U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA
www.nhtsa.gov

DOT HS 811 109

March 2009

An In-Service Analysis of Maintenance And Repair Expenses for the Anti-Lock Brake System and Underride Guard for Tractors and Trailers

DISCLAIMER

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 811 109		

4. Title and Subtitle An In-Service Analysis of Maintenance and Repair Expenses for the Anti-Lock Brake System and Underride Guard for Tractors and Trailers	**5. Report Date** March 2009 **6. Performing Organization Code**
7. Author(s) Kirk Allen, Ph.D.	**8. Performing Organization Report No.**
9. Performing Organization Name and Address Evaluation Division; National Center for Statistics and Analysis National Highway Traffic Safety Administration Washington, DC 20590	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE Washington, DC 20590	**13. Type of Report and Period Covered** NHTSA Technical Report **14. Sponsoring Agency Code**

15. Supplementary Notes

16. Abstract

Federal Motor Vehicle Safety Standards (FMVSS) Nos. 121 and 105 mandate antilock braking systems (ABS) on all air-braked vehicles and hydraulic-braked trucks and buses with a gross vehicle weight rating (GVWR) of 10,000 pounds or greater. The primary purpose of this report is to analyze the maintenance and repair expenses to the ABS systems of tractors and trailers. A contractor assembled a database with a census of repair receipts from 13 trucking fleets during the period of about 2000 to 2003, with over 4,000 vehicles total.

- The average ABS expenses per month of operation were $0.85 for tractors and $0.25 for trailers (in 2007 dollars), for vehicles classified built after the effective date for ABS implementation.
- Across a vehicle lifetime, the net present value of the maintenance and repair expenses is estimated to range from $56 to $102 for tractors and from $16 to $30 for trailers. These values are relatively small compared to the cost of equipping new vehicles with ABS systems, estimated as $639 for tractors and $513 for trailers in an earlier NHTSA report.
- The presence of the ABS system does not appear to increase overall maintenance expenses to the brake system. Older vehicles, manufactured before the effective date for ABS implementation, had higher brake expenses, both per month of service and as a percentage of total maintenance expenses during the survey.
- The average maintenance and repair expenses to the underride guards, mandated on trailers with a GVWR of 10,000 pounds or greater by FMVSS Nos. 223 and 224, were $0.16 per month of service, representing a net present value of $15 over the vehicle's lifetime.

17. Key Words	18. Distribution Statement
anti-lock braking system (ABS); underride guard (URG); in-service; tractors; trailers; statistical analysis; FMVSS; maintenance; repair	This report is free of charge from the NHTSA Web site at www.nhtsa.dot.gov

19. Security Classif. (Of this report)	20. Security Classif. (Of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

An In-Service Analysis of Maintenance and Repair Expenses for the Anti-Lock Brake System and Underride Guard for Tractors and Trailers

Summary

Federal Motor Vehicle Safety Standards (FMVSS) numbers. 121 and 105 mandate antilock braking systems (ABS) on all air-braked vehicles and hydraulic-braked trucks and buses with gross vehicle weight ratings (GVWRs) of 10,000 pounds or greater. Standards number 223 and 224 mandate strength-tested underride guards (URGs) on trailers with GVWRs of 10,000 pounds or greater. NHTSA evaluates the cost of its regulations to the consumer, including the initial cost of adding safety technology or systems to new vehicles and the lifetime cost of maintaining and repairing the systems.

For a study of the maintenance and repair costs of ABS and URG, NHTSA contractors assembled a database consisting of repair-line details for over 4,000 in-service vehicles from 13 trucking fleets that perform in-house maintenance. In general, repairs were tracked during 1998-2003. NHTSA contractors and staff prepared the database for analysis by identifying repairs involving ABS components, the brake system generally, or URG and ascertaining for how many months each vehicle's repairs were tracked. That made it possible to estimate maintenance and repair costs per month. Costs were estimated for tractors and semi-trailers; single-unit-trucks were originally part of the study, but the fleets did not operate enough of them for meaningful cost estimates.

The principal finding is that the repair and maintenance costs for the ABS system averaged $0.85 per month on tractors and $0.25 per month on trailers, in 2007 dollars. Over the lifetime of the vehicles, given a 7-percent discount rate and assuming costs per mile increase by 10 percent a year as a vehicle ages (up to year nine), that amounts to a net present value, in 2007 dollars, of $81 per tractor and $24 per trailer. The net present value could be lower if maintenance expenses remain constant on a per-mile basis ($56 for tractors, $16 for trailers) or higher if the expense stream is discounted at only 3 percent ($102 for tractors, $30 for trailers). The derivation of these estimates is presented in sufficient detail that the interested reader could modify the parameters to suit his needs. The lifetime maintenance costs are substantially smaller than the initial costs of equipping tractors and trailers with ABS, $639 and $513, respectively, reported in earlier NHTSA studies.

A second study objective was to determine if the addition of ABS increased the cost of maintaining and repairing the brake system as a whole. The results indicate that the presence of the ABS system did not increase maintenance and repair expenses to the brake system, either in terms of dollars per month of service or brake expenses as a percentage of total vehicle expenses. In fact, the monthly total and brake expenses, as well as brake expenses as a percentage of total repair and maintenance expenses, were shown to be significantly lower for post-Standard 121 vehicles for both tractors and trailers, based on a statistical test which controlled for fleet-to-fleet differences.

Two caveats are necessary for applying the ABS results of this report. First, though the contractor attempted to select fleets representing a range of operating characteristics, it remains a convenience sample, rather than one based on probabilistic sampling. The results may not therefore apply to the population of all trucking fleets. Second, most

vehicles were tracked for a period of less than three years. Post-mandate vehicles could have been at most 6 years old by the end of the survey. If the ABS system begins to break down more frequently at later dates, this could not have been captured.

The cost of replacing, repairing or maintaining URG on trailers averaged $0.16 per month, a net present value of $15 over the life of a trailer. Expenses were analyzed separately for conspicuity tape, a small portion of which is placed on the URG but in minimal length compared to the rest of the trailer. The best estimate for the application of conspicuity tape is $0.37 per month, representing $35 over a trailer's lifetime. As with ABS expenses, the caveat is that very few trailers in the database incurred expenses for URG and conspicuity tape. It may take additional years to accumulate sufficient wear and tear to merit replacement. There is no indication that a large number of URG replacements occurred due to crash involvement.

List of Figures

List of Tables

Background

Scope of current project

This report analyses the impact of several Federal Motor Vehicle Safety Standards (FMVSS)[1] on tractor and trailer maintenance expenses:

- FMVSS No. 121 mandates anti-lock braking (ABS) systems on all new air-braked tractors manufactured on or after March 1, 1997 and semi-trailers and single-unit trucks manufactured on or after March 1, 1998.
- FMVSS No. 105 mandates ABS systems on all new hydraulic-braked vehicles with a gross vehicle weight rating (GVWR) of 10,000 pounds or greater manufactured on or after March 1, 1999.
- FMVSS Nos. 223 and 224 require underride guards (URG) meeting a strength test on trailers with a GVWR of 10,000 pounds or greater manufactured on or after January 24, 1998. This standard replaced a part of the Federal Motor Carrier Safety Regulations (effective January 1, 1952, to January 25, 1998) that required rear-impact guards but of substantially smaller size and lacking a strength test. In accordance with the Truck Trailer Manufacturers Association's recommended practice (April 1994), some vehicle manufacturers voluntarily installed rear impact guards before 1998. These rear impact guards meet NHTSA's standard except for the energy absorption requirement.[2]
- Part of the maintenance and repair of a URG is the replacement of the conspicuity tape that is on them. Although contained in a different standard (FMVSS 108),[3] conspicuity tape is required on underride guards, which naturally couples their maintenance expenses. Therefore, maintenance and repairs costs to conspicuity tape are included in this report.

This project serves as a link between ongoing studies of brake system capital expenses and improvements in crash avoidance/crash survivability. The intent of the present report is to analyze the direct ABS repair and maintenance expenses for in-service vehicles, plus any potential effects of the presence of ABS on other brake and total maintenance expenses as well.

Earlier work

The Federal Motor Carrier Safety Administration (FMCSA) reports that brake failure was a contributing factor in 29 percent of large-truck fatal and injury accidents.[4] Large trucks were involved in 11 percent of all fatal traffic accidents, although they comprise only 3.4

---

[1] 49 CFR 571; http://www.access.gpo.gov/nara/cfr/waisidx_06/49cfr571_06.html

[2] These details are discussed in *Proposed Evaluations of Antilock Brake Systems for Heavy Trucks and Rear Impact Guards for Truck Trailers*; August 2000; http://www.nhtsa.dot.gov/cars/rules/regrev/evaluate/121223.html

[3] Background on FMVSS 108 and the safety benefits can be found in *The Effectiveness of Retroreflective Tape on Heavy Trailers*; Christina Morgan; March 2001; http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NCSA/Regulatory%20Evaluation/809222.pdf

[4] *Report to Congress on the Large Truck Crash Causation Study*, March 2006; http://www.fmcsa.dot.gov/facts-research/research-technology/report/ltccs-2006.htm

percent of all registered vehicles. On a per mile basis, large trucks incurred fatal crashes at a 53 percent higher rate than all vehicles.[5] Miles traveled by single-unit large trucks (+26%) and combination unit trucks (+24%) increased at faster rates than passenger cars (+17%) in the period 1995 to 2005, [6] suggesting that large trucks may bear a heftier burden in safety analysis in the future.

Prior to implementation of the mandates, two NHTSA reports included analysis of ABS maintenance expenses for tractors[7] and trailers[8] for in-service vehicles. These studies were meticulous, with mechanics paying special attention to the ABS components and carefully documenting the types of repairs. The number of vehicles (200 tractors, 50 trailers) was necessarily smaller than the current study. Because these vehicles were built well before the mandate's effect date, the ABS systems may have been prototypes and therefore have maintenance requirements or costs different from production ABS systems found in current vehicles.

Each study analyzed ABS maintenance over a two-year period. During this time, 62 percent of tractors (125 of 200) and 46 percent of trailers (23 of 50) required at least one ABS-related maintenance action due to normal wear, as opposed to pre-installation problems. The majority of the maintenance actions were inspections or adjustments (76% of all tractor repair actions; 66% for trailers), with the remainder being repairs or replacements.

The repair/replacement subset of all maintenance actions is likely the closest analog to the current study. Only 32 trailers (16%) and 6 tractors (12%) required repairs or replacements during the two-year study. Including all other in-service related inspections and adjustments, the average in-service maintenance and repair expenses were $20.34 for tractors and $35.27 for trailers. On a monthly basis, these values are $0.85 for tractors and $1.47 for trailers. Inflating from the publications dates to 2007, these values become $1.25 per month for tractors and $2.11 per month for trailers.

The consumer cost for an initial ABS system installation was reported by NHTSA[9] as $554.41 for tractors and $445.46 for trailers,[10] as well as $96.79 for the tractor-trailer

---

[5] *Commercial Motor Vehicle Facts*, April 2005. From 2003 data, Large trucks fatality rate 2.3 per 100 million miles versus 1.5 for all vehicles; http://www.fmcsa.dot.gov/facts-research/facts-figures/analysis-statistics/cmvfacts.htm

[6] *National Transportation Statistics 2006*, Table 1-32; December 2006; http://www.bts.gov/publications/national_transportation_statistics/2006/index.html

[7] *An In-Service Evaluation of the Reliability, Maintainability, and Durability of Antilock Braking Systems (ABSs) for Heavy Truck Tractors*; DOT HS 807 846, March 1992. Accessible as FHWA-1997-2318-0024.

[8] *An In-Service Evaluation of the Performance, Reliability, Maintainability, and Durability of Antilock Braking Systems (ABSs) for Semitrailers*; DOT HS 808 059, October 1993. Accessible as FHWA-1997-2318-0023.

[9] *Cost and Weight Added by the Federal Motor Vehicle Safety Standards for Model Years 1968-2001 in Passenger Cars and Light Trucks*; DOT HS 809 834, December 2004. Footnote therein refers to *Teardown Cost Estimates of Automotive Equipment Manufactured to Comply With Motor Vehicle Standards, FMVSS 121 (Air Brake Systems) and FMVSS 105 (Hydraulic Brake Systems), Antilock Brake Features*; DOT HS 809 808, November 2002.

connection (in all 2002 dollars). These are equivalent to $638.98, $513.41, and $111.55, respectively, in 2007 dollars.

[10] These are the mean values of two systems each – *Tractors*: 2000 Navistar International Class 7 Bendix ABS ($612.45), 2000 Freightliner Class 8 Meritor/Wabco ABS ($496.36); *Trailers*: 2000 Great Dane Meritor/Wabco ABS ($494.85), 2000 Utility International Haldex ABS ($396.06)

Methodology

This project has a unique history. NHTSA's contractor on several projects related to ABS evaluation, the KRA corporation, awarded a subcontract to the National AfterMarket Data Exchange (NAMDX) to assemble a database of the repair and maintenance history of vehicles with and without ABS. KRA and NAMDX analyzed the database. In 2004, KRA delivered a final report on the analyses, plus the database itself to NHTSA in fulfillment of the contract.[11]

The results in KRA's 2004 report can be replicated from the database if accepted as provided. However, inspection of the database revealed numerous blemishes, resulting in a decision by NHTSA not to publish the 2004 report. These deficiencies include apparent programming errors in the construction of the database, such as incorrect classification of repair charges to the ABS system, which can be corrected with subject matter knowledge. Inconsistent data collection is another problem, especially related to vehicle exposure, further invalidating the findings and conclusions of the 2004 report. The identification and rectification of these problems and others comprise a large portion of the current report. Difficulties in reinterpreting the data are compounded by the expiration of the contract with KRA and the death of J.E. Paquette, the president of NAMDX. Nevertheless, the principal problems in the original database have been corrected, and the findings of this report accurately describe the repair and maintenance costs of ABS and URG, at least for the fleets and time period included in the database.

Data characteristics

Thirteen trucking fleets that perform in-house maintenance provided a census of repair order-line costs and descriptions. The timeframe is unreported but is believed to be from 1998 to 2003 (discussed later in this report). These fleets are intended to represent a variety of operational scope and geographic area; Table 1 contains fleet statistics. Vehicles are classified as single-unit trucks, tractors, or trailers. The contractor classified each vehicle as either pre-mandate or post-mandate, relative to the effective date of the ABS standard, based only on the vehicle's model year, as opposed to the actual build date. Because the mandates were effective on March 1 of the respective years, it is possible that vehicles are mis-classified as "post-mandate" if they were produced before March 1 of the appropriate year. Further, a small number of vehicles classified "pre-mandate" required repairs or maintenance to the ABS system. These vehicles are assumed to have contained voluntary installations of ABS in advance of the mandate. In the absence of the actual build date or at least the model year, the variable defining pre-mandate versus post-mandate must be relied on as provided to NHTSA by KRA.

[11] *Fleet Maintenance Data Analysis: Final Report*; Contract no. DTNH22-98-D-066003; Task order number: 0004; February 19, 2004.

Table 1: Fleet characteristics and number of vehicles

Fleet Characteristics				Single-Unit Trucks		Tractors		Trailers		
ID	Size	Vocation	Scope	Pre	Post	Pre	Post	Pre	Post	*Total*
2	Large	Truckload	Transcontinental	14	1	86	188	424	105	*818*
4	Medium	Truckload	West Coast	0	1	39	149	120	103	*412*
5	Large	Truckload	Transcontinental	3	0	85	182	102	95	*467*
6	Large	Truckload	Continental	43	2	201	119	293	13	*671*
7	Small	LTL	East Coast	5	0	43	2	153	73	*276*
8	Small	Dedicated	Continental	1	0	15	17	61	36	*130*
9	Medium	Truckload	Transcontinental	3	1	46	55	76	165	*346*
10	Medium	Truckload	Transcontinental	2	0	49	66	70	44	*231*
11	Medium	Dedicated	West Coast	0	0	30	18	46	11	*105*
12	Medium	Specialized	West Coast	0	0	16	38	133	131	*318*
14	Medium	Truckload	Transcontinental	0	0	58	296	12	7	*373*
15	Medium	Truckload	Transcontinental	18	4	7	216	120	203	*568*
17	Small	Specialized	East Coast	26	5	1	3	0	0	*35*
			Totals	*115*	*14*	*676*	*1,349*	*1,610*	*986*	***4,750***

Notes: The field *fleetid* is provided in the database; some numbers are skipped because not all fleets contacted to participate provided data.

Size is based on 10 to 50 power units (Small), 50 to 250 (Medium), and over 250 (Large); these are according to NAMDX, not implied from the counts above.

Vocations are based on industry standard definitions. According to the KRA report:

- "Truckload fleets transport cargo with weights over 10,000 pounds, or a quantity large enough to qualify a shipment of a truckload rate."
- "LTL or less-than-load fleets transport cargos less than 10,000 pounds, or of a quantity less than necessary to qualify for truckload rates."
- "Specialized fleets transport cargo that, because of size, weight, or other characteristics, may require special equipment of loading and transport."
- "Dedicated fleets transport freight in equipment that is dedicated to a specific community."

Scope is self-reported by fleets, according to KRA:

- "East coast fleets operate primarily on the East coast"; analogous for West coast.
- "Continental fleets had vehicles operating in all parts of the continental U.S."
- "Transcontinental fleets had vehicles that operated over long routes between the east coast and west coast."

Several factors make this survey less than ideal:

- There are very few single-unit trucks, especially post-mandate. To avoid erroneous conclusions based on small sample sizes, all single-unit trucks are excluded from the analysis.
- Fleet 17 is very small, apparently engaging in "specialized" truck operations with a few tractors. This fleet is excluded due to the compositional differences from the other fleets, which are primarily tractors and trailers.
- Differences between fleets may introduce confounding factors into the analysis. The influence of fleet differences is discussed towards the end of the report but should be kept in mind throughout. For example:
  - Fleet 6 contributes a hefty portion of the pre-mandate tractors (30%).
  - Fleet 2 over-contributes to pre-mandate trailers (26%).

- Some fleets have a large discrepancy between the number of tractors and trailers. Summed across a fleet, tractors and trailers should accrue miles at approximately the same rate. The tallies in Table 1 do not reflect this fact. For example:
    - Fleet 7 has 45 total tractors and 226 trailers. Are the trailers idle around 80 percent of the time or are they used by outside operators?
    - Fleet 14 has 354 tractors and only 19 trailers. Whose trailers does this fleet haul?

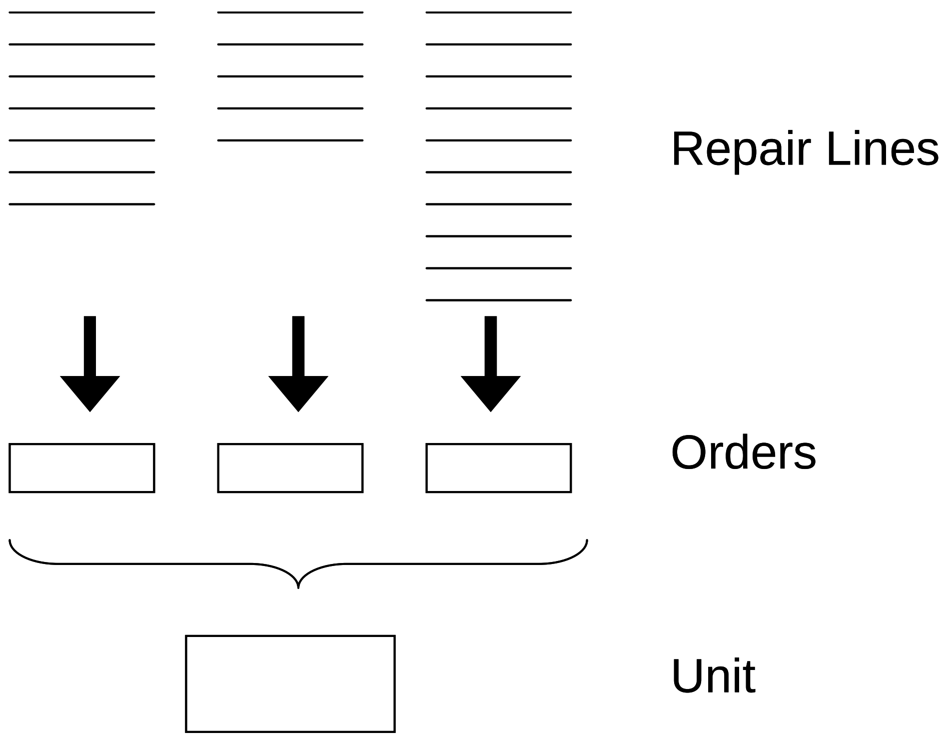
Database structure

The data supplied through NAMDX were collected using the Vehicle Maintenance Reporting Standards[12] (VMRS) system. The VMRS were developed in 1970 to facilitate communication within the trucking industry – between suppliers, manufacturers, maintainers, operators, et cetera. The latest version of the system, VMRS 2000, is distributed by the Technology and Maintenance Council of the American Trucking Associations.

