.0000	0.4756	0.6325	0.2616
Ward Trucking	92	0.0000	0.6756	0.6321	0.4082
Ward Trucking	93	0.0000	0.7437	0.5912	0.4940
Ward Trucking	95	0.0000	0.6894	0.6908	0.5182
Ward Trucking	96	0.0000	0.5229	0.4955	0.1717
Ward Trucking	97	0.0000	0.7585	0.5332	0.7877
Watkins Motor Lines	91	0.0181	0.3719	0.0000	0.2251
Watkins Motor Lines	92	0.0098	0.3621	0.0000	0.2651
Watkins Motor Lines	93	0.0000	0.4033	0.0000	0.3668
Watkins Motor Lines	94	0.0000	0.0729	0.0000	0.0904
Watkins Motor Lines	95	0.0000	0.4834	0.0000	0.5456
Watkins Motor Lines	96	0.0000	0.5136	0.0000	0.6268
Watkins Motor Lines	97	0.0000	0.3053	0.0000	0.3763
Yellow Freight System	90	0.0000	0.7339	0.6910	0.6901
Yellow Freight System	91	0.0000	0.7419	0.6900	0.7109
Yellow Freight System	92	0.0000	0.7375	0.6920	0.7064
Yellow Freight System	93	0.0000	0.7763	0.6915	0.8129
Yellow Freight System	94	0.0000	0.8174	0.7021	0.9306
Yellow Freight System	95	0.0000	0.8185	0.6978	0.9031
Yellow Freight System	96	0.0000	0.7953	0.9266	0.8801
Yellow Freight System	97	0.0000	0.7091	0.6261	0.7969

[a] Percent inefficiency is calculated by scaling the actual value minus the projected efficient value by the actual value. The number of inefficient observations is 147

pertain to company-year observations classified as efficient. To make inter-company comparisons, the percent inefficiency is next calculated by scaling the amount of inefficiency by the actual input value.

Table 5 displays the percent inefficiency on an overall and a yearly basis for the inefficient observations (147 observations or 92 percent of the total observations). Because the efficient companies all have 0.0000 values for inefficiency, they are excluded from this analysis. The tires and tubes variable is the only variable that never has a value of 0.0000. The parts variable achieves a zero value 93 times (63 percent of inefficient observations), while maintenance labor reaches 0.0000 12 times (8 percent), and outside (outsourced) maintenance reaches 0.0000 only once. In a year by year analysis, outsourced maintenance and the tires and tubes variables have the highest and second highest average levels of inefficiency.

In examining the individual company-year observations, outsourced maintenance has the largest percent inefficiency 87 times (59 percent of inefficient observations), and the tires and tubes variable has the largest percent inefficiency 48 times (33 percent). The second highest value for percent inefficiency occurs 70 times (48 percent) for the tires and tubes variable and 39 times (27 percent) for outsourced maintenance. There is no observation that does not have one of these two variables as either the highest or second highest percent inefficiency. It is clear that outsourced maintenance and tires and tubes, even though they are the two lowest expenditures in the maintenance function (Table 1), are the cause of the output inefficiency. A reduction in the expenditures for these items could increase the efficiency of the maintenance operations.

Table 6—Descriptive Statistics For Data

Panel A – All Observations

Variable[a]	Minimum	Maximum	Average	Median
Operating Revenue Change	-27.72%	52.11%	10.10%	8.47%
Maintenance Expenditures Change	-24.55	53.93	8.37	7.50

Panel B – Operating Revenue Change

Variable[a]	Minimum	Maximum	Average	Median
Efficient Observations	0.54%	41.66%	16.55%	15.46%
Non-efficient Observations	-27.72	52.11	9.62	8.42

Panel C – Maintenance Expenditures Change

Variable[a]	Minimum	Maximum	Average	Median
Efficient Observations	-11.99%	33.88%	14.31%	18.07%
Non-efficient Observations	-24.55	53.93	7.93	7.48

[a] Data are obtained from the American Trucking Association's financial database, *Financial and Operating Statistics*. These data are calculated annually and then accumulated over the eight-year period of the study. The total number of observations for these tests is less than 160 due to missing data at the beginning of the time series

Panel A of Table 6 presents results of the comparison of the annual changes in operating revenue and total maintenance expenditures for all observations. A comparison of the efficient and nonefficient observations over the period reveals that the average, median, and minimum annual change in both operating revenue and total maintenance expenditures are lower for the nonefficient observations. The nonefficient group also obtains the maximum for these variables. These extreme observations for the nonefficient observations further augment the argument that the nonefficient observations are not using their maintenance dollars wisely.

Table 7—Linear Rank Statistics - Efficient Vs Inefficient Motor Carriers

Panel A – Change in Operating Revenue[a]

	N[b]	Mean Score	H_0: Mean (Inefficient), Mean (Efficient)
Inefficient	135	72.0741	
Efficient	10	85.5000	
WILCOXON TEST			Prob > |Z| = 0.1657

Panel B – Change in Total Maintenance Expenditures[a]

	N[b]	Mean Score	H_0: Mean (Inefficient), Mean (Efficient)
Inefficient	135	71.3556	
Efficient	10	95.2000	
WILCOXON TEST			Prob > |Z| = 0.0420

[a] Data are obtained from the American Trucking Association's financial database, *Financial and Operating Statistics*. These data are accumulated over the eight-year period of the study

[b] The total number of observations for these tests is less than 160 due to missing data at the beginning of the time series

The nonparametric Wilcoxon test is used to determine whether there is a significant difference between the efficient and nonefficient observations for the two variables. Table 7 presents the results of the tests. The alternative hypothesis that the efficient observations have a greater increase in operating revenue than the do nonefficient observations is not supported. The test of the change in maintenance expenditures shows that the efficient observations have a greater increase in maintenance expenditure than the nonefficient observations at a significance level of 0.04. These results are not surprising. As discussed earlier, although maintenance is an extremely important expenditure, it comprises less than six percent of total operating expenditures. Changes in operating revenue are affected by many other variables, most importantly cost structure. This study only examines short-term customer satisfaction regarding maintenance/safety issues. In the long run, lapses and inefficiencies in maintenance spending can affect operating revenues as contracts are renegotiated.

Conclusion

This paper provides insight into the efficiency of maintenance operations of motor carriers over the eight-year period, 1990 through 1997 using data envelopment analysis. Using DEA, we determine the degree to which the individual observations fail to achieve best practice status and point to directions where improvements in maintenance technology can be made. Efficiency is measured in terms of cost of maintenance operations compared with the perceived quality of the service delivered to the shippers.

It is found that although the maintenance strategy chosen has a significant effect on customer perceived quality, there is no immediate impact on operating revenue. It is shown that efficient observations are associated with increases in total maintenance expenditures. The long-term effect of this strategy should lead to increased operating revenues.

Significant improvements in all inputs can be made for more than 90 percent of the observations. Of particular importance are the need for changes/reductions in expenditures for tires and tubes and outsourced maintenance. Kee (1998) notes that activities that are outsourced should only be those that contribute little to the firm's competitive position. The data envelopment analysis suggests that LTL carriers should reconsider the decision to outsource the maintenance function and perform this function internally.

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