The data consist of individual repair lines, identifiable by *fleet*, *unit*, and *order*. Repair lines are summed across *order* to create a second table containing all orders. Orders are then summed across *unit* to create a vehicle-level table. The database creation process is depicted in Figure 1, for a hypothetical vehicle with three repair orders of 7, 5, and 10 repair lines. The database contains 957,588 repair-lines for 185,371 orders on 4,750 units.

[12] http://www.truckrealm.com/vmrs.htm

Figure 1: Database components



The repair lines include VMRS codes that, at minimum, identify the vehicle system on which maintenance was performed and ideally contain further information on the assembly and components involved. For example, a code 013-001-015 refers to the brake system (013), specifically the brake & drum assembly (001), and the lining component (015). The value "13" or "013" in the first portion corresponds to brakes, and the second portion "011" is specifically ABS (i.e., "13-011" or "013-011"). Appendix A.1 contains the vehicle systems according to VMRS codes. Appendices A.2 (brakes) and A.3 (ABS) were compiled from frequent occurrences within the database, based on text in the *DESCRIPTION* field of the repair lines table.

Figure 2 illustrates the structure of the repair-line data in terms of the types of lines and how charges are allocated. Fields containing vehicle characteristics are suppressed for display purposes. Each line is classified by the field *TYPE* as parts ("P"), labor ("L"), services ("S"), or Comment ("C"). The *CODE* is as defined within VMRS. The full three-section code is not always used, especially for labor, often identifying only the vehicle system (first portion of the code[13]). Some rows do not contain valid VMRS codes, such as the third row ("XX") in this example. The *DESCRIPTION* is a text field, usually consistent with VMRS but apparently sometimes entered manually (e.g., the final line "ADDED OIL TO TRUCK").

[13] The first portion is sometimes given with the leading zero ("013") and other times not ("13"). Inspection of the repair lines indicates no difference between these conventions. The two-digit version is used within this report for consistency except when the intent is to display the data as provided.

Labor lines contain a value in the *HRS* column, indicating the number of hours charged to the specified vehicle system. KRA used a standard value of $40 per hour for labor, which they considered to be the typical cost to a trucking company for in-house maintenance during the survey's timeframe (shown later in this report to be approximately 1998-2003).

Parts and services contain dollar values in the respective *PT* and *SVC* columns (rounded to the nearest dollar here for simplicity). Parts and service are reported as the actual charge at the time of the order, rather than standardized values for particular items. Services are generally similar to labor in nature but are charged in dollars rather than hours. Comment lines, which are sparse in the database, do not contain charges but can elaborate on other items within the order.

There are three sets of columns labeled *TOTAL*, *BRAKE*, and *ABS*. Except for comments, every line has a value in one of the *TOTAL* columns corresponding to the line type. Lines containing charges to any part of the brake system are further mapped onto the corresponding column under *BRAKE* (examples highlighted in blue). Those brake lines which are specific to the ABS system are mapped across into the respective *ABS* column as well (examples highlighted in red). The *ABS* columns are a subset of the *Brake* columns, which are a subset in themselves of the *Total*. For example, the first item is part of the ABS sub-system (a part worth $40). Therefore, the item has the charged value in all three sets of columns. The second item, on the other hand, is part of the brake system but not specifically for the ABS. It is thus listed under the *Brake* column but not under the *ABS* column. Similarly, the third item is not part of the brake system and is listed only in the *Total* column.

Figure 2: Sample order

			TOTAL			BRAKE			ABS		
TYPE	CODE	DESCRIPTION	HRS	PT	SVC	HRS	PT	SVC	HRS	PT	SVC
P	13-011-068	ABS RELAY VALVE	-	$40	-	-	$40	-	-	$40	-
P	13-001-015	FRONT BRAKE PADS	-	$38	-	-	$38	-	-	-	-
P	XX	DOOR GUARD	-	$154	-	-	-	-	-	-	-
P	53-000	SEAL	-	$15	-	-	-	-	-	-	-
L	13	BRAKES	3	-	-	3	-	-	-	-	-
P	44-002	FUEL FILTER	-	$4	-	-	-	-	-	-	-
L	00-021	IGNITION TUNE-UP	1	-	-	-	-	-	-	-	-
P	00-105	OIL FILTER	-	$3	-	-	-	-	-	-	-
P	53-999-016	10/30 OIL	-	$12	-	-	-	-	-	-	-
L	00-001	PM LEVEL A	0.5	-	-	-	-	-	-	-	-
S	13-011-002	SENSOR REPAIR	-	-	$64	-	-	$64	-	-	$64
C	00-018	CHECKOVER	-	-	-	-	-	-	-	-	-
S	53	ADDED OIL TO TRUCK	-	-	$17	-	-	-	-	-	-

Misclassifications of brake and ABS repairs

The sample order (Figure 2) has correct classification of brake and ABS items, for illustrative purposes. This is what the data should look like. As provided, many items are over-allocated towards ABS and brake maintenance, most likely a programming error. It appears that certain keywords (e.g., “ABS” and “drum”) triggered entire orders, rather than only the appropriate lines, to be placed into the ABS and brake columns.

Figure 3 is a simplification of the correction process. Here, some repairs to the tires have been classified within the brake system and ABS components. The corrected version keeps the repairs to other vehicle systems separate from the brakes. The brake and ABS charges in the corrected version are slightly smaller to reflect exclusion of incorrectly classified items. The given data is partially correct in that all repairs classified as ABS are also classified within brakes – the bubble “ABS” falls completely within the bubble “Brake.”

Figure 3: Illustration of database correction

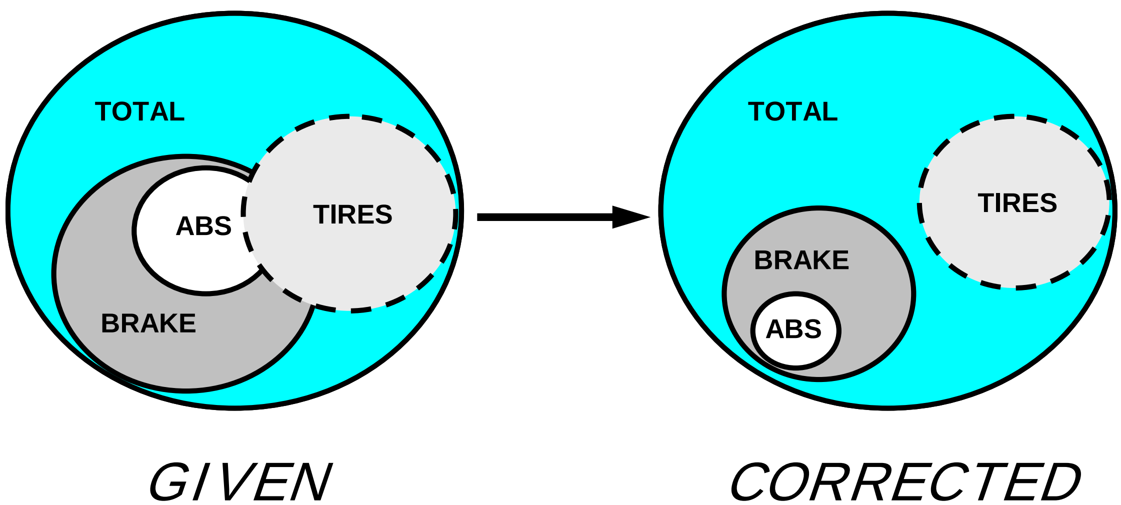


Figure 4 shows an order as provided, having been classified as ABS charges in its entirety. The part “KIT ECU [electronic control unit] BRAKE CONTROL” (highlighted, row 5) is a component of the ABS system. The code “13” identifies the brake system but does not specify ABS with a code of “13-011.” Items on rows 3 and 4 relate to the brake system. The VMRS code “13” reinforces classification of these items as brake-related, but it is not correct to classify these as ABS-related, as occurs on the database from NAMDX. Other lines of the order are not brake-related, either by code or description, yet are mistakenly allocated to ABS and thus brakes. The labor lines at the top (rows 1 and 2) suggest this order was a check-up, with some regular maintenance (e.g., “FILTER OIL,” row 9) and other items discovered during the inspection (e.g., “FOGLITE,” row 6). Some labor was presumably devoted to ABS and the brake repairs, though allocating the full 5.76 hours is excessive.

Figure 4: Example of actual data, entire order counted towards ABS

				ABS			Brake			Total		
Row	Code	Description		Hrs	Pts	Svc	Hrs	Pts	Svc	Hrs	Pts	Svc
1	00-001	15000 SERVICE CHECK PERFORMED	L	2.97	0	0	2.97	0	0	2.97	0	0
2	00-001	15000 SERVICE CHECK PERFORMED	L	2.79	0	0	2.79	0	0	2.79	0	0
3	13	BRAKESHOE Q-PLUS ROCKWELL	P	0	164	0	0	164	0	0	164	0
4	13	KIT BRAKE SHOE (FITS ROCKWELL	P	0	29.6	0	0	29.6	0	0	29.6	0
5	13	KIT ECU BRAKE CONTROL	P	0	133.39	0	0	133.39	0	0	133.39	0
6	34	FOGLITE ASSEMBLY 99 TRUCKS	P	0	35.96	0	0	35.96	0	0	35.96	0
7	41	FILTER AIR 2000 9200	P	0	68.639	0	0	68.639	0	0	68.639	0
8	44	FILTER DAVCO FOR WATER SEPERATOR.	P	0	5.28	0	0	5.28	0	0	5.28	0
9	45	FILTER OIL SER. 60	P	0	17.08	0	0	17.08	0	0	17.08	0
		TOTAL		***5.76***	***453.95***	***0***	***5.76***	***453.95***	***0***	***5.76***	***453.95***	***0***

Database improvements

Nearly every order with items classified as ABS charges contained at least one item that legitimately belonged to the ABS system. All these ABS orders were reviewed manually so that only the correct repair lines were included as ABS expenses. Repairs and maintenance to the core components of the ABS system were identified – namely, the wheel sensors, warning light, and ECU. Auxiliary components were included when they were clearly associated with ABS repairs, most commonly "wires" or "bulbs." One item was excluded from ABS charges, although it had been classified as such in the provided database – typically described "ABS 7WAY CORD," this item does not exclusively serve the ABS system, as it contains electrical components for seven connections between a tractor and trailer. Examples of the manual reclassification of ABS charges follow.

<u>Examples of reclassified orders</u>

Figure 5 shows an order with a straight-forward reclassification. The final row lists the part "ABS SENSOR," and its installation labor is clearly associated with a row of identical description. One additional column is shown here – the *CHGAMT* is the dollar amount per unit. For labor, the charge amount is the rate per hour, while for parts it represents the charge per item. For small parts, e.g., "MISC-SCREW" in this example, the total charge in the *PT* column is the product of the charge and a quantity (not shown). For larger parts, the quantity is generally one, thus the *CHGAMT* and the value in the *PT* column are identical. The total ABS charge for this order is \$19.21 labor (0.50 × \$38.42) and \$62.52 parts, summing to \$81.73.

Figure 5: Reclassified order, ABS sensor repair

DESCRIPTION	HRS	PT	SVC	CHGAMT
LABOR WINDOW REGULATOR	1.00	--	--	$38.42
LABOR RT DOOR WONT STAY SHUT	0.50	--	--	$38.42
LABOR TRIM & MISCELLANEOUS HARDWARE	0.50	--	--	$38.42
LABOR OIL PRESS	0.25	--	--	$38.42
LABOR ABS SENSOR	0.50	--	--	$38.42
PART MISC-SCREW	--	$1.28	--	$0.43
PART WINDOW REGULATOR	--	$126.51	--	$126.52
PART ABS SENSOR	--	$62.52	--	$62.52

Unfortunately, the connection between parts and labor is not always so evident. Figure 6 shows a repair to the electronic control unit (ECU). Only one labor row is given in this order, and it is classified as a 15,000 mile service check. Aside from the ECU, the other parts rows suggest routine maintenance. Some amount of the 3.13 hours labor should be apportioned towards the ABS repair. Other orders from this fleet were reviewed, and it was determined that an allocation of one hour was appropriate for an ECU replacement. Some of these other orders had very precise labor hours of 0.87, 1.25, etc. – all near one. The total ABS charge for this order is thus 1 hour × $29 plus $133.39, equaling $162.39. (The one cent difference between the column *PT* and *CHGAMT* arises from rounding somewhere in the database construction; this is inconsequential.)

Figure 6: Reclassified order, ECU with labor uncertain

DESCRIPTION	HRS	PT	SVC	CHGAMT
LABOR 15000 SERVICE CHECK PERFORMED	3.13	--	--	$29.00
PART FILTER OIL SER. 60	--	$17.08	--	$8.54
PART FILTER DAVCO FOR WATER SEPERATOR.	--	$5.28	--	$5.28
PART AIR FILTER 93/99 9200	--	$36.34	--	$36.34
PART FILTER WATER	--	$6.03	--	$6.03
PART KIT ECU BRAKE CONTROL	--	$133.39	--	$133.40

Repairs to the ABS warning light can be of two sorts – sometimes the light will not turn off, and other times it is burned out. Figure 7 and Figure 8 depict these two types of ABS light repairs. In fact, these are from the *same vehicle*. In the first repair, a small amount of labor was devoted to a light which apparently remained illuminated, a charge of $4.50 (0.25 hours × $18). Later, this vehicle received a new warning lamp bulb, accruing a charge of $10.87 (0.25 hours × $38.42 plus $1.26). The VMRS codes are listed to indicate that the codes cannot be relied on exclusively to classify ABS repairs. In the first order, the code "13" for the brake system was used, while in the second the code "34" represents the lighting system. In the latter, the part can be associated with the labor because no other items are listed with a code of "34."

Figure 7: Reclassified order, ABS light stays on

VMRS	DESCRIPTION	HRS	PT	SVC	CHGAMT
L 82	BEZEL	0.50	--	--	$35.00
L 82	CHANGE AIR FILTER	0.25	--	--	$35.00
L 44	CHANGE FUEL FILTER	0.25	--	--	$35.00
L 32	CRANKING SYSTEM	0.20	--	--	$35.00
L 42	COOLING SYSTEM	0.10	--	--	$35.00
L 00-005	AUTOMATIC/MANUAL CHASSIS LUBRICATOR	0.25	--	--	$18.00
L 79	SAFETY DEVICES	0.20	--	--	$18.00
L 82	MECHANICAL REFRIGERATION UNIT	0.25	--	--	$35.00
L 13	BRAKES	0.10	--	--	$18.00
L 78	AIR CHUTE	0.50	--	--	$35.00
L 17	TIRES	0.25	--	--	$18.00
L 45	CHANGE OIL & FILTER	0.25	--	--	$35.00
L 34	LIGHTING SYSTEM	0.50	--	--	$18.00
L 55	LOAD MYLAR BLANKETS & PALLET JACKS	0.25	--	--	$18.00
L 13	ABS LIGHT STAYS ON	0.25	--	--	$18.00
P 34	CLEAR LITE	--	$5.84	--	$5.84
P 53	MISC-SCREW	--	$0.56	--	$0.19
P 53	OIL BULK	--	$14.24	--	$0.89
P 82	FILTERS AIR CLEANER	--	$24.79	--	$24.79
P 82	FILTER-WATER	--	$135.00	--	$135.00
P 82	OIL FILTER ELEMENT	--	$8.90	--	$8.90

Figure 8: Reclassified order, ABS light not functioning

VMRS	DESCRIPTION	HRS	PT	SVC	CHGAMT
L 13	BRAKES	0.25	--	--	$38.42
L 51	GENERAL ACCESSORIES	0.10	--	--	$38.42
L 42	COOLING SYSTEM	0.10	--	--	$38.42
L 82	MECHANICAL REFRIGERATION UNIT	0.25	--	--	$38.42
L 32	CRANKING SYSTEM	0.20	--	--	$38.42
L 17	TIRES	0.25	--	--	$18.79
L 79	SAFETY DEVICES	0.20	--	--	$38.42
L 00-006	AUTOMATIC/MANUAL CHASSIS LUBRICATOR	0.25	--	--	$38.42
L 13	BRAKES	0.10	--	--	$38.42
L 18	WHEELS	0.25	--	--	$38.42
L 78	MUDFLAP	0.50	--	--	$38.42
L 34	ABS LIGHT	0.25	--	--	$38.42
P 34	"2"" RND 2 PIN LAMP (A)"	--	$1.26	--	$1.26
P 19	LUBE GREASE	--	$1.42	--	$1.42
P 13	AIR LINE ANTIFREEZE	--	$1.55	--	$1.55
P 78	MISC-SCREW	--	$8.97	--	$0.56

The two orders above serve to note that labor is not charged at a constant rate, even within a given order (Figure 7). This may be due to mechanics of different skill levels that perform certain tasks. These differences are retained, on the assumption that they represent the true charges incurred by the fleets. The preliminary analysis conducted by KRA employed a standard labor rate of $40.

In some cases, it is possible to associate miscellaneous small items with ABS repairs. Figure 9 shows a small repair order to the ABS sensor. Because there are no other major components, it is assumed that the entire amount of labor and the other low-value parts were utilized to complete this repair. The full charge for this order is $199.19 (2.5 hours × $50 plus $73.51 for the sensor plus $0.68 for the four small items).

Figure 9: Reclassified order, sensor repair with small extra parts

	DESCRIPTION	HRS	PT	SVC	CHGAMT
LABOR	BRAKES	2.50	--	--	$50.00
PART	CLAMP-LOOM-5/8 ID W 3/8 BOLT	--	$0.17	--	$0.17
PART	TIE-NYLON-8 INCH BLACK-STD	--	$0.15	--	$0.03
PART	TIE-NYLON- 15IN.-HD-BLACK	--	$0.24	--	$0.12
PART	CLAMP-LOOM-3/8 ID W/3/8 BOLT	--	$0.12	--	$0.12
PART	SENSOR-ABS	--	$73.51	--	$73.51

<u>Calculation of brake repair costs</u>

Repair and maintenance expenses to the brake system as a whole provide a baseline from which to compare ABS repair and maintenance expenses. It is not possible to manually review and classify orders with brake expenses – there are over 30,000 such orders in the database.

Repair lines were classified as brake-related using the VMRS codes and a few simple keyword searches. All rows with the first portion of the VMRS code "13" were included as brake expenses. This classifies 76,767 rows as brake-related. To account for brake expenses outside of VMRS code "13," a simple keyword search was conducted for the words "brake" *or* "shoes" in the *DESCRIPTION* field of the database. Rows were excluded if they also contained a term which relates to other types of brakes – "engine," "jake" or "j-brake," "exhaust," and "clutch." The term "braket" was excluded, as it appears to be an error in data entry of "bracket." The keyword search identified an additional 4736 repair lines as relating to the brake system – a relatively small number (6%) compared to those with VMRS code "13." Inspection of some orders containing the keywords – in both the included and excluded sets – indicates that repair lines were classified correctly.

The labor charges on these brake-related expenses are calculated as the product of the hours and the amount charged ($HRS \times CHGAMT$). Parts and services expenses are taken from the respective columns *PT* and *SVC*.

As noted in the ABS repair of Figure 6, labor is sometimes listed in ways that do not clearly correspond to the parts in an order. The opposite can occur as well – when labor for an entire order is classified on a row that indicates brakes in the VMRS code or the description field (it is common for these rows to be listed as VMRS code "13" with no additional digits and to be described simply "BRAKES"). This is not a database error and merely reflects the practical difficulties of classifying and charging labor for any type of vehicle.

The labor hours and charge amounts devoted to the brake system are calculated based on the VMRS codes and keyword matching. This will result in some under-counting and some over-counting at the order level. It is not clear the extent that this will equalize when summed across all orders for each vehicle. Charges are also calculated strictly for parts, providing a check to the overall brake expenses. The contribution of brake repairs to all repairs can be estimated in two fashions – *all* brake expenses relative to *all* expenses; and *brake parts* expenses relative to *all parts* expenses.

<u>Calculation of underride guard repair costs</u>

Unlike ABS and brake repair costs, the repairs to the underride guard were nearly classified correctly by NAMDX. The exception is the inclusion of conspicuity tape, which is placed on the URG but in minimal lengths compared to the rest of the trailer. In manually reviewing orders with URG repair costs, the repair lines relating to conspicuity tape were separated (described in the next section).

There are two types of repairs to the URG. The most severe is a replacement of the bumper, presumably due to some strong impact. Figure 10 shows an example where the labor hours were assigned manually. There are four labor lines ("L" in the left-hand column), and there are also four different VMRS codes ("13," "18," "34," "70"). The row with the largest labor charge (3.68) hours was assigned to the URG bumper because it is the most expensive part and presumably the most complicated to install.

Figure 10: Order with URG replacement

	VMRS	DESCRIPTION	HR	PT	CHGAMT
L	00-006	TRAILER PM	1.5	--	29.00
L	00-006	TRAILER PM	3.08	--	29.00
L	00-006	TRAILER PM	3.1	--	29.00
L	00-006	TRAILER PM	3.68	--	29.00
P	13	BRAKESHOE ROCKWELL QUICKCHANGE	--	71.96	17.99
P	13	KIT BRAKE SHOE (FITS ROCKWELL	--	14.02	7.01
P	18	SEAL WHEEL TRL.	--	33.78	16.89
P	34	BASE 1900 SERIES TRUCKLITE	--	1.78	1.78
P	34	LITE AMBER TRUCKLITE	--	1.94	1.94
P	70	GDICC BUMPER 95 SERIES	--	446.36	446.37

?

The second type of order with URG expenses is difficult to describe because there is no part. These repairs could be due to small impacts of force insufficient to merit fully replacing the bumper. The labor would therefore be body work to straighten the bumper. An example is shown below. If these types of repairs are listed under generic descriptions, such as in the example above ("TRAILER PM"), there is no way to recognize repairs to the URG. This could lead to some under-counting of URG repair charges.

Figure 11: Order with other URG repair

	VMRS	DESCRIPTION	HR	PT	CHGAMT
L	34	LIGHTING SYSTEM	1	--	38.42
L	71	HOLE IN FLOOR	4	--	38.42
L	77	ICC BUMPER	0.5	--	38.42
L	78	MUDFLAP HANGER	0.5	--	38.42
P	34	"7"" HOT WIRE PIG TAIL"	--	0.92	0.46
P	34	MARKER LAMP TOP-0812-2BL	--	6.36	3.18
P	71	ALUM PLATE .250 X 48 X 96	--	164.14	20.52
P	71	WELDING SUPPLIES	--	35.00	35.00

Calculation of conspicuity tape repair costs

The database provided by NAMDX originally considered repair orders including conspicuity tape as a part of the underride guard expenses. This is not correct, because the tape runs the length of the trailer, with only a small portion along the URG. Very few orders listed items pertaining to both the URG *and* conspicuity tape.

Figure 12 shows an order including application of conspicuity tape to a trailer. An additional column is included here that is not relevant in other portions of the analysis – the unit of measure, "UNIT." In this example, the trailer required 30 feet of conspicuity tape, at a charge of 79¢ per foot, a total charge of $23.70. In orders with no clear link to labor, the hours were assigned manually, using orders with associable hours as a guide – ¼ hour for short lengths, some as little as several feet; ½ hour for moderate lengths, such as 30 feet in this sample; and 1 hour for lengths approximating one side of a trailer or more, e.g., 80 or 100 feet.

Figure 12: Order with other conspicuity tape replacement, labor uncertain

	VMRS	DESCRIPTION	UNIT	QTY	CHGAMT	PT	HR
C	00-004	PERFORM FEDERAL INSPECTION	EACH	--	--	--	--
L	00-003	PM LEVEL C TRAILER SERVICE	EACH	--	45.50	--	1
L	13	BRAKES	EACH	--	45.50	--	5
P	12	STABILIZER ARM ASSY.	EACH	1	147.88	147.88	--
P	13	GLAD HAND SEALS	EACH	2	0.20	0.40	--
P	17	LP 24.5 XZE RECAP	EACH	1	94.80	94.80	--
P	18	RECON RIMS	EACH	1	16.00	16.00	--
P	53	ULTRA-DUTY GREASE	LBS	2	1.96	3.92	--
P	78	MISC. HARDWARE	EACH	100	0.50	50.00	--
P	94	1/2 AIRLINE	EACH	25	0.60	15.00	--
P	99	REFLECTIVE TAPE	FOOT	30	0.79	23.70	--

?

Figure 13 shows an order where the labor is clearly associated with the application of conspicuity tape, based on the VMRS code. It is not clear what a "conspicuity tape kit" contains exactly. Presumably, any un-used tape could be kept in stock for use on another trailer. The use of the unit of measure, as above, and the less precise terminology of the example below are differences within the record-keeping policies of the fleets that provided data. When summed across a large number of vehicles, the reported costs should still be reasonably accurate.

Figure 13: Order with other conspicuity tape replacement, labor identifiable

	VMRS	DESCRIPTION	UNIT	QTY	CHGAMT	PT	HR
L	00-005-300	TK 1500 HOUR SERVICE	EACH	--	69.00	--	1.7
L	00-006-100	TRAILER SERVICE	EACH	--	69.00	--	0.5
L	53-004-005	REFLECTOR DEVICES	EACH	--	69.00	--	0.4
P	53-004-005	CONSPICUITY TAPE KIT	EACH	1	72.95	72.95	--
P	53-999-016	OIL	EACH	17	1.00	16.92	--
P	XX	FILTER	EACH	1	15.58	15.58	--
P	XX	FUEL FILTER	EACH	1	13.27	13.27	--
P	XX	OIL FILTER -T.K.	EACH	1	6.58	6.58	--

Other adjustments and corrections

The database was inspected for vehicles and repair lines that seem to have unreasonably high or even negative expenses. Some manual adjustments were made, but these were few in number. The most common mistakes seem to be in data entry, such as omission of a decimal point (e.g., a charge of $180,000 for tires was reset to $1,800). Negative costs are sometimes encountered as warranty credits. It is assumed that these credits have a matching expense somewhere in the database, but this cannot be positively affirmed because descriptions are vague (e.g., "WARRANTY CREDIT") and listed as services with no associated VMRS code to match against. Similarly, negative labor hours are present in a few cases. These are assumed to be something like warranty credits, differing only in accounting (e.g., internal to fleet versus external). Negative values might be used to correct earlier over-charges, in which case ignoring the negatives would result in over-estimating the actual expenses incurred by the vehicles.

Fleet 5 recorded labor charges on essentially no orders. So that data from this fleet could be retained and placed on a comparable scale as other fleets, labor charges were assigned based on the parts charges. Using other fleets as a guideline, brake expenses for vehicles in Fleet 5 were increased by 60 percent for tractors and 100 percent for trailers, on top of the parts charges. For non-brake charges (i.e., total minus brake), the expenses were increased by 90 percent for tractors and 160 percent for trailers. The labor on ABS expenses was assigned manually at a rate of $40 per hour. Sensor and relay valve repairs were credited one hour (1 × $40 = $40), while light/bulb replacements were credited one-fourth hour (¼ × $40 = $10). These values should be consistent with other fleets.

Vehicle Exposure

For each vehicle, a valid measure of exposure for this survey period must be determined. Expenses can then be placed on a rate-basis, such as $500 per million miles traveled or $100 per month. From there, estimated expenses from this survey can be compared for pre-mandate versus post-mandate vehicles and amortized over a vehicle's lifetime.

It cannot be assumed that vehicles in the survey had similar exposure. Possible scenarios include retirement of old vehicles (primarily pre-mandate) before the end of the survey and acquisition of new vehicles (primarily post-mandate) at points after the beginning of the survey.

The optimal measure of vehicle exposure is the miles traveled. Unfortunately, the dataset provided by NAMDX does not contain usable mileage. For each tractor unit, the value does not vary within the repair lines file. The report from KRA states only that miles are "total miles." These are in fact the total miles over the vehicle lifetime (i.e., odometer reading) rather than miles accumulated during the survey period.

Time in service is an alternate measure of vehicle exposure. For trailers, it is the only available measure because mileage was not consistently recorded by NAMDX. Fortunately, tractors have these data as well. Like mileage, each vehicle has only one value for this variable throughout the datafile. However, unlike mileage, the "time in service" variable does not necessarily measure the full age of the vehicle. Another variable, the *flag*, defines months in two formats:

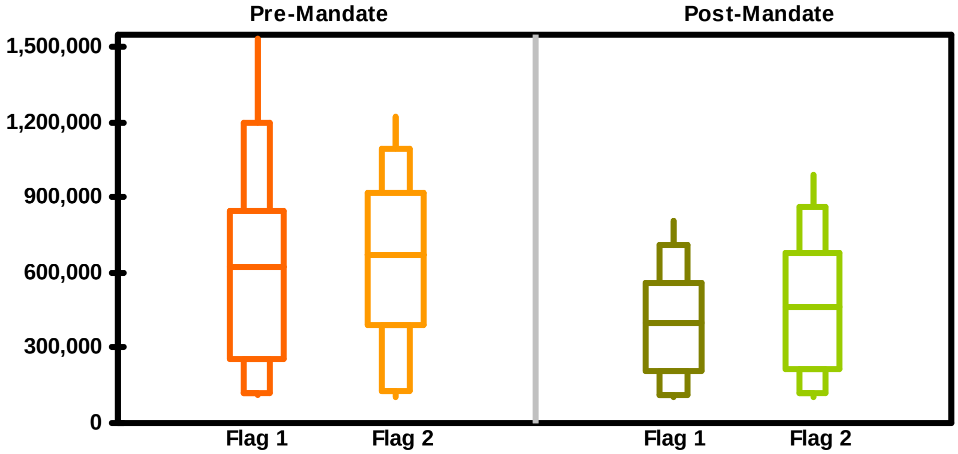
- When *flag* = 1, it is indeed the total number of months the vehicle has been in service.
- When *flag* = 2, it is the number of months that have elapsed since the date of the first repair order in the database. In other words, it is the difference (in months) between the date of the first order and the end of the survey period. For vehicles in service until the end of the survey period, this should be the actual number of months that this vehicle in service. However, this value will over-estimate the exposure for vehicles which were not in active service up until the end of the survey period.

Time in service for the *flag* 1 vehicles has the same problem as mileage, in that it extends over a vehicle's lifetime, up to 15 years on some pre-mandate trailers, and may greatly exceed the length of time these vehicles' repairs were actually tracked in the survey. However, the database contains a sufficient density of *flag* 2 vehicles that *flag* 1 vehicles can have an estimated service time in a comparable format as the *flag* 2 vehicles. This process is demonstrated in the forthcoming pages, making use of a variable *orderid*, which sequentially locates all orders within each fleet.

<u>Invalidity of *miles*</u>

The validity of the given *miles* can be assessed relative to the month flag: i.e., are miles recorded as total lifetime travel (*flag* 1) or since first repair order *(flag 2*)? Figure 14 uses a form of boxplot to assess this question. The vertical axis displays the miles as provided. The left-hand pane contains pre-mandate units, with post-mandate on the right. Within each pane, the left-hand box represents units with *flag 1*, with *flag 2* to the right. Each box has several demarcations, to allow comparison across the distribution of *miles*: the middle bar is the median; the inner box contains 68 percent of the tractors; the outer box contains 95 percent (*cf*. normal distribution percentages); the extremities extend to include the upper and lower 1 percent.

Figure 14: Enhanced boxplot of tractor miles, stratified by *mandate* and *flag*



How to read this graph:

- Each box is constructed from the *miles*; stratification by mandate and month flag is annotated.
- For each box, the summary metrics are the following:
  - the middle bar is the median;
  - the innermost box contains 68 percent of the data (i.e., 16th and 84th percentiles);
  - the outermost box extends to capture 95 percent of the data (i.e., 2½th and 97½th percentiles);
  - the tips extend to the extreme-most 1 percent of the data (i.e., 1st and 99th percentiles).

The utility of *miles* rests on units with *flag 2* having lower reported mileage, due to a restricted timeframe, which is not the case. In fact, the *flag 2* vehicles have slightly higher mileage at most percentile-point comparisons. Moreover, pre- and post-mandate vehicles should have similar distributions if the mileage was recorded over a specific timeframe, whereas Figure 14 shows pre-mandate vehicles to have much higher mileage. Thus the *miles* as given must be over the vehicle lifetime, invalidating this measure of a tractor's mileage accumulated during the survey.

Exposure using *months*

Figure 15 shows the distribution of database field *months* by type and mandate for all fleets, further divided by the *flag* variable (left = months in service; right = months since first repair order)[14]. For both vehicle types, the pre-mandate units are generally older or were tracked for a longer time-frame, though most of the distributions overlap. Notably, post-mandate tractors with *flag 1* extend exactly one year higher than post-mandate trailers,[15] which is appropriate considering the mandate for tractors was one year earlier (March 1, 1997, versus March 1, 1998).

Comparing across *flag 2* post-mandate units, the similarity in maximum values suggests the study's timeframe began around 1999 (i.e., two years after the tractor mandate and

[14] The months have been "jittered" by adding a small random number, reducing overlap due to the coarseness of months.

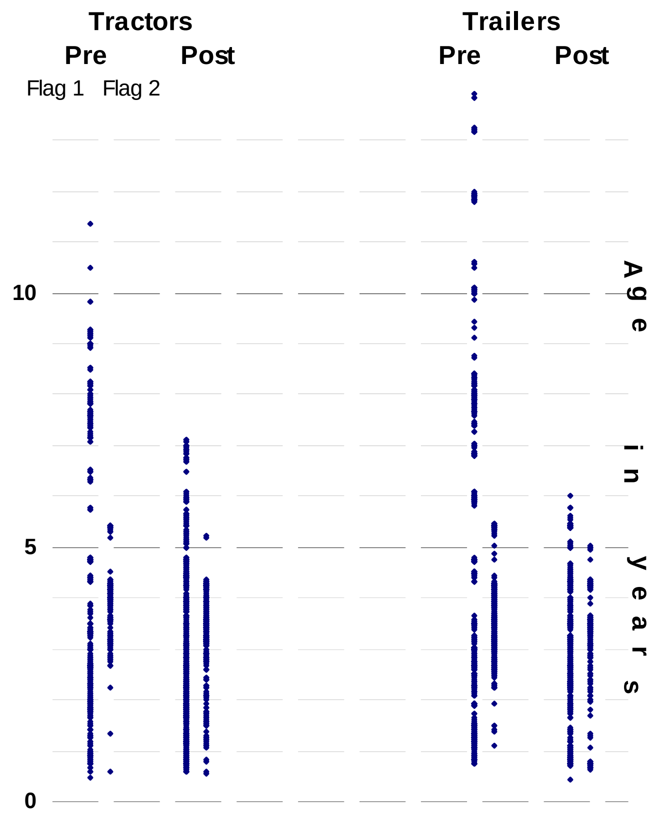
[15] One pre-mandate tractor with *flag 2* is unreasonable (97 months, fleet 10, unit 167) and was changed before further analysis (set to 47 based on adjacent units from same fleet).

one year after the trailer mandate). The low-end (9 months) implies data collection ran up to around 2003, based on KRA's report date of February 19, 2004. A reasonable guess at the study's time frame then is five-and-a-half years somewhere in the range March 1, 1998, to December 31, 2003.[16] [17] Among pre-mandate units, those with *flag 2* have an interesting "trickle" pattern at the low end, indicating that a few vehicles managed three years with no repairs or else joined the fleet at a later date as a used vehicle. Pre-units with *flag 1* curiously do not have this pattern but extend to minimum values at the same distribution as post-mandate and *flag 2* units (these could be data-entry errors, for example entry of years instead of months).

[16] Envision a letter addressed to trucking fleets requesting maintenance receipts with a statement such as, "We request that you provide records of repair expenses for all vehicles collected during the period March 1, 1998, to February 28, 2003."

[17] The youngest vehicles (5 months) would then have been purchased in late 2002 or early 2003, accruing some repair orders before the end of the survey. A short amount of time should be factored in for KRA to perform the analysis as well.

Figure 15: Distribution of vehicle age (months), as provided by NAMDX



How to read this graph:

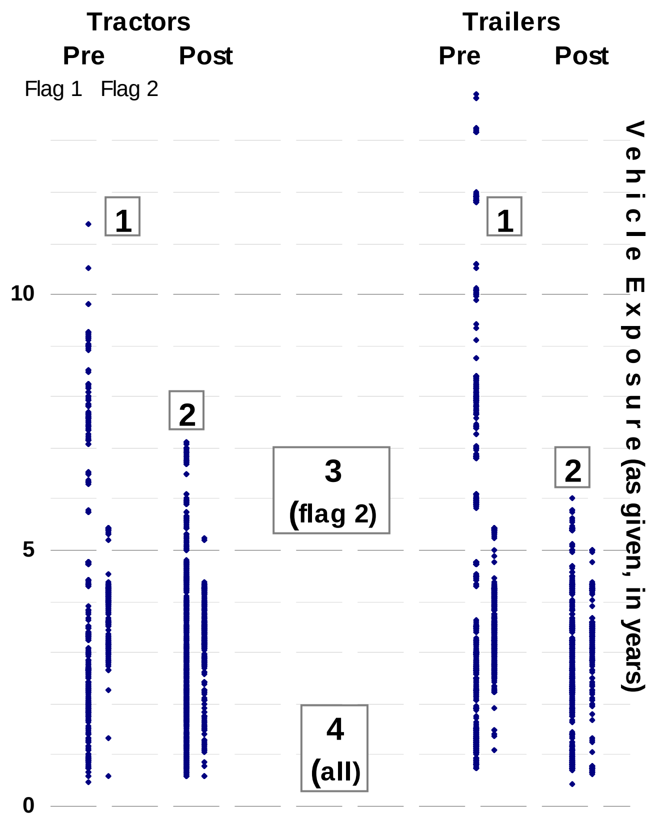
- Vehicles are stratified according to type, mandate, and month flag.
- Each pip is the given age for one vehicle.
- The scale is reported in years for aesthetics, but the given data are in months.
- Each type-mandate combination has two sets of pips, with those on the left being vehicles with *flag 1* and vehicles with *flag 2* on the right.

An annotated version of Figure 15 is presented in Figure 16, to highlight several regions of interest in the graph. They are marked as follows:

1. The *flag* 1 vehicles clearly have a different distribution than *flag* 2 vehicles. The ages provided by NAMDX extend back to points that would have had to have been before 1990, based on KRA's report date in 2004.
2. Among post-mandate *flag* 1 vehicles, tractors are at most one year older than trailers, which is appropriate because the mandates were effective one year earlier for tractors.
3. For all four type × mandate combinations, *flag* 2 vehicles are at most 5½ years old, providing evidence of the study's timeframe.
4. For all vehicles, -- regardless of type, mandate, or flag -- there are very "young" units. The given *months* extends to as low as five months in the case of post-mandate trailers. Because the minimum is not zero or one, this raised a concern that some uniform cut-off date was used for repair

receipts (e.g., June 31, 2003), while the ages were back-calculated from some other date (e.g, December 31, 2003). Inspection of the repair orders assuages this fear: these "young" vehicles do have repairs later in sequence (based on the field *orderid*, discussed more in following sections), although not at the extreme end and generally incurring multiple repair orders before the end of the survey.

Figure 16: Distribution of vehicle age (months), as provided by NAMDX, annotated



<u>Evidence that orders are time-sequential</u>

Further analysis is needed to determine if the *months* variable restricts the study's time-frame to, approximately, 1998 to 2003 as suggested by the dot plot above (Figure 15). If the earliest orders were performed on only pre-mandate vehicles, this would indicate receipts were collected on some indeterminate time-frame, perhaps beginning at some point before 1998 or possibly including a vehicle's entire in-service history.

An additional variable is used here, the *orderid*, which varies for each vehicle within the repair lines, unlike *months* which has a single value for each vehicle. As discussed in the section on adjustment procedures, this *orderid* is presumably a grouping variable for repairs which were conducted at the same time, though the precise definition of an "order" might vary by fleet. A crucial assumption is required: the variable *orderid* is time-sequential within each fleet. For example, the order "1000" in Fleet 2 occurred temporally before order "2000," although it can only be estimated how much earlier and nothing can be inferred regarding order "2000" for, say, Fleet 15.

The graphics below (Figure 17 and Figure 18) shed light on the repair trends with respect to *mandate*. Orders have been placed into class intervals of size 100,[18] assuming that orders are numbered sequentially within each fleet. Blue dots are the percentage of tractor orders that are post-mandate (e.g., 40 of 50 tractor orders within the 100-block are post-mandate = 80%), with red corresponding to trailers. A high-order polynomial has been fit to each set, to serve as a visual guide. Overall fleet compositions are indicated by the dashed lines (i.e., within-fleet percentages from Table 1). In Fleet 2, for example, post-mandate tractors experience more frequent repair orders than pre-mandate tractors, relative to the overall fleet composition. This is implied by the dashed line generally falling below the trendline and the bin data points; the opposite is true for trailers.

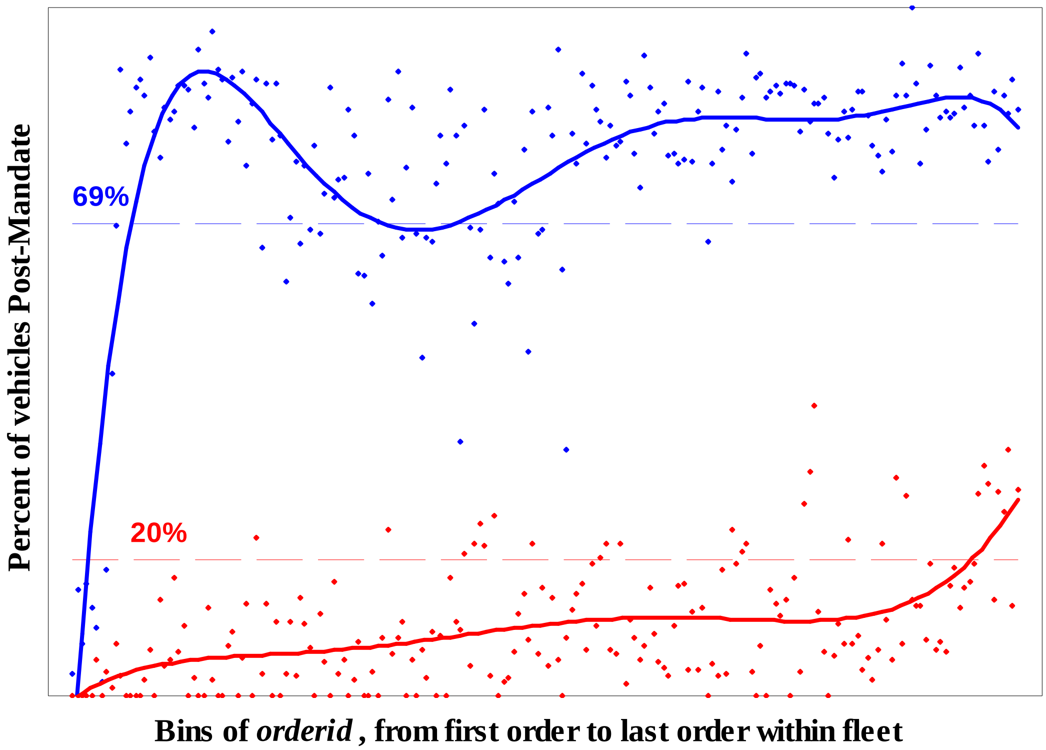
The samples below were selected because they are the two largest fleets. Both fleets show an increasing presence of post-mandate tractors with respect to time. Fleet 6's trend is not monotone with respect to trailers, while Fleet 2 shows a slower increase than in its tractors. Grossly, these trends hold across fleets: post-mandate tractors become more prevalent with time, while trailers are level or only slightly tilting towards newer units. Most importantly, the presence of post-mandate units at the earliest points indicates a closed interval for the survey, rather than receipts representing a vehicle's full lifetime. Further, the survey began after the mandate took effect. This has important implications for estimating vehicle exposure.

The uneven distribution with time raises several additional points:

- Repairs to post-mandate units may appear slightly more expensive on average due to inflation;
- Conversely, pre-mandate units were older at the beginning of the study period, implying orders may have represented more substantial repairs;
- Some combination of the following:
    - Pre-mandate units were retired during the period;
    - Post-mandate units required little maintenance as brand-new vehicles but required more repairs as they aged;
    - New vehicles (post-mandate) entered the fleets.

[18] For example, the first point summarizes orders 1 to 100, the second point summarizes orders 101 to 200, etc. An alternate representation would be a moving average, which would not change the nature of the analysis.

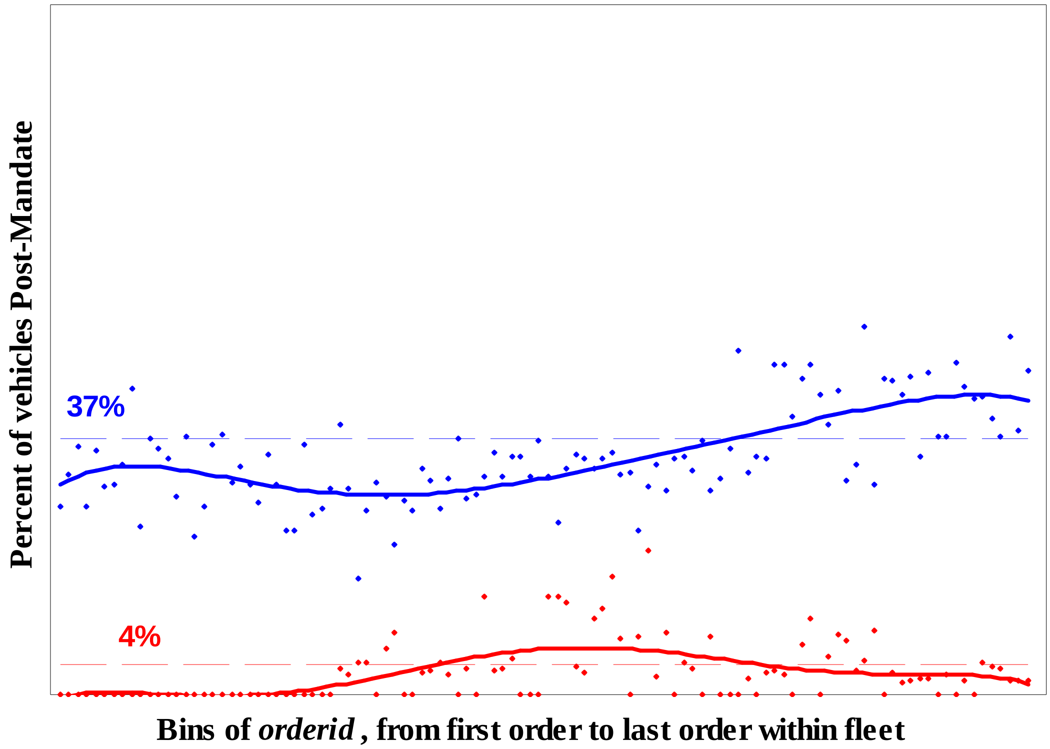
Figure 17: Trends in mandate by vehicle type; partialled; Fleet #2



How to read this graph:

- Repair orders have been placed into bins of size 100, assuming *orderid* is sequential.
- Blue are tractors; red are trailers.
- Each mark is the percent of post-mandate units in the bin, out of the total number of same-typed units in that bin (e.g., 80% would represent 40 tractors out of 50 tractors in a bin).
- Solid lines are sixth-order polynomial trendlines; these are provided as visual guides with no inferential value expressed or implied.
- Dashed lines are the overall proportion of post-mandate units for that type (e.g., 69% of tractors in Fleet 2 are post-mandate).
- The vertical axis runs from 0 percent to 100 percent. The horizontal axis is scaled to show all order-bins.

Figure 18: Trends in mandate by vehicle type; partialled; Fleet #6



Adjustments to *months*

Table 2 shows the number of vehicles having the flag variable value of 1 and 2 for each fleet. The high frequency of zero and other small values shows that the flag variable is dependent on the fleet. A potential strategy for eliminating uncertainty about exposure would simply be to exclude the Flag 1 vehicles. However, as Table 2 shows, exclusion of the Flag 1 vehicles would unduly weight the results towards those fleets which used Flag 2. If this were done, Fleet #2 would dominate the analysis (e.g., 51% of pre-mandate trailers with Flag 2 are from Fleet #2). The retention of the Flag 1 vehicles will help this report maintain a more representative picture of maintenance expenditures for in-service vehicles in an uncontrolled setting.

Table 2: Vehicle counts according to flag variable

	Tractors				Trailers			
	Pre-Mandate		Post-Mandate		Pre-Mandate		Post-Mandate	
Fleet	Flag 1	Flag 2	Flag 1	Flag 2	Flag 1	Flag 2	Flag 1	Flag 2
2	6	80	13	175	10	414	63	42
4	3	36	63	86	0	120	3	100
5	81	4	158	24	102	0	95	0
6	162	39	95	24	279	14	12	0
7	43	0	2	0	153	0	73	0
8	15	0	17	0	61	0	35	0
9	46	0	54	0	76	0	165	0
10	5	44	48	18	10	60	34	10
11	10	20	11	7	1	45	2	9
12	0	16	2	36	0	133	36	94
14	56	2	284	11	12	0	7	0
15	6	1	172	44	97	23	201	2
Total	*433*	*242*	*919*	*425*	*801*	*809*	*725*	*257*

Rather than ignoring a large number of vehicles, potentially limiting generalizability and losing statistical power, a system was devised to adjust the given months. This analysis was conducted at the fleet level. Examples are forthcoming. The steps are as follows:

0. Assume order IDs are sequential in time.
    - The field *orderid* is numeric.
1. Calculate the relative position of each vehicle's first and last repair order within the fleet (0 to 1 scale).
2. Visually inspect months (as given) versus first repair order (lowest *orderid*).
    - Look at overall patterns with an eye towards local linearity
3. When local linearity is violated, adjust months for those vehicles that are out of line.
    - This means that "most" vehicles have acceptable months as given.
    - Generally, when there are few vehicles to adjust or else the pattern has a great deal of clustering, vehicles are simply set to a certain value consistent with the pattern of that region.
    - If linearity exists over a large area, the adjustment is based on a linear interpolation (adjusted months are rounded to whole numbers for consistency).
4. Calculate a second value based on the difference between first and last order, intended to approximate each vehicle's time in the survey.
    - It is not clear if the provided months are from first to last repair order or from first repair order to the end of the survey.[19] The validity of this step is examined later.

    a) For example, consider a vehicle with its first order at 0.10 and its last order at 0.90 (a difference of 0.80).

[19] It could even be the case that the date-calculation reference date is different from the last date wherefrom receipts were collected.

b) The value for months is 50 – this could be adjusted based on Step 3 above or could be the given value if it did not require adjustment.

c) Months are truncated using the last order's relative position. This is a quantitative approximate of the following verbal statement: "Most vehicles require regular maintenance. If a vehicle did not incur any repair orders, it was either not in the fleet or else was used so little that it did not require any. Whatever the reason, we should not 'credit' these vehicles for time in service if they were not in use." For the hypothetical values in point (a), the following steps would be performed:

    i. This vehicle was 'in the fleet' for 80 percent of the total survey, out of a maximum possible 90 percent based on the first order occurring at 0.10 and final order at 0.90.
    ii. The age is scaled back by a factor of 8 to 9.
        - $^{8}/_{9} \times 50 = 44.4$
    iii. One month is added to the adjustment (45.4) and rounded (45), serving two purposes:
        1. This prevents vehicles with a very small number of closely-spaced repair orders from having "zero" months.
        2. A vehicle is given a token amount of service-time after its final repair.
    iv. If the "add one" step makes this second adjustment higher than the first, the value is lowered to the adjustment from the first step.
        - This can happen for vehicles with very late final repair orders.
        - Rounding usually prevents this occurrence.

The graphics below (Figure 19 – Figure 23) illustrate the adjustment process for Fleet #2. Figure 19 plots the given months against the first repair order.

Figure 19: Given months versus first repair order (Fleet #2)

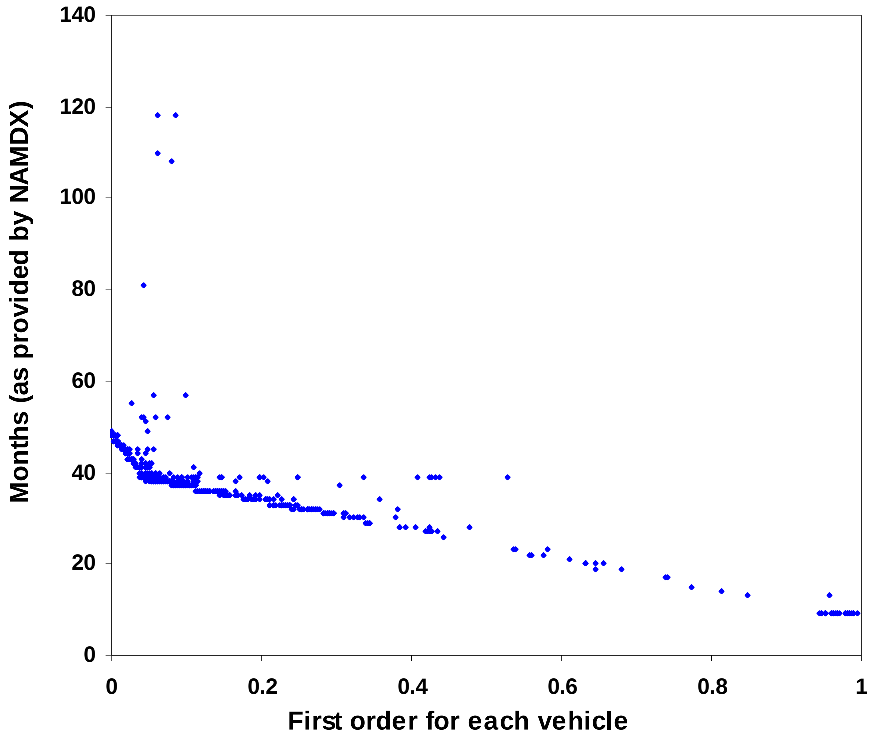


Figure 20 contains the same data as Figure 19, with notation added to capture the trends in local linearity and highlight points which violate the trend. Most points fall near the line segments. Two groups are exceptions: (1) vehicles with very early first repair orders and given months exceeding 50, up to 120 at the extreme (orange ellipses); and (2) a string of vehicles all given 36, 37, or 38 months having first repair orders in the range 0.2 to 0.5 (green ellipse).

Figure 20: Given months versus first repair order (Fleet #2, highlighting trends and exceptions)

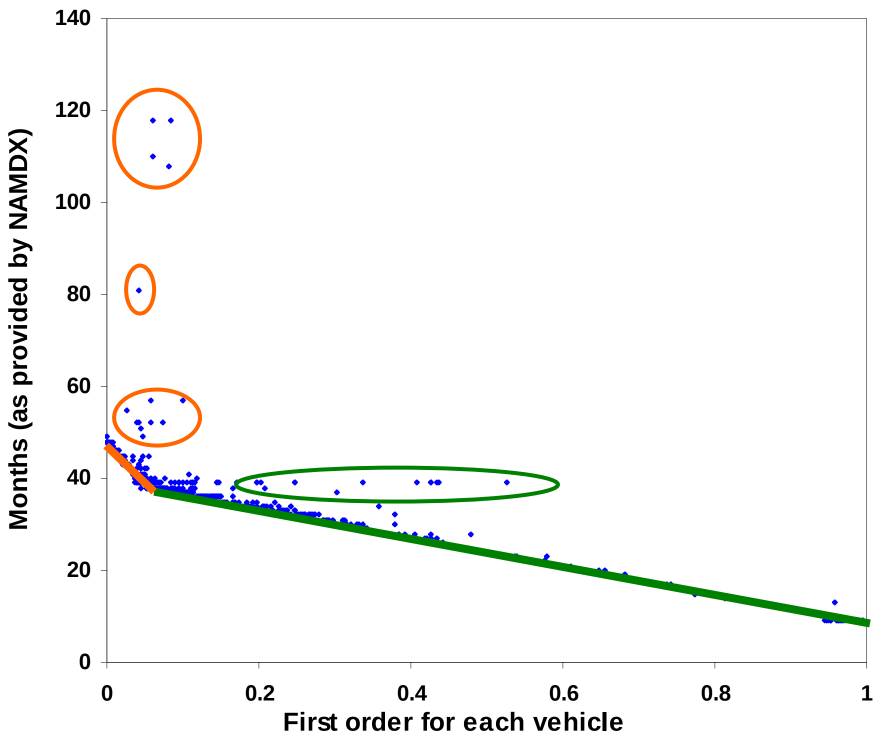


Figure 21 shows the results of adjusting those units noted in Figure 20 as being out of line with the fleet's overall trend. The vertical scale has been reduced to allow inspection of the linearity.

Figure 21: Adjusted months versus first repair order (Fleet #2, highlighting adjusted vehicles) (vertical scale reduced)

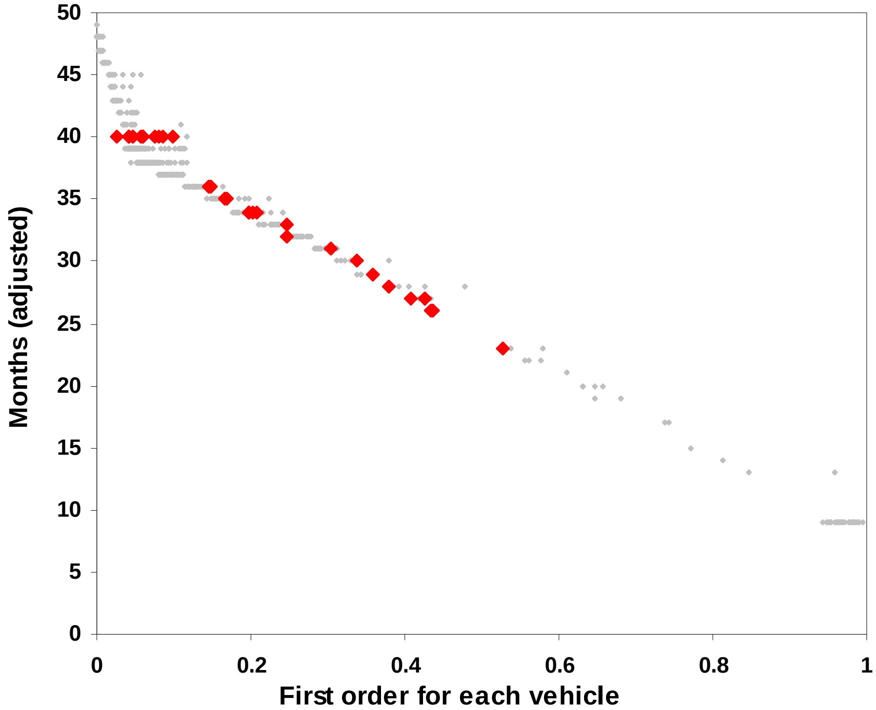


Figure 22 (upper left) and Figure 23 (lower right) are zoomed-in versions of Figure 21, so that piecewise linearity can be further inspected. Figure 22 shows that placing all high-valued points at 40 months fits well with the pattern in that region of the graph. For practical purposes, the alternative of interpolating on the range 45 to 35 would make little difference. The adjusted vehicles with later first-repair orders (Figure 23) contribute to a trend that is as linear as one can reasonably expect. Fourteen of the 19 vehicles in this region are post-mandate trailers with month flag 1. Speculatively, these could have been purchased around the same time but incurred different usage patterns that caused some units to have much later first-repair orders (e.g., they were serviced by outside agents due to the types of routes undertaken or else were simply used little initially).

Figure 22: Adjusted months versus first repair order (Fleet #2, highlighting adjusted vehicles, zooming in on upper left region)

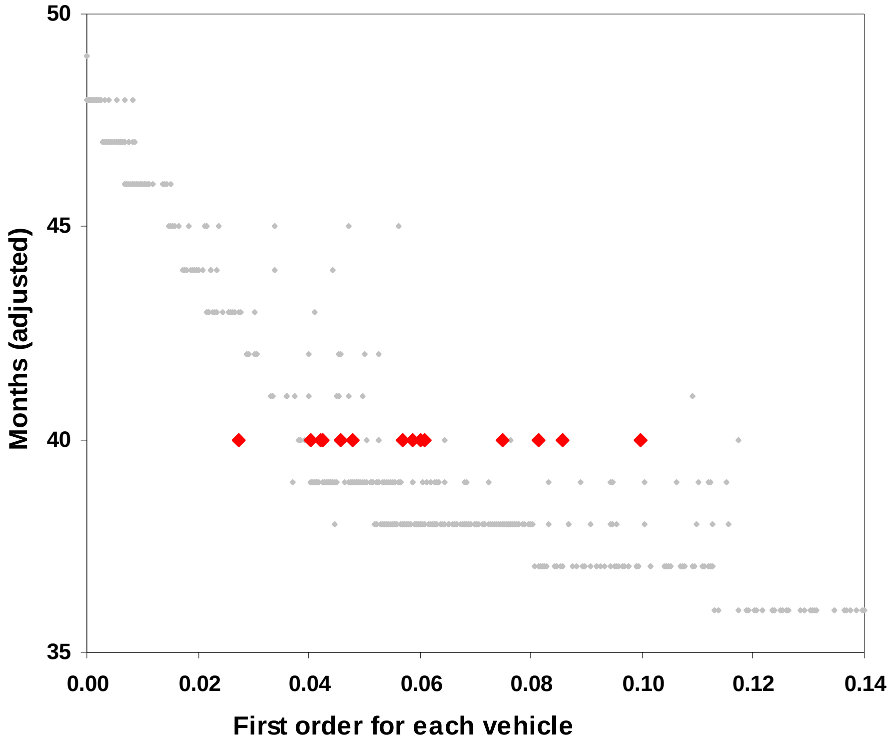
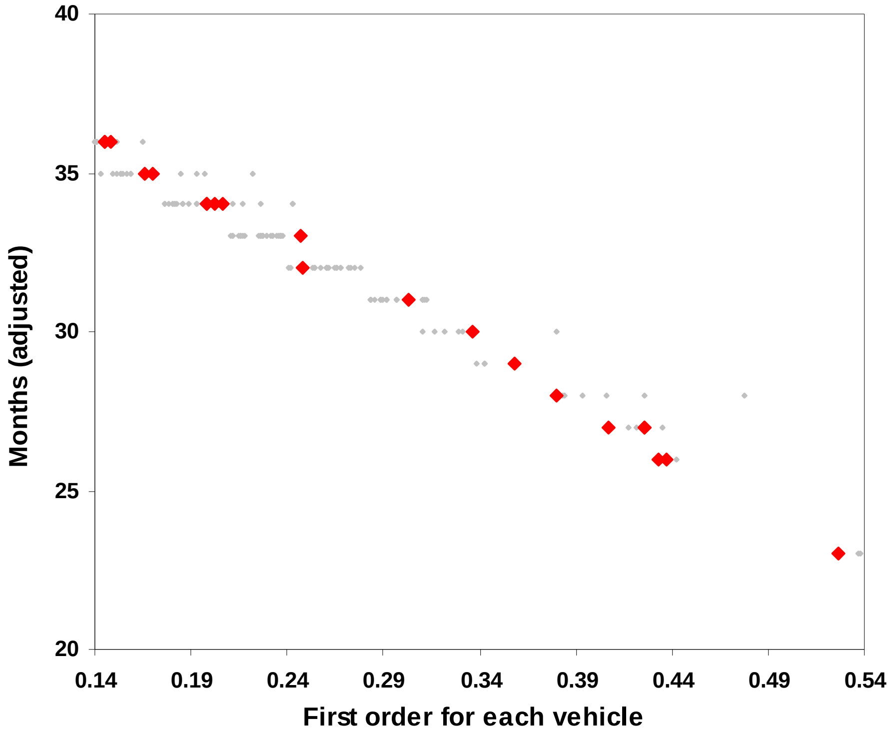


Figure 23: Adjusted months versus first repair order (Fleet #2, highlighting adjusted vehicles, zooming in on lower right region)



The next series of figures shows the adjustments for Fleet #5. While Fleet #2 required few adjustments (35 of 803 vehicles: 4%), Fleet #5 was more troublesome, with 76 percent of vehicles (352 of 464) out of alignment. Figure 24 shows the given months versus first repair order. The problematic regions have been highlighted. The upper portion is too high based on analysis of all fleets, which suggests a survey timeframe of approximately five years (Figure 15). There is a lower cluster of vehicles with first repairs orders very close based on the order numbers but given ages varying over a wide range (14 to 43 months). An overall linearity is noted based on vehicles with early repair orders and months less than 60, along with a few having later repair orders and months around 40.

Figure 24: Given months versus first repair order (Fleet #5, highlighting trends and exceptions)

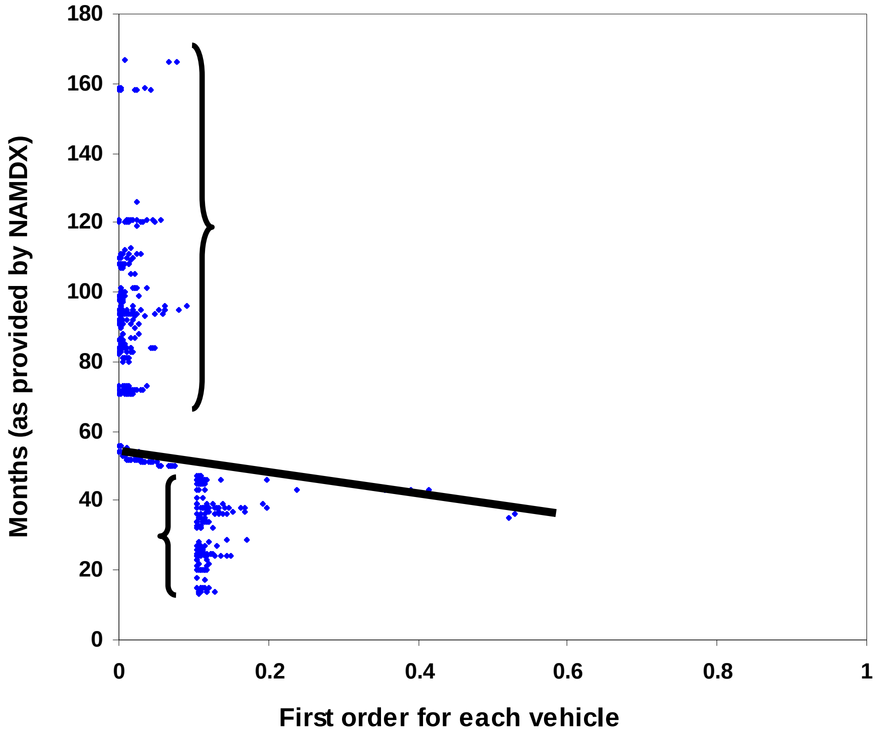
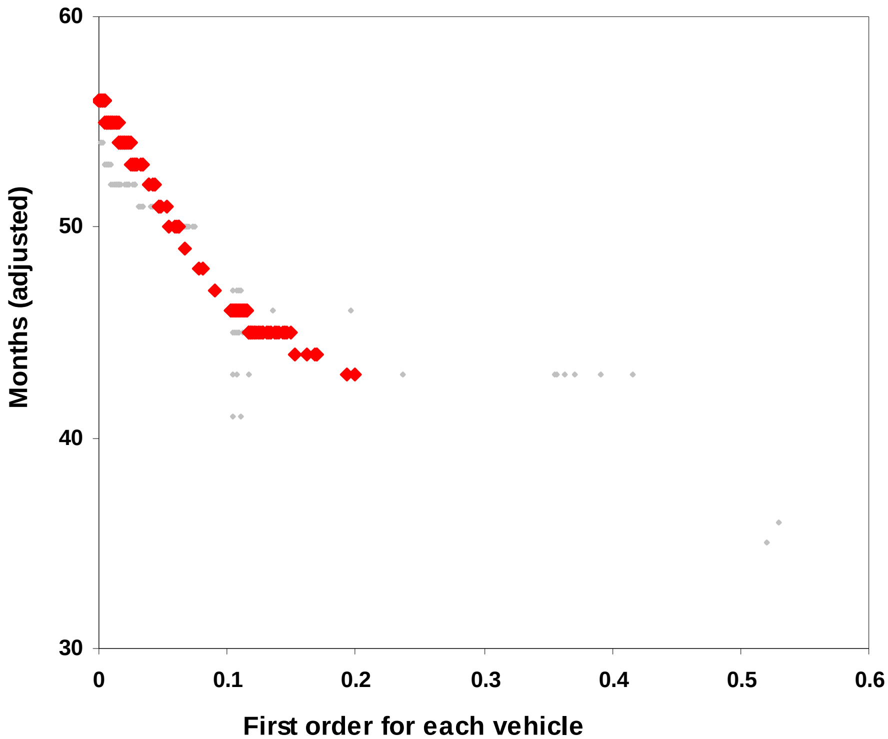


Figure 25: Adjusted months versus First repair order (Fleet #5, highlighting adjusted vehicles); note reduction in scales for illustrative purposes



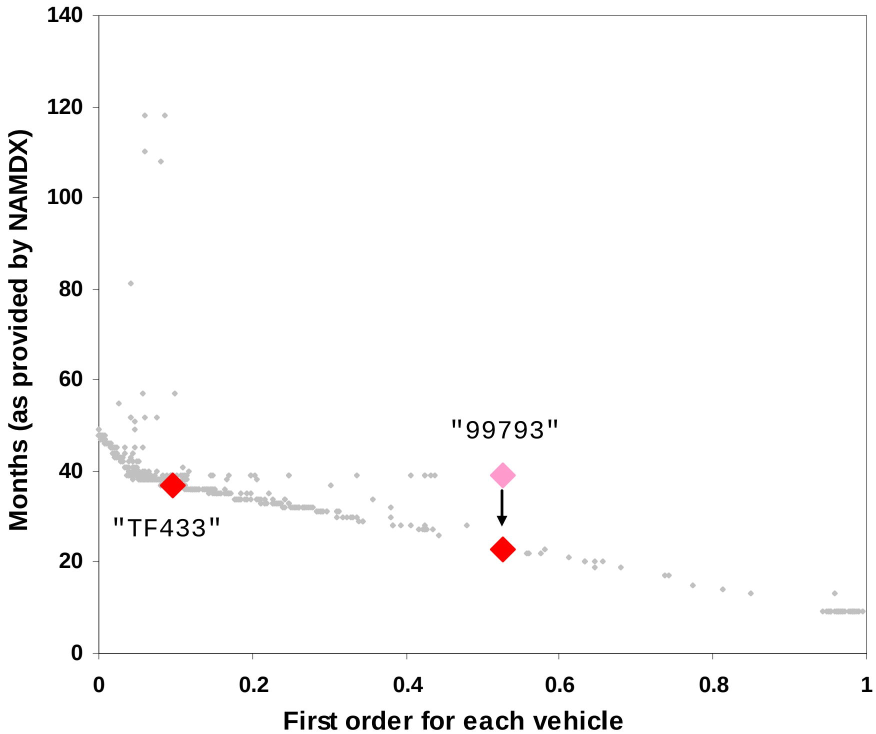
Graphical analyses similar to those for Fleets #2 and #5 were conducted for all fleets. Fleet #2 is typical of most fleets: for the few vehicles requiring adjustment, the steps are intuitively clear. Fleets #5 and #15 have similarly troublesome patterns, resulting in the most extreme uncertainty about how to perform the adjustments.

The following list describes the adjustment procedure for two individual vehicles from Fleet #2, highlighted in Figure 26. The adjustment procedure includes establishing the time of the first and last repair order. The actual exposure will be the difference between these two times.

0. For fleet #2, there are 19,536 orders.
1. Relative order positions are calculated:
   a. Unit "TF433," a pre-mandate tractor, given 37 months with flag 2:
      - First order at position 1882 → 1882 ÷ 19536 = 0.096
      - Last order at position 10183 → 10183 ÷ 19536 = 0.521
   b. Unit "99793," a post-mandate trailer, given 39 months with flag 1:
      - First order at position 10292 → 10292 ÷ 19536 = 0.527
      - Last order at position 19255 → 19255÷ 19536 = 0.986
2. In Figure 26, the two sample vehicles are highlighted. For "99793," the upper point (pink) is the given value and the lower value is the adjustment.

a. The given value for "TF433" falls within the overall pattern for the fleet, thus it was not adjusted.
b. The given value for "99793" is higher than those with first repair orders around the same time, thus it is lowered by a linear interpolation to 23 months (step 4).

Figure 26: Adjustment procedure for two vehicles in Fleet #2



3. Local linearity is evident in Figure 26 and was highlighted previously in Figure 20.
4. The months are adjusted based on the first repair order. For the two examples:
   a. Unit "TF433" does not require adjustment.
   b. Unit "99793" falls in the group with late first repair orders. The months were reduced according to the interpolation, rounded to an estimate of 23 months.
      - Linear interpolation according to point-slope form of a line: $y - y_1 = m\ (x - x_1)$, where y is the estimated *months* and x is the relative first order position[20] → y = -32.5 (0.527 – 0.14) + 36 = 23.4 → 23
5. The previous adjustment, if any, is further adjusted based on the final repair order (stage c on page 30). For the two examples:

[20] The slope is estimated from the points (0.14, 36) and (0.54, 23), with a corresponding slope of -13 ÷ 0.40 = -32.5. These points were selected from visual inspection rather than a regression analysis. Either point placed back into the point-slope equation as (x_1, y_1); the first point was used in the calculation here.

a. Unit "TF433" has its last order very early, perhaps because it was retired from use, being a pre-mandate unit:
   - $\frac{0.521-0.096}{1-0.096}\times 37=17.4\xrightarrow{+1}18.4\xrightarrow{round}18$
b. Unit "99793" has a very late final repair order, thus this second adjustment retains the same value as the first step (23 months), indicating the vehicle was in the fleet and in use until the end of the survey period.
   - $\frac{0.986-0.527}{1-0.527}\times 23=22.3\xrightarrow{+1}23.3\xrightarrow{round}23$

Table 3 summarizes the number of vehicles requiring adjustment. A large portion of *flag* 1 vehicles required adjustment, up to 49 percent in the case of pre-mandate trailers. The accuracy of the provided data is evident in the small percentage of *flag* 2 vehicles requiring adjustment.

Table 3: Number of vehicles requiring adjustment to months, based on first repair order

			No. adjusted	Total vehicles	Perc. adjusted
Tractors	Pre-Mandate	Flag = 1	168	433	39%
		Flag = 2	4	242	2%
	Post-Mandate	Flag = 1	192	919	21%
		Flag = 2	6	425	1%
Trailers	Pre-Mandate	Flag = 1	369	801	46%
		Flag = 2	4	809	< 1%
	Post-Mandate	Flag = 1	108	724	15%
		Flag = 2	1	258	< 1%

As noted in the sample calculations for units "TF433" and "99793," there can be large differences not only in the temporal location of the first order but also the last order. Table 4 shows the average first and last repair order for each type-mandate combination. The metric is the rescaled order position, where zero (0) would be the first order for each fleet and one (1) would be the final order. Pre-mandate vehicles experience their first repair order earlier than post-mandate units, on average. The final repair orders are generally towards the end, except where they fall notably short for pre-mandate tractors, at 0.73. The final column shows the average amount of time that vehicles were in the survey; again, pre-mandate tractors have noticeably lower exposure than others. Lowering the adjusted months to account for these differences may be merited.

Table 4: Average position of first and last repair order (rescaled *orderid* on 0 to 1)

		First order position	Final order position	Difference
Tractors	Pre-Mandate	0.15	0.73	0.59
	Post-Mandate	0.20	0.87	0.67
Trailers	Pre-Mandate	0.17	0.90	0.74
	Post-Mandate	0.24	0.92	0.68

Table 5 shows the results of carrying forth the adjustment to the last repair order. It needs to be clearly stated that the final values represent the amount of time that each vehicle was tracked in the survey, as opposed to the age of the vehicle. Thus, these values do not imply that pre-mandate tractors are "younger" (29 months) than post-mandate tractors

(31 months) but rather that pre-mandate tractors were tracked in the survey for a shorter period of time on average (e.g., due to dis-use or scrappage).

Table 5: Averages for (1) given months, (2) adjustment based on first repair order, and (3) estimate of actual exposure based on first and last repair orders

		Given (1)	Adjustment (2)	Actual Exposure (3)
Tractors	Pre-Mandate	49	41	29
	Post-Mandate	35	35	31
Trailers	Pre-Mandate	48	40	36
	Post-Mandate	36	36	33

(1) The values listed in the database from NAMDX, ignoring the *flag* variable
(2) The effect of linearizing the trend in months versus first repair order
(3) Further adjustment of (2) to reflect the position of each vehicle's final repair order

The validity of the adjusted months is illustrated in Table 6, which is a portion of a correlation matrix relevant to this issue. The given months, first-order adjustment, and actual exposure run across rows. The columns show three measures of a vehicle's total repair exposure: expense (total dollars across the survey), number of orders, and number of repair lines. First, it is apparent that the given months do not correlate highly with the measures of repair orders for pre-mandate vehicles. For the two stages of adjustment, the adjustment based on both first *and* last repairs ("Actual Exposure" in Table 5) has slightly higher correlations in all cases compared to the first-order adjustment. Although most differences are slight, this is a preponderance of evidence beyond chance (i.e., higher in 12 of 12 instances). While the given months are sufficient for post-mandate vehicles, the second adjustment is used for all vehicles for the sake of consistency.

Table 6: Correlations between various Months and measures of repairs

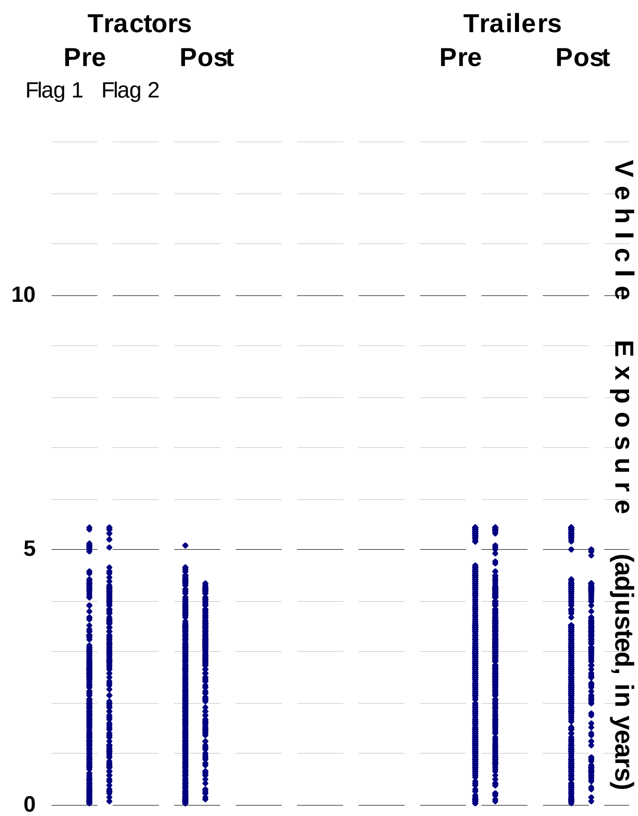
		Pre-Mandate			Post-Mandate		
		Total $ (a)	No. orders (b)	No. lines (c)	Total $ (a)	No. orders (b)	No. lines (c)
Tractors	(1) Given	0.21	0.42	0.30	0.48	0.64	0.52
	(2) Adjusted	0.44	0.52	0.44	0.57	0.72	0.60
	(3) Exposure	0.67	0.62	0.57	0.63	0.79	0.64
Trailers	(1) Given	0.13	0.28	0.13	0.45	0.57	0.37
	(2) Adjusted	0.42	0.54	0.36	0.45	0.60	0.38
	(3) Exposure	0.49	0.59	0.39	0.46	0.61	0.40

How to read this table:

- This is a portion of a correlation matrix.
- Columns are labeled as follows:
  - (a) This is the total dollars in maintenance and repair expenses in the survey period.
  - (b) This is the number of repair orders that a vehicle required during the survey period (i.e., the number of entries in the *Orders* table).
  - (c) This is the total number of repair lines for each vehicle during the survey period (i.e., the number of entries in the *Repair Lines* table).
- For example, the correlation between the given months and the total repair expenses is 0.21 for pre-mandate tractors (upper left cell of table).
- Rows are labeled (1), (2), and (3) as in Table 5.

Figure 27 shows the distribution of actual vehicle exposure, estimated based on both first and last repair orders. The scale here is exaggerated to accentuate the difference to the "months in service" given in the database (Figure 15), namely, the lack of pre-mandate units extending beyond 15 years. If the Figure 15 values are used as the denominator (as they were in the unpublished 2004 report), the repair cost per month could be substantially underestimated, especially for the pre-mandate vehicles. The minimum values are also lower here, because some vehicles had a small number of closely-spaced orders.

Figure 27: Distribution of actual vehicle exposure, adjusted based on first and last orders



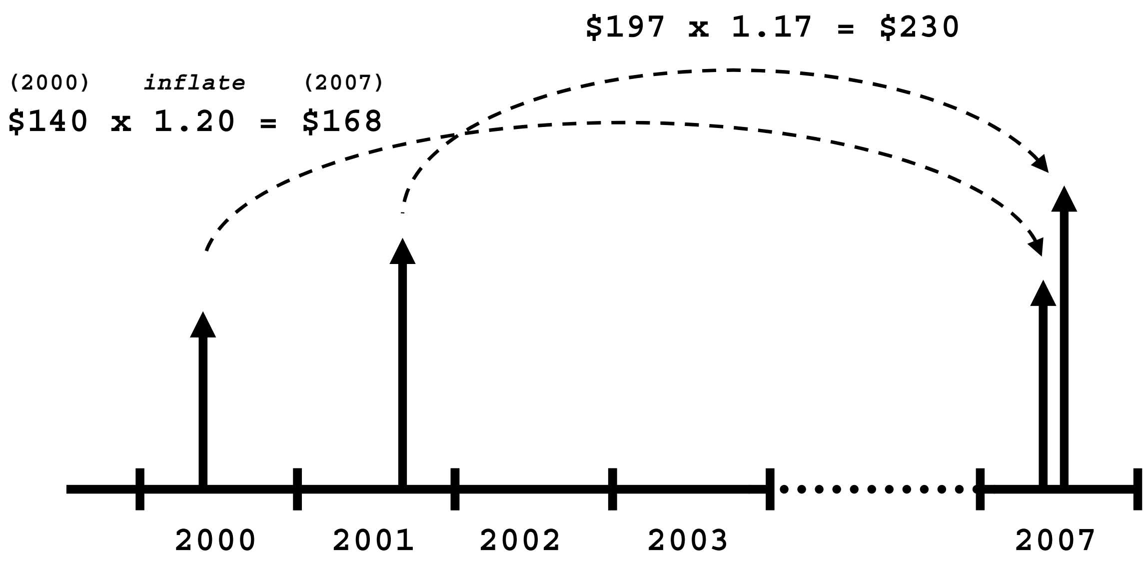
Cost inflation method

Due to the length of the survey, with some vehicles tracked for up to five years, a method was devised to place the cost of each order in 2007 dollars. It has been shown (e.g., Figure 17) that pre-mandate vehicles had more repair orders early in the timeframe, and lower costs for these vehicles could reflect lower prices at the earlier times. By placing all costs on a common baseline, the comparisons become more comparable – oranges-to-oranges, as opposed to, say, oranges-to-grapefruits.

Each order was placed in its relative position on the 0 to 1 scale, within fleet, as described in the section on calculating actual exposure. The maximum adjusted months was found for each fleet, i.e., the adjustment based on the first order but before calculating actual exposure based on both first and last order. This maximum value for each fleet is assumed to represent the time from the beginning to the end of the survey period. The maximum varies by fleet from 32 months (Fleet #9) to 65 months (Fleet #7). The survey timeframe is assumed to run until December 31, 2003, for all fleets, and the differences in age represent different starting points of data collection. Taking the product of relative order position and maximum fleet age, each order is placed into a year. The costs for each order are adjusted using the Consumer Price Index,[21] with 2007 as the baseline.[22]

Figure 28 shows the inflation calculation for two orders for the vehicle "TF433" from Fleet #2 (previously highlighted in Figure 26). The maximum *months* (not the *exposure*) for this fleet is 49. Counting backwards from December 31, 2003, the year 2000 corresponds to orders in the range 0.02 to 0.27, and orders in the year 2001 fall in the range 0.27 to 0.51. The first sample order for this vehicle has a relative *orderid* of 0.096 and is therefore placed in 2000; for the second sample, the positions are 0.458 and year 2001. Inflating to 2007 dollars, the total cost of the first order increases by 20 percent, to $168 from $140. The total cost of the second order increases by 17 percent, to $230 from $197. These calculations are performed on all relative components as well, e.g., brake costs are inflated at the order level from the approximated year of order to 2007.

Figure 28: Inflation of two orders to 2007 dollars



[21] Consumer Price Index, http://www.bls.gov/cpi/; calculations here are based on "All Items" for "All Urban Consumers," available at http://data.bls.gov/cgi-bin/surveymost?cu; accessed January 16, 2008.
[22] CPI data are provided with 1982-1984 as the baseline. To set the baseline to 2007, the given value for 2007 (207.3) is divided by the value for each year (e.g., 179.9 in 2002) such that earlier years have values greater than one (e.g., 1.1523 for 2002) which represents the inflation (e.g., 15.23% from 2002 to 2007).

To amortize expenses over a vehicle's lifetime, the method found in the 1995 Economic Assessment of FMVSS Nos. 105 and 121[23] is adapted. These calculations rely on two additional pieces of information: (1) survival probability of heavy vehicles, as a function of age; and (2) vehicle miles traveled, as a function of age. These data are available from (1) R.L. Polk & Co.'s vehicle registration counts (described in Appendix C); and (2) the Census Bureau's *Vehicle Inventory and Use Survey* (VIUS).[24] These values should provide accurate estimates of lifetime expenses for tractors. However, there is no such data available for trailers, and these same calculations are applied to both vehicle types. The method is presented so that it could be applied in the existence of data specifically for trailers, though at present, the simplest solution is to apply the tractor data.

Unfortunately, there is no data on the extent that vehicle maintenance and repair expenses vary by age. Though there are many scenarios, two counteracting forces can be at work: (a) vehicles incur more substantial repairs as parts age; and (b) younger vehicles are given greater care in the form of preventive maintenance. The extent to which these two factors neutralize each other can only be inferred by presenting several possibilities. In reality, the nature of vehicle maintenance is likely to vary by fleets, for example, due to the availability of capital to replace aging vehicles. It is also unclear how maintenance expenses vary with age for specific vehicle systems, which introduces further uncertainty in the reported values for the components of interest in this study.

Table 7 shows the annual cash-flow discount factors for amortizing maintenance and repair expenses across a vehicle lifetime, where the basis is $1 in year one. These values apply across a population of all vehicles, by incorporating survival probability. The values should therefore be interpreted in terms of a large number of vehicles, where some continue to accrue expenses over long time spans and others are decommissioned after several years.

[23] *Final Rules FMVSS Nos. 105 & 121, Stability and Control During Braking Requirements and Reinstatement of Stopping Distance Requirements for Medium and Heavy Vehicles*; February 1995. Accessible as FHWA-1997-2318-0022.
[24] *Vehicle Inventory and Use Survey*, 2002, U.S. Census Bureau, Service Sector Statistics Division; http://www.census.gov/svsd/www/vius/products.html

Table 7: Lifetime and Annual discount factors

Year	VMT	Survival	Survival-Weighted VMT	Scenario X: Per-mileage expenses constant			Scenario Y: Per-mileage expenses increase 10% annually		
	(1)	(2)	(1 x 2)	Raw	3%	7%	Raw	3%	7%
1	100,000	0.9995	99,950	1	0.9848	0.9663	1	0.9848	0.9663
2	90,000	0.9985	89,865	1	0.8597	0.8119	1.10	0.9456	0.8931
3	81,000	0.9953	80,615	1	0.7487	0.6807	1.21	0.9060	0.8237
4	72,900	0.9874	71,979	1	0.6490	0.5680	1.33	0.8639	0.7560
5	65,610	0.9747	63,951	1	0.5599	0.4717	1.46	0.8197	0.6905
6	59,049	0.9574	56,531	1	0.4805	0.3897	1.61	0.7738	0.6275
7	53,144	0.9354	49,713	1	0.4102	0.3202	1.77	0.7268	0.5673
8	47,830	0.9092	43,488	1	0.3484	0.2618	1.95	0.6790	0.5102
9	43,047	0.8790	37,840	1	0.2943	0.2129	2	0.5887	0.4258
10	38,742	0.8453	32,747	1	0.2473	0.1722	2	0.4946	0.3444
11	34,868	0.8083	28,184	1	0.2066	0.1385	2	0.4133	0.2770
12	31,381	0.7687	24,124	1	0.1717	0.1108	2	0.3434	0.2216
13	28,243	0.7270	20,532	1	0.1419	0.0881	2	0.2838	0.1763
14	25,419	0.6836	17,377	1	0.1166	0.0697	2	0.2332	0.1394
15	22,877	0.6392	14,622	1	0.0953	0.0548	2	0.1905	0.1096
16	20,589	0.5942	12,233	1	0.0774	0.0429	2	0.1547	0.0857
17	18,530	0.5491	10,175	1	0.0625	0.0333	2	0.1250	0.0666
18	16,677	0.5045	8,414	1	0.0502	0.0257	2	0.1003	0.0515
19	15,009	0.4608	6,916	1	0.0400	0.0198	2	0.0801	0.0396
20	13,509	0.4183	5,651	1	0.0318	0.0151	2	0.0635	0.0302
21	12,158	0.3774	4,589	1	0.0250	0.0115	2	0.0501	0.0229
22	10,942	0.3385	3,704	1	0.0196	0.0086	2	0.0392	0.0173
23	9,848	0.3017	2,971	1	0.0153	0.0065	2	0.0306	0.0130
24	8,863	0.2673	2,369	1	0.0118	0.0048	2	0.0237	0.0097
25	7,977	0.2353	1,877	1	0.0091	0.0036	2	0.0182	0.0072
26	7,179	0.2058	1,478	1	0.0070	0.0026	2	0.0139	0.0053
27	6,461	0.1789	1,156	1	0.0053	0.0019	2	0.0106	0.0038
28	5,815	0.1545	898	1	0.0040	0.0014	2	0.0080	0.0028
29	5,233	0.1326	694	1	0.0030	0.0010	2	0.0060	0.0020
30	4,710	0.1130	532	1	0.0022	0.0007	2	0.0045	0.0014
31	4,239	0.0957	406	1	0.0016	0.0005	2	0.0033	0.0010
32	3,815	0.0805	307	1	0.0012	0.0004	2	0.0024	0.0007
33	3,434	0.0673	231	1	0.0009	0.0003	2	0.0018	0.0005
34	3,090	0.0558	172	1	0.0006	0.0002	2	0.0013	0.0004
35	2,781	0.0460	128	1	0.0005	0.0001	2	0.0009	0.0002
36	2,503	0.0377	94	1	0.0003	0.0001	2	0.0007	0.0002
36+	2,253	0.0338	76	1	0.0003	0.0001	2	0.0005	0.0001
Sums	974,968		796,420		6.68	5.50		9.98	7.89

Several points of interpretation follow:

- A lifetime of 36 years was selected in accordance with the 2006 reported on light truck survival rates.[25] The1995 Economic Assessment used a lifetime of 25 years.
- Column (1) is the vehicle miles traveled (VMT), estimated from the Census Bureau's 2002 VIUS. The magnitudes are not used explicitly in any calculations, in part because the mileage in this study is not valid. These values *are* used in

[25] *Vehicle Survivability and Travel Mileage Schedules*; S. Lu, September 2006, DOT HS 809 952.

ratio form, based on decreasing mileage of 10 percent per year. Therefore, the value of 100,000 in year one is simply a baseline and could be listed as 1.0 or any other value.[26] Because of the way these mileage estimates are used, a rigorous analysis was not conducted.

- Column (2) is the survival probability. These estimates are based on tractor registrations from R.L. Polk & Co. The method is described in Appendix C. These values should be more accurate than those in the 1995 Economic Assessment, which were based on Polk data of light trucks rather than heavy trucks, and values found in the Transportation Energy Data Book,[27] which were adopted from a method of the Federal Reserve and may therefore define survival in financial terms. It is assumed that non-surviving vehicles accrue an average of one-half year of service during the year in which they are retired.
- The survival-weighted VMT (1 × 2) is the product of the two preceding columns. It accounts for both the decreases in mileage and survival across the universe of heavy vehicles.
- Two scenarios for the trend in maintenance and repair expenses are presented:
    - Scenario X assumes that the expenditure varies only in accordance with the miles traveled: the nature of repairs may change as vehicles age but mileage is the determinant of the expenses.
    - Scenario Y assumes that older vehicles require more costly maintenance and repairs as they age, to the order of 10 percent more per mile driven per year, up to the point where per-mile expenses are double that of a new vehicle. Because this is on a mileage basis and multiplied by the survival probability, the discount factors still decrease but do so less rapidly than in Scenario X.
        - In the Results section, it is shown that pre-mandate (i.e., older) vehicles have higher average monthly expenses. It is not possible to fully justify the selection of 10 percent because there is no way to know how many miles the vehicles were driven during the survey period, further complicated by knowing the true age of only *flag* 1 vehicles.
        - A rough analysis was conducted only on the *flag* 1 vehicles, by estimating the number of miles that would have been driven using the VIUS model of 10 percent decreases per year. The results suggest that tractors have increasing per-mile maintenance expenses as they age (Scenario Y), but trailers are relatively flat with respect to age (Scenario X).
- The column **Raw** shows the annual maintenance expenses per mile for those vehicles that survive.

---

[26] Flippancy should not be inferred from this statement: 100,000 miles in year one and 10 percent decreases thereafter produce a phenomenally strong fit for years 1 to 14. The empirical and modeled miles, summed across these years, differ by only 2 percent. These estimates use the unweighted miles in VIUS, which are not adjusted for partial-year operation of tractors. Therefore, the values reported here should more accurately represent the actual mileage driven as a function of age, rather than a weighted value which treats all vehicles as if they were in operation for the full year.

[27] *Transportation Energy Data Book: Edition 26*, 2007, Oak Ridge National Laboratory; http://cta.ornl.gov/data/index.shtml; survival probability found in Table 3-10.

- Discount factors of 3 percent and 7 percent are reported, as recommended by the Office of Management and Budget.[28]
- Discount factors represent the present value (PV) in 2007, where a new vehicle requires $1 of maintenance and repair expenses in year one.
    - The annual discount factors are calculated according to:

      $$PV = FV\,(1 + i)^{-n}$$

      where: FV is the future value of expenses
      i is the interest rate in decimal form, e.g., 3% = 0.03
      n is the mid-year time period, e.g., year 2 is 1.5.
    - Future values (FV) account for the survival probability and decreasing mileage with age (Scenario X), with these decreases somewhat offset by assuming greater expenditures with vehicle age (Scenario Y).
    - For example, the column for 3 percent interest is constructed as follows:
        - In year 1, the present value is $1 \times (1 + 0.03)^{-0.5} = 0.985$.
        - In year 2, the expenses have decreased 10 percent due to lower mileage, making the present value $0.90 \times (1 + 0.03)^{-1.5} = 0.861$.
        - When survival begins to decrease, i.e., after year 3, the present values are also multiplied by the survival, e.g., in year 10 the present value is $0.33949 \times (1 + 0.03)^{-9.5} = 0.256$.
        - When maintenance becomes more costly (Scenario Y), the values under Scenario X are increased by a compounded 10 percent, e.g., in year 10 maintenance expenses have increased by 10 percent nine times ($1.10^{9} = 2.36$), making the present value $0.256 \times 2.36 = 0.604$.
- The final row shows the sums across a 36-year lifetime.
    - For example, under Scenario X at 3 percent interest, the value of 6.68 means that a fleet would expect an investment of $668 to account for the maintenance and repairs of 100 vehicles.

[28] Circular A-4; http://www.whitehouse.gov/omb/circulars/a004/a-4.html,

Results

Expenses per month of exposure

Table 8 shows the average monthly maintenance expenses per vehicle, inflated to 2007 dollars.

Table 8: Monthly Maintenance Expenses per vehicle, expenses inflated to 2007 dollars at the order level (see also Figure 29 – Figure 33)

		No. of Vehicles	Total	Brakes	ABS	URG	Tape
Tractors	Pre-Mandate	675	$525	$35.52	$0.10	--	--
	Post-Mandate	1344	$499	$26.78	$0.85	--	--
Trailers	Pre-Mandate	1610	$151	$21.93	$0.08	$0.17	$0.37
	Post-Mandate	982	$143	$13.66	$0.25	$0.14	$0.19

Initial observations and comments:

- ABS: the average repair and maintenance costs specifically for ABS in post-mandate vehicles are $0.87 per month for tractors and $0.24 per month for trailers (inflated to 2007 economics). That is the principal finding of the analysis.
    - A small number of pre-mandate vehicles (4.0% of tractors, 3.9% of trailers) had repairs to the ABS system, and correct classification of these expenses was confirmed by inspecting the repair lines.
    - Comments from NHTSA engineers indicate that extremely few pre-mandate vehicles had ABS systems, and these percentages should be smaller. It could be that KRA mis-classified these vehicles, but there is no evidence to support that claim.
    - Earlier NHTSA studies[29] reported expenses of $1.25 per month for tractors[7] and $2.11 per month for trailers,[8] when prices are inflated to 2007 dollars. For tractors, the result of the present study is 32 percent lower. This could be due to differences in technology between in the approximately 10 years between surveys. However, the monthly expenses for trailers are substantially lower (88%), nearly an order of magnitude. It cannot be determined why the results are so discrepant between tractors and trailers.
- Brakes: a key question is whether the presence of ABS has increased maintenance or repair to brake components beyond those that are specifically ABS-related. The analysis shows that, in fact, overall brake repairs decreased from $35.52 to $26.78 per month in tractors and from $21.93 to $13.66 in trailers.
    - Based on these results, the presence of ABS clearly did not increase maintenance or repair to brake components beyond those that are specifically ABS-related. At the same time, there is no basis for concluding that these observed decreases are due to ABS, either. It is

[29] These comparisons refer to post-mandate vehicles, because it is not accurate to compare the averages for the pre-mandate units in this study when very few vehicles had ABS systems.

assumed that the addition of ABS to the overall brake system would not, in itself, lower maintenance and repair expenses. That is, the additional components would have their own direct expenses while potentially indirectly causing extra attention to be devoted to associated components. Further, because the ABS operation is not activated under normal braking conditions, the presence of the ABS system should not alter the normal wear-and-tear patterns to the brake system as a whole, which to a large extent contribute to the need for replacing and servicing brake parts. Therefore, the addition of ABS neither increased nor decreased maintenance or repair to brake components beyond those that are specifically ABS-related.

- Total repair and maintenance cost: The total monthly expenditure for repairs to all vehicle subsystems decreased from $525 in tractors to $499, and from $151 to $143 in trailers.
  - These reductions (except within the brake systems) are unlikely to be related to ABS. They presumably reflect that the post-mandate vehicles are newer on the average (in absolute age, not necessarily exposure months during the survey), therefore in better condition and less in need of repair. The newer vehicles would presumably accumulate greater mileage over a given time period (e.g., Table 7), making the differences even larger than what can be reported on a per-month basis.
- Brake repair as a proportion of total repair: the proportion decreased from 6.8 percent ($35.52 ÷ $525) in pre-mandate tractors to 5.4 percent in post-mandate. It decreased from 14.5 percent to 9.6 percent in trailers. This is further evidence that the addition of ABS did not result in an overall increase in brake repairs. At the other end, as with overall brake expenses, it is not plausible that the addition of the ABS system would be the cause of lower brake expenses as a percentage of the total.
  - This result is checked against the parts expenses. The proportion of brake parts expenses out of total parts expenses is 7.8 percent for pre-mandate tractors ($18.45 ÷ $242) and 5.5 percent for post-mandate tractors ($13.27 ÷ $233). For trailers, the proportions are 18.9 percent ($10.41 ÷ $53.67) for pre-mandate units and 13.4 percent ($5.97 ÷$39.77) for post-mandate units. These proportions are slightly higher than the proportions which included labor and service charges, but the conclusions are not changed – pre-mandate vehicles devote a larger proportion of their total expenses to the brake system compared to post-mandate vehicles, and trailers require relatively higher brake repair expenses compared to tractors.
- Underride guards: “pre-mandate” and “post-mandate” refer to the ABS mandate. Because underride guards were required both before and after the ABS mandate, repair costs are likely to be the same, except to the extent that pre-mandate trailers are older.
  - Maintenance and repair costs are 16 cents per month in trailers, combining “pre-mandate” and “post-mandate” averages.
  - This item is not applicable to tractors, as only the trailers are equipped with the guards.

- Conspicuity tape: here, too, "pre-mandate" and "post-mandate" refer to the ABS mandate; tape was required before and after. Because tape runs the length of the trailer, only a very small portion of the cost would be appropriate to allocate specifically to the URG.
  - In the older, pre-mandate trailers, cost for replacing worn-out tape averaged 37 cents per vehicle per month.
  - Cost in post-mandate trailers was smaller because few were old enough for the original tape to have worn out.
  - Tractors do not require sufficient lengths of tape to be applicable to this survey.

Figure 29: Monthly total expenses per vehicle, by type/mandate

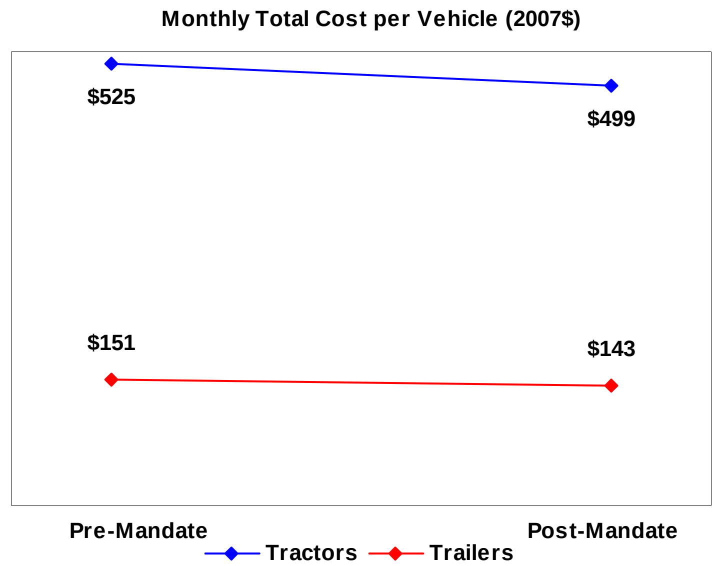


Figure 30: Monthly brake expenses per vehicle, by type/mandate

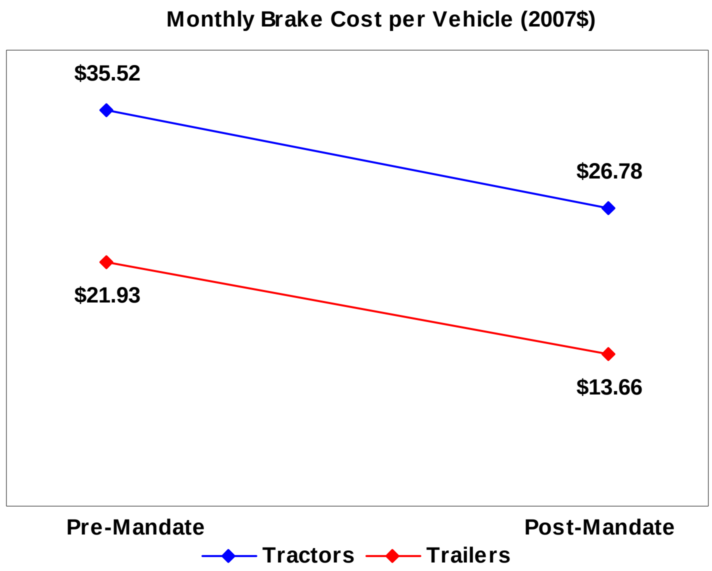


Figure 31: Monthly ABS expenses per vehicle, by type/mandate

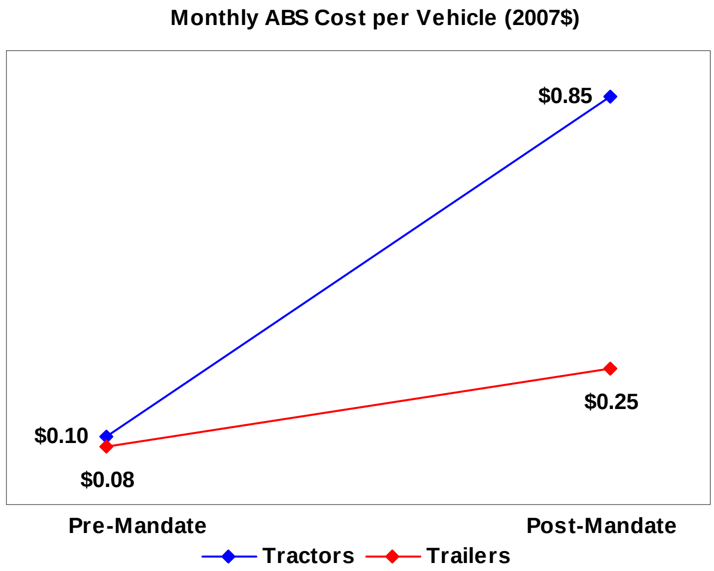


Figure 32: Monthly underride guard expenses per vehicle, by type/mandate

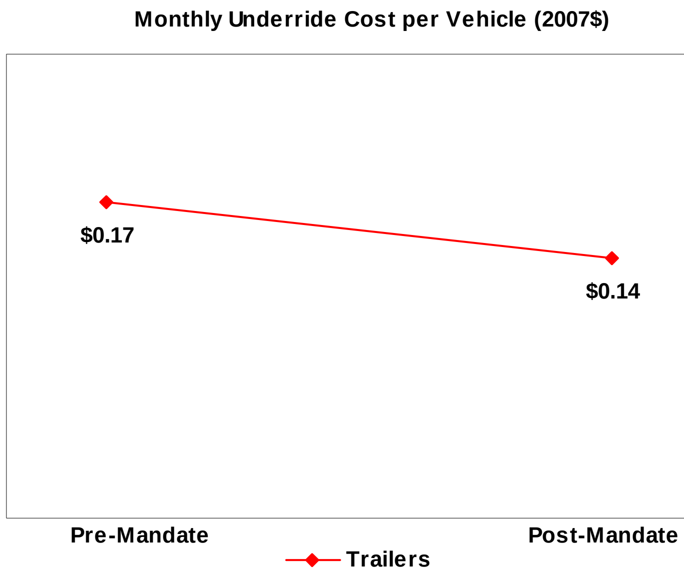


Figure 33: Monthly conspicuity tape expenses per vehicle, by type/mandate

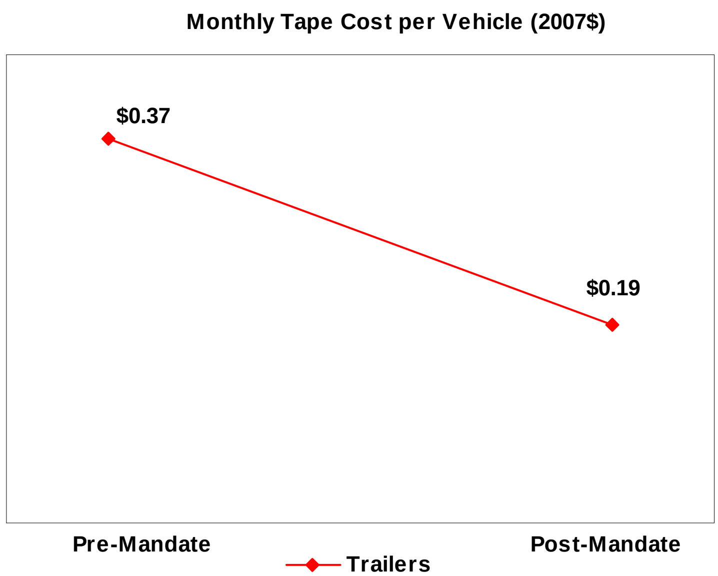
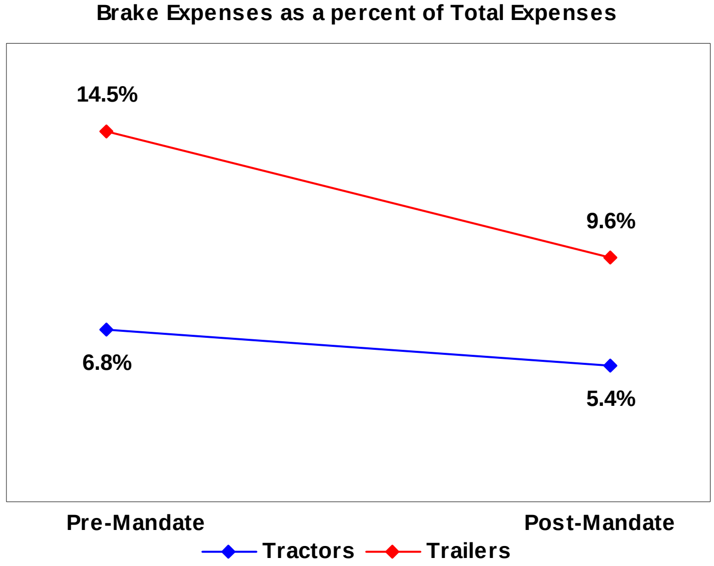


Figure 34 shows the average brake expenses per vehicle as a percentage of the total maintenance expenses. Although Figure 30 showed that both brake and total expenses are lower for post-mandate vehicles, it could still be the case that the presence of the ABS system leads to increased brake expenses compared to the total expenses. Here, this is seen not to be the case, where post-mandate units devote a lower percentage of their total expenses to brake repairs.

Figure 34: Monthly brake expenses as a percentage of total monthly expenses, by type/mandate



In reviewing the repair lines for orders with ABS charges, it was noted which component required repairs. Repair lines were classified as pertaining to the ECU, wheel sensor, or warning light. Items classified as "Others" are secondary components of the ABS system (e.g., valves and wires) or else were described too vaguely in the database to allow classification (e.g., "CHECK ABS"). A small number of orders listed repairs to two different components, and these are counted in each column.

Table 9 shows the number of orders per 100 vehicles on an absolute scale (i.e., not normalized on a monthly basis) for each of the ABS components. Compared to trailers, tractors required more frequent repairs to the wheel sensors and ECU. Trailers more often required repairs of the warning light. In sum, the total number of items requiring repair is similar for tractors (21.0 per 100 vehicles) and trailers (19.3).

Table 9: Nature of ABS repairs (number of orders per 100 vehicles)

		Wheel Sensor	ECU	Warning Light	Others	Total
Tractors	Pre-Mandate	1.2	0.6	0.3	1.3	3.4
	Post-Mandate	7.4	4.2	5.3	4.1	21.0
Trailers	Pre-Mandate	0.9	0.1	1.6	2.2	4.8
	Post-Mandate	3.5	0.3	8.8	6.8	19.3

Lifetime expenses

Table 10 shows the estimated lifetime maintenance and repair expenses for the ABS system. As described in the Methodology section (Table 7, page 44), there are two values used to discount the cash flow and two scenarios for the variation in maintenance expenses with age. The discount rates of 3 percent and 7 percent were selected as recommended by the Office of Management and Budget.[28] The maintenance expenses under *Scenario X* remain constant on a per-mile basis, while under *Scenario Y* the per-mile expenses increase 10 percent per annum until they are double the initial costs. The combination of Scenario Y with a 7 percent discount rate is the best single estimate,[30] but all values are displayed to provide a range.

Table 10: Lifetime ABS maintenance & repair, net present value (2007 dollars)

	Discount Rate	Scenario X	Scenario Y
Tractors	3%	$68	$102
	7%	$56	$81
Trailers	3%	$20	$30
	7%	$16	$24

Table 11 combines the lifetime maintenance and repair expenses (column B) to the consumer costs (column A) cited in an earlier NHTSA report.[9] The ranges in column B represent the least-costly (Scenario X at 7%) and most-costly (Scenario Y at 3%) combination present in Table 10. All values are in 2007 dollars. The final column (B÷A) is the percentage that maintenance and repair add to the consumer cost. The bottom row represents the purchase of a tractor and trailer in combination, including the connection, which was not analyzed in the current study.

Table 11: Comparison of maintenance & repair expenses to consumer cost for the ABS system (2007 dollars)

	(A) Consumer Cost	(B) Maintenance & Repair	(A+B) Total	(B÷A)
Tractor	$639	$56 – 102	$695 – $741	9% – 16%
Trailer	$513	$16 – 30	$529 – $543	3% – 6%
Connection	$112	--	$112	--
Total	$1,264	$82 – $132	$1,346 – $1,396	6% – 9%

The most accurate lifetime maintenance and repair expenses for the underride guard are $18, based on all trailers combined, i.e., there is no reason why classification as "pre-mandate" or "post-mandate" in this study would make a difference in expenses. This value could range from $14 to $20, for the different discount rates and scenarios as presented for the ABS system. The lifetime expenses for conspicuity are estimated as $35, ranging from $24 to $44. This is based on the pre-mandate trailers, because the post-mandate trailers would be unlikely to have accumulated a great deal of wear and tear in (at most) six years of use. The consumer costs have not been evaluated by NHTSA.

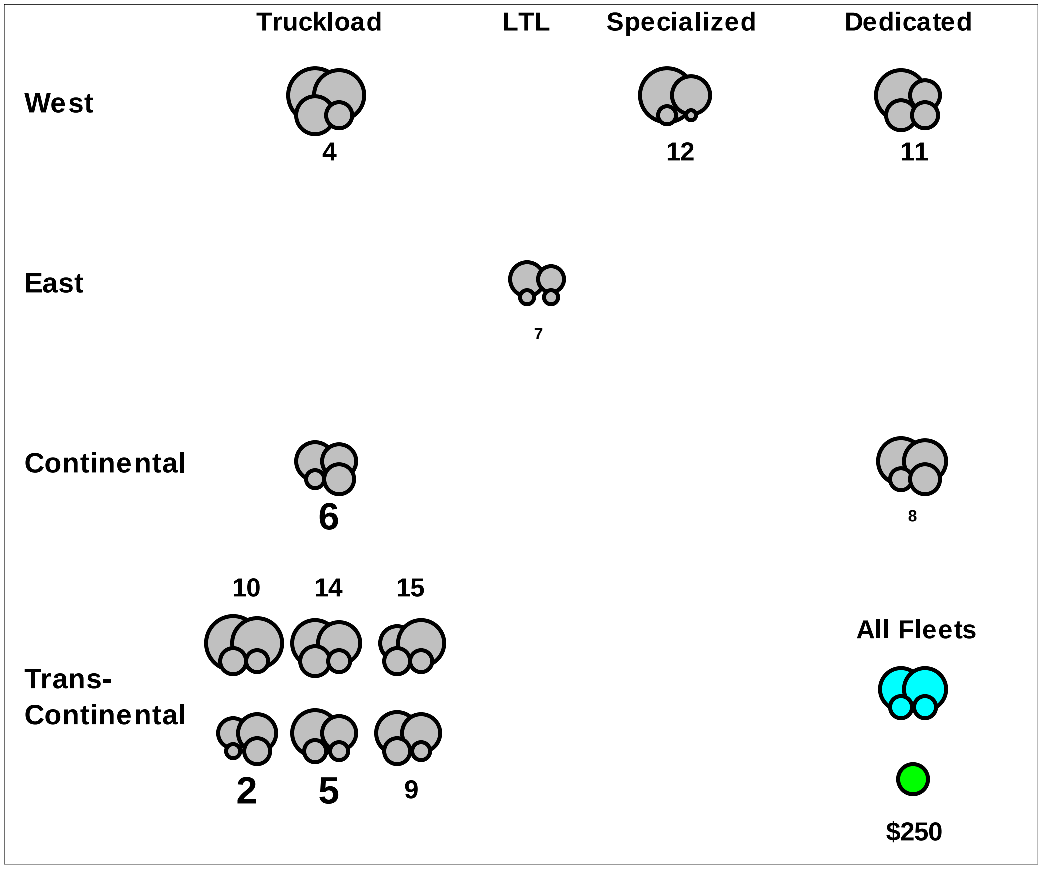
[30] Pre-mandate vehicles in this study had higher average monthly costs and were likely driven fewer miles during the timeframe, as suggested by VIUS. The 7 percent interest rate represents the average pre-tax return on investment in the private sector and is used as the standard value in most financial analyses. See, for example, §7.d of the FHWA's *Procedural Guidelines for Highway Feasibility Studies*; http://www.fhwa.dot.gov/hep10/corbor/feastudy.html

Fleet differences

From the outset, it was acknowledged that fleets vary in vehicle-type composition[31] and potentially in vehicle use and maintenance policies. In this section, the validity of the results with respect to type and mandate is assessed to ensure that results are consistent within each fleet. Figure 35 portrays the average monthly total maintenance per vehicle. Each family of bubbles is one fleet, with pre-mandate units to the left and tractors to the top, as are most charts throughout the report. Three fleet characteristics are depicted according to KRA's classification: scope, vocation, and size (the latter represented by the font size of the *fleetid* label). The lower right family represents the average across all fleets, and the "$250" bubble is included for size reference.

[31] Refer to Table 1 on page 9.

Figure 35: Monthly total expenses per vehicle, by type/mandate, classified by Fleet according to vocation, scope, and size



How to read this figure:

- The summary statistic is the mean monthly maintenance cost per vehicle.
  - The area of each bubble is proportional to the cost.
- Each fleet is represented by a set of four bubbles.
  - The lower pair are trailers; the upper pair are tractors.
  - The left-side pair are pre-mandate; the right-side pair are post-mandate.
- The mean across "All Fleets" is included at the bottom right.
  - The bubble "$250" provides scale.
- Fleet numbers are listed above or below each fleet.
- Three fleet characteristics are depicted, as defined by NAMDX:
  - *Scope* is the vertical classification (West, etc.).
  - *Vocation* is the horizontal classification (truckload, etc.).
  - *Size* is represented by the font size of the fleet number (small, medium, large).

Figure 35 simply illustrates that differences exist between fleets. Without knowledge of the operating conditions and maintenance procedures for these twelve fleets, it is not possible to form conclusions about the reasons for this variability. The small number of fleets is insufficient to draw conclusions with respect to scope, vocation, and size. For example, Fleet 7 is the only eastcoast and the only less-than-load fleet, and it is one of only two small fleets (along with Fleet 8). Inferences drawn in regards to these classifications would be unable to unravel whether differences between Fleet 7 and others are due to scope, vocation, size, or simply idiosyncrasies in that fleet's maintenance policies.

The differences in fleet composition could give rise to Simpson's Paradox.[32] This occurs when the directionality of overall means differs from the directionality of individual group means. For example, a basketball coach wants to know which of two players is a more accurate shooter. The number of shots converted and attempted are shown in Table 12 for two games. Player B made a higher percentage of his shots in each game, while Player A made a higher percentage overall. Each player also made 40 percent more of his shots in Game 2 compared to Game 1. The grouping variable "Game" invokes differing weights (i.e., the number of shots taken) in computation of the total average.

Table 12: Illustration of Simpson's Paradox

	Game 1	*Game 2*	*Total*
Player A	5 of 10 (50%)	18 of 20 (90%)	**23 of 30 (77%)**
Player B	**12 of 20 (60%)**	**10 of 10 (100%)**	22 of 30 (73%)

The intent here is not to determine where Player A or Player B is a better shooter. Such a decision could rest on other factors, such as the quality of teams played in Game 1 and Game 2. Context and subject matter knowledge are crucial. The example merely illustrates the arithmetical possibility of Simpson's Paradox.

For the present analysis, differences in fleet means (Figure 35) and type × mandate composition (Table 1) could give rise to Simpson's Paradox. Table 13 shows how this might occur, simplified to the case of one vehicle type for two fleets. The data are average monthly total maintenance expenses. Each fleet has a higher average for post-mandate vehicles, while the overall average is higher for pre-mandate vehicles. The disparate conclusions arise from differences in number of vehicles.

Table 13: Hypothetical case of Simpson's Paradox

	Fleet A	Fleet B	Total
Pre-Mandate	$400 (400)	$200 (100)	**$360 (500)**
Post-Mandate	**$500 (100)**	**$300 (400)**	$340 (500)

For the real data, the combined data across fleets (Table 8 and Figure 29) showed that pre-mandate vehicles had higher total monthly costs than post-mandate vehicles and that tractors had higher costs than trailers. From lowest to highest, the data were ranked (1) post-mandate trailers, (2) pre-mandate trailers, (3) post-mandate tractors, and (4) pre-mandate trailers. It is important that this pattern hold across fleets, illustrated in Figure 36. There are four sets of blocks, each containing the within-fleet rank of average by type × mandate. Each set contains 12 digits, corresponding to the 12 fleets. Critically, the rank-orders within fleet show few exceptions to the overall pattern. Ideally, each block would have the same digit occurring throughout (e.g., all 4 in the upper left for pre-

[32] http://en.wikipedia.org/wiki/Simpson's_paradox

mandate tractors). The differences are fortunately minimal, implying that the grouping variable “Fleet” does not give rise to Simpson’s Paradox.

Figure 36: Rank orders of total expenses per month, by fleet (4 = highest)

4	4	4	3	2	3	3	4
4	4	4	4	3	3	3	3
3	4	4	4	4	3	3	3
Pre-Mandate Tractors				**Post-Mandate Tractors**			
Pre-Mandate Trailers				**Post-Mandate Trailers**			
3	2	2	2	1	1	1	1
2	1	2	2	1	2	1	1
1	2	2	1	2	1	1	2

The fleet rank orders for brake expenses per month (Figure 37) and brake expenses as a percentage of total expenses (Figure 38) are not as consistent as those for total expenses per month. This is in part due to the fact that post-mandate tractors had only slightly higher monthly brake expenses than pre-mandate trailers (Figure 30), though this comparison is not one of particular interest.

Figure 37: Rank orders of brake expenses per month, by fleet (4= highest)

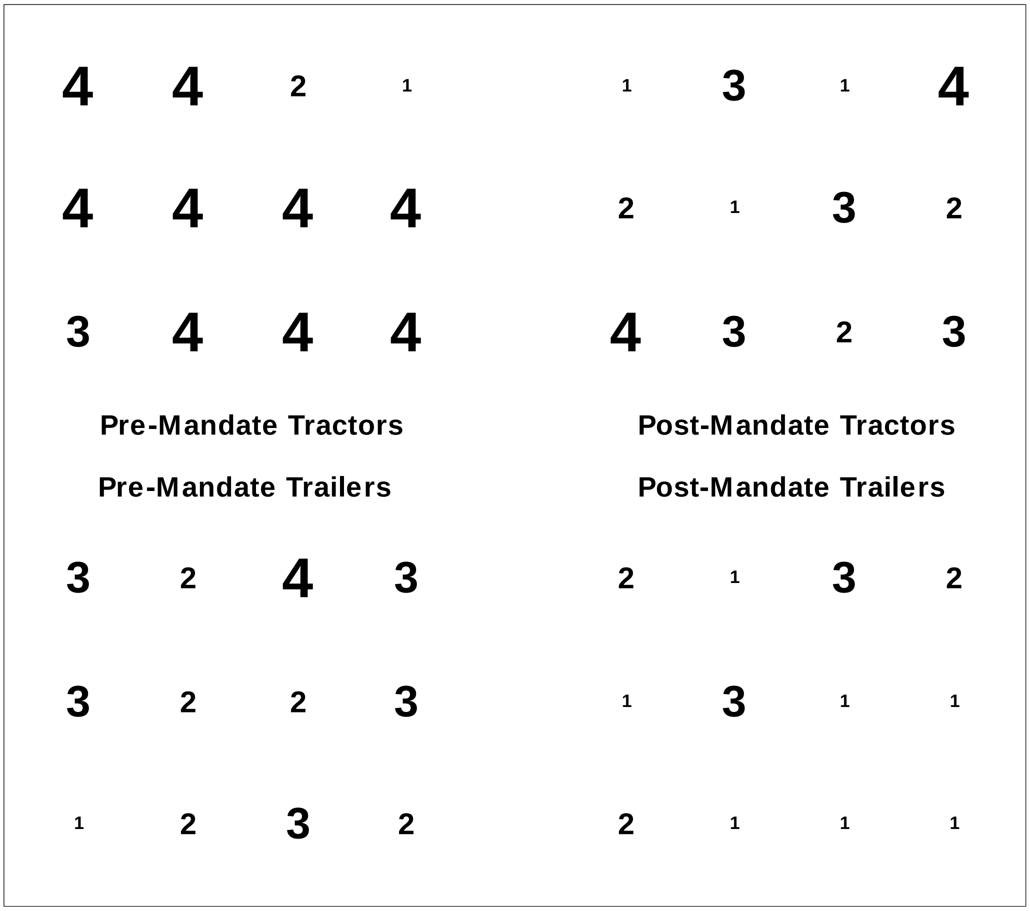
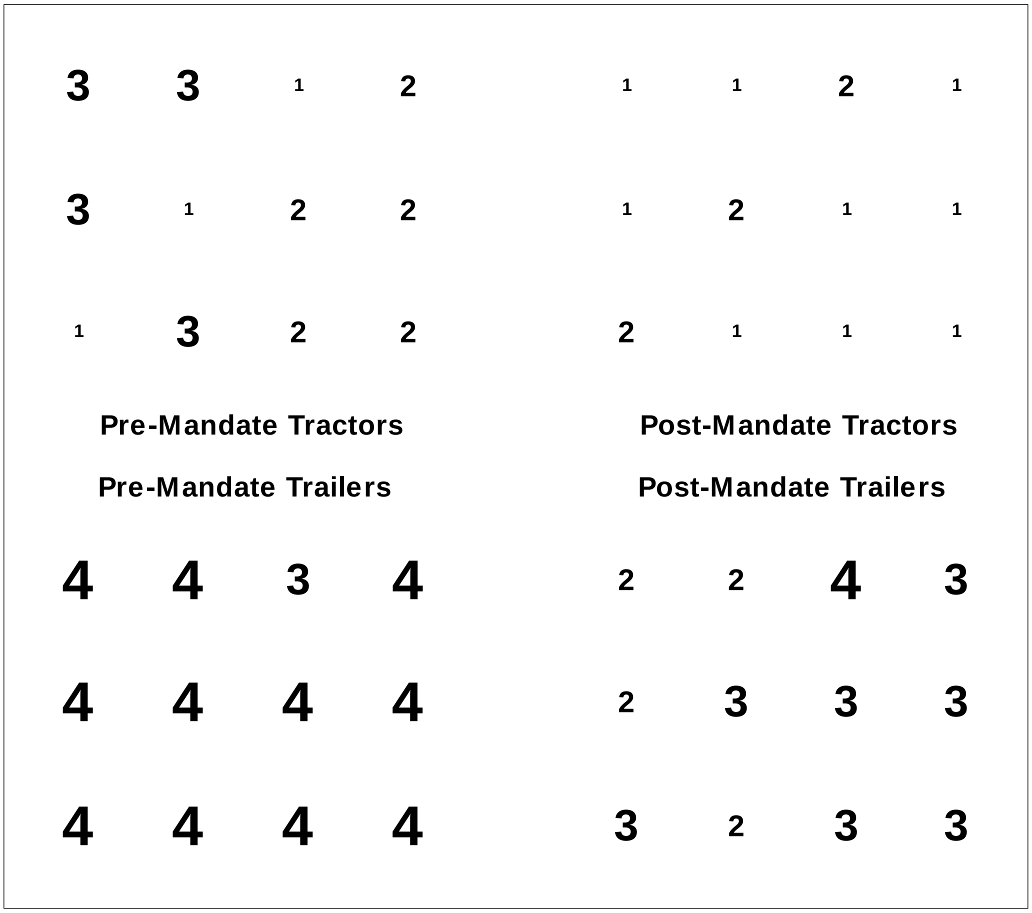


Figure 38: Rank orders of brake expenses as a percentage of total expenses, by fleet (4= highest)



The patterns in the above figures can be tested statistically using the exact binomial test.[33] For each vehicle type, a tally is made of the number of fleets where the post-mandate costs are lower than the pre-mandate costs. The tallies are compared to an expectation of 50 percent (6 out of 12), equivalent to flipping a fair coin. The *p*-value is a quantitative assessment of the strength of the evidence against the 50 percent assumption. A result of 10 out of 12 is significantly different from 50 percent at the generally accepted level of $\alpha < 0.05$, while 9 out of 12 can be considered marginally significant at $\alpha < 0.10$.

Table 14 shows the results of the exact binomial test based on the rank-order of expenses within each fleet. Four of the six metrics indicate lower expenses for post-mandate vehicles at a statistically significant level of $\alpha < 0.05$, while the other two metrics are marginally significant at $\alpha < 0.10$. Taking the “total per month” for tractors as an example, the results are interpreted as follows – the post-mandate vehicles had lower expenses than the pre-mandate vehicles in 10 of the 12 fleets, and this occurrence is

[33] A binomial calculator can be found at http://www.stat.tamu.edu/~west/applets/binomialdemo.html

unlikely compared to an assumption that expenses should be equal for pre-mandate and post-mandate tractors.

Table 14: Summary of fleet rank-order statistical tests (based on 12 total fleets)

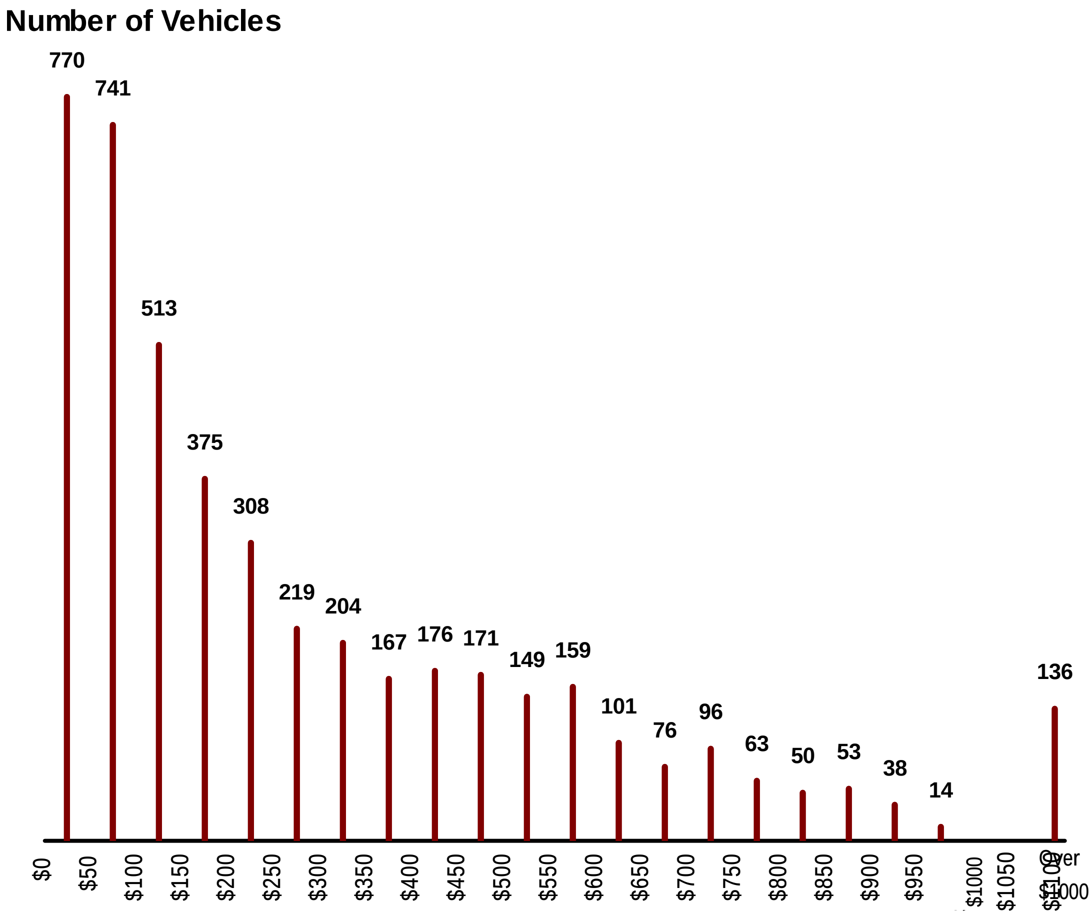
	Metric	Post-Mandate Lower	Binomial Test *p*
Tractors	Total per month	10	0.0193
	Brake per month	10	0.0193
	Brake as % of Total	9	0. 0730
Trailers	Total per month	9	0.0730
	Brake per month	10	0. 0193
	Brake as % of Total	11	0. 0032

Inferential analysis of cost differences

This section describes an inferential analysis of the total cost per month, brake cost per month, and brake cost as a percent of total cost. The intent is to demonstrate whether the differences between pre-mandate and post-mandate vehicles are statistically significant.

Because the costs are positively-skewed, standard statistical methods based on parametric assumptions may be invalid. Figure 39 shows a histogram of the monthly total cost per vehicle. The distributions for brake costs per month and brake cost as a percentage of total cost have distributions of the same general shape.

Figure 39: Histogram of monthly total cost per vehicle



How to read this graph:

- Monthly total cost per vehicle is counted in bins of $50, e.g, the 2nd bar represents $50 to $100.
- The number atop each bar is the frequency of vehicles in that bin.
- Bins extend consecutively up to $1000 per vehicle.
- The rightmost bar represents vehicles with costs above $1000. The extra spacing is stylistic and does not imply empty bins.

A non-parametric procedure was developed to mitigate violations of distributional assumptions. The ability to control for fleet differences is desirable as well (Figure 35). The procedure is as follows:

1. All vehicles are ranked according to total cost per month. In the rare event of ties, the mean rank is used (e.g., a tie at positions 500 and 501 would assign 500.5 to each vehicle).
2. On the ranked data, ANOVA is conducted. The model includes *type*, *mandate*, the *type-mandate* interaction, and *fleetid*. In SAS, *proc glm* is used.
3. The least-squared means (*lsmean*) are requested for *type* × *mandate*, controlling for *fleetid*. This essentially gives a “mean of the means” based on fleet averages for each *type* × *mandate*, rather than the grand means.

4. The *lsmean* for each type-mandate combination is back-mapped to the un-ranked total costs. For example, an *lsmean* of 1,000 would be mapped to the vehicle with the 1,000th highest total cost, ignoring type and mandate.

Table 15 and Table 16 summarize the overall model effects for total and brake costs. Other sub-costs are not presented because the excess of zeroes make the data too skewed.

Table 15: Model results for total Cost per month

Source	**F (*df1, df2*)**	***p***
Fleet	109 (11, 4595)	< 0.0001
Type	2,943 (1, 4595)	< 0.0001
Mandate	112 (1, 4595)	< 0.0001
Type × Mandate	3.7 (1, 4595)	0.055

Table 16: Model results for brake Cost per month

Source	**F (*df1, df2*)**	***p***
Fleet	107 (11, 4595)	< 0.0001
Type	393 (1, 4595)	< 0.0001
Mandate	355 (1, 4595)	< 0.0001
Type × Mandate	40 (1, 4595)	< 0.0001

Table 17: Model results for brake Cost as a percentage of total Cost

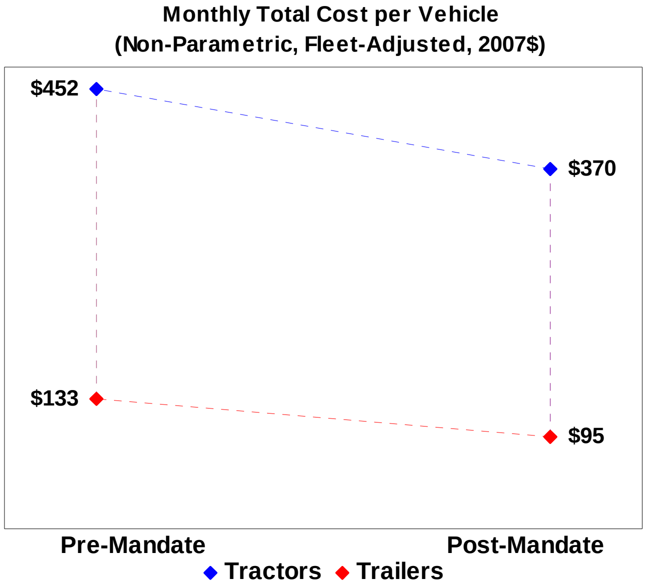
Source	**F (*df1, df2*)**	***p***
Fleet	51 (11, 4595)	< 0.0001
Type	86 (1, 4595)	< 0.0001
Mandate	238 (1, 4595)	< 0.0001
Type × Mandate	49 (1, 4595)	< 0.0001

All effects are highly significant, with $p < 0.0001$ for all cases except the interaction on total Cost ($p = 0.0019$). Because the type × Mandate interactions are significant, cell means (adjusted for fleet) are compared. There are six possible comparisons, based on four combinations of vehicle and mandate. Therefore, use of the standard $\alpha = 0.05$ for comparisons will inflate the overall error rate. Only four comparisons are of interests, out of the possible six, because there is no need to compare across type and mandate (e.g., do not compare pre-tractors to post-trailers). The formula below is used to calculate an appropriate alpha level. The solution is 0.0127.

$$1 - (1 - \alpha)^{4} = 0.05$$

Figure 40 and Figure 41 summarize the findings of this analysis for total and brake costs. The ranking procedure reduces the scale, more akin to an analysis on medians rather than means. The patterns for both total and brake costs are similar to those for raw averages (*cf*. Figure 29 and Figure 30), with the differences slightly more pronounced here. All differences of interest are statistically significant ($p < 0.0127$), represented by dashed lines rather than solid lines to signify statistical inequality.

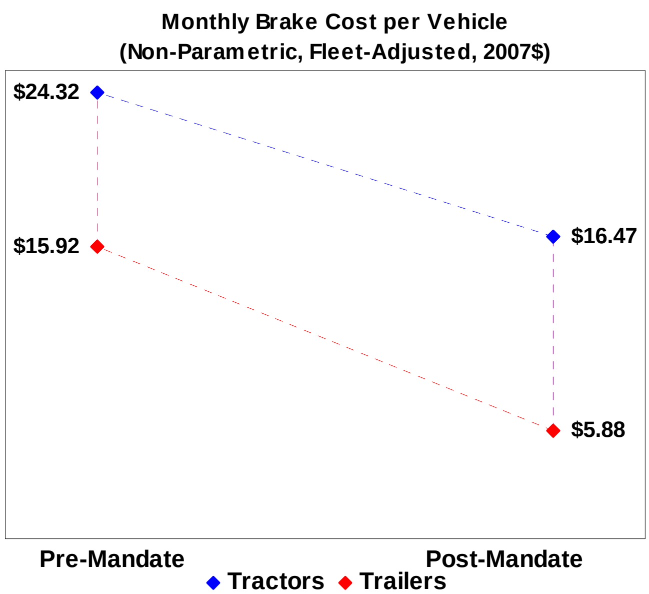
Figure 40: Fleet-adjusted non-parametric monthly total cost per vehicle (2007$)



How to read this graph:

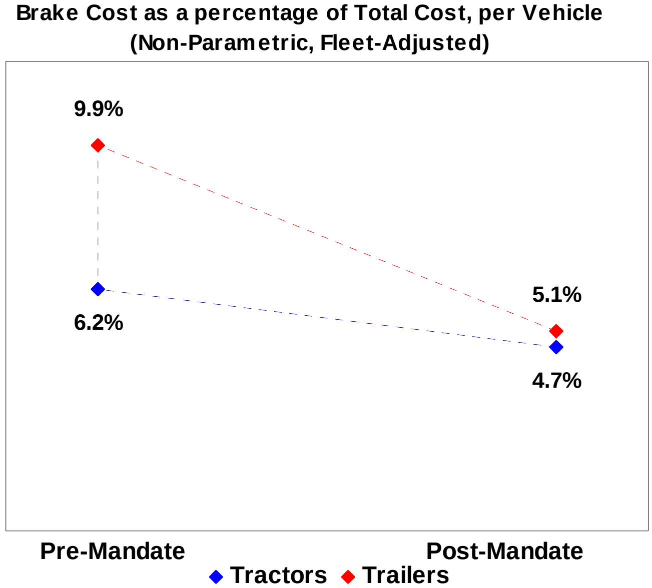
- Analysis is performed on the ranked data, as described on page 61.
- Reported values are the fleet-adjusted least-squared means from *proc glm* in SAS.
- Comparisons of interest are connected by dashed lines, representing significant differences.
- Comparisons are not made across the type-mandate combinations (i.e., do not compare pre-tractors to post-trailers, and vice versa).
- The ranking procedure reduces the magnitudes, compared to the means.

Figure 41: Fleet-adjusted non-parametric monthly brake cost per vehicle (2007$)



The analysis conducted on brake costs as a percentage of total cost (Figure 42) leads conclusions in the same manner as analysis of costs per month. Again, post-mandate vehicles have lower values. The difference here, as in Figure 34, is that trailers require a higher percent of their maintenance and repair expenses for brakes, because the total expenses for trailers is so much lower than for tractors.

Figure 42: Fleet-adjusted non-parametric brake cost as a percentage of total cost



Appendix A
VRMS codes

A.1 Vehicle systems

First section of codes, often given in 2-digit format (e.g., 001 is the same as 01) from http://www.truckrealm.com/vmrs.htm

Cab, Climate Control, Instrumentation and Aerodynamic Devices
001 Air Conditioning, Heating, and Ventilating System
002 Cab and Sheet Metal
003 Instruments, Gauges (All), and Meters
004 Aerodynamic Devices

Chassis
011 Axles Front—Non-Driven
012 Axles Rear—Non-Driven
013 Brakes
014 Frame
015 Steering
016 Suspension
017 Tires
018 Wheels, Rim, Hubs, and Bearings
019 Automatic Chassis Lubricator

Drivetrain
021 Axle Driven—Front Steering
022 Axle Driven—Rear
023 Clutch
024 Drive Shaft(s)
025 Power Take Off
026 Transmission—Main, Manual
027 Transmission—Main, Automatic
028 Transmission—Auxiliary and Transfer Case
029 Auxiliary Section (Transmission—Main, Manual)

Electrical
031 Charging System
032 Cranking System
033 Ignition System
034 Lighting System

Engines
Code System
041 Air Intake System
042 Cooling System
043 Exhaust System
044 Fuel System
045 Power Plant
046 Electric Propulsion System
047 Filter Kits (Multi-Piece)

Accessories
051 General Accessories (for power units, trailers, etc.)
052 Electrical Accessories (for power units, trailers, etc.)
053 Expendable Items (for power units, trailers, etc.)
054 Horns and Mounting and Reverse Signal Alarms
055 Cargo Handling, Restraints and Lift Systems (for power units, trailers, etc.)
056 Power Take Off
057 Spare Wheel Mounting
058 Winch (for power units, trailers, etc.)
059 Vehicle Coupling

Special Applications
061 Terminal Equipment Systems and Accessories
065 Hydraulic Systems

Bodies and Vessels
071 Body (except bulk carrier body)
072 Rear Wall and Door
073 Tank Vessel, inner shell
074 Tank Vessel, outer jacket
075 Manholes
076 Rings and Bolsters
077 Trailer Frame and Support
078 Trim and Miscellaneous Hardware
079 Safety Devices

Heating and Refrigeration
081 Heating Unit (for power units, trailers, etc.)
082 Refrigeration, Mechanical (for power units, trailers, etc.)
083 Refrigeration, Nitrogen (for power units, trailers, etc.)
084 Refrigeration, Holdover Plate (for power units, trailers, etc.)

Bulk Product Transfer Systems
091 Blowers, Conveyors, and Vibrators (for power units, trailers, etc.)
092 Compressor, Bulk Product Systems (for power units, trailers, etc.)
094 Engine, Auxiliary (for power units, trailers, etc.)
095 Manifold (for power units, trailers, etc.)
096 Power Shaft (for power units, trailers, etc.)
097 Pump (for power units, trailers, etc.)
098 Valves and Controls (for power units, trailers, etc.)
099 Safety Devices, Instruments and Gauges (for power units, trailers, etc.)

A.2 Brake Components

Second section of code for 013 Brakes
(most common description occurrences in repair-line file)

13-001	FRONT BRAKES & DRUMS
13-002	REAR BRAKES & DRUMS
13-003	PARKING BRAKES
13-004	BRAKE CHAMBER
13-005	<uncertain> (13-005-001 is BEARING; all others low frequency)
13-006	MASTER CYLINDER

13-007	BRAKE LINES & FITTINGS - HYDRAULIC & AIR
13-008	(infrequent; subcodes indicate valves or hoses)
13-009	AIR COMPRESSOR
13-010	SEAL-GLAD HAND
13-011	<ABS-related; see below>
13-012	BRAKE KIT (several variants)

A.3 ABS assemblies

Third section of code for 013-011 ABS subsystem
(items **BOLD** are those most common)

13-011-001	BRAKE ROTOR
13-011-002	**ABS SENSOR**
13-011-003	BRACKET – SENSOR
13-011-004	CABLE
13-011-007	SWITCHES
13-011-009	CLIP - ABS SENSOR
13-011-066	RELAY - ELECTRICAL ANTILOCK
13-011-067	SENSOR LOCK
13-011-068	**ABS RELAY VALVE**
13-011-069	CONTROLLER - ELECTRONIC ANTILOCK
13-011-070	CABLE – ABS
13-011-071	ABS MOD VALVE and VALVE ECU ABS
13-011-072	VALVE
13-011-073	**SENSOR - ABS**
13-011-076	**ELEC. CONTROL UNIT** (or similar)
13-011-077	TRACTION CONTROL VALVE
13-011-078	SWITCHES (shortened)
13-011-079	**ABS LIGHT**
13-011-080	CONNECTOR - ELECTRICAL SPEED SENSOR
13-011-096	HARNESS-MODULATOR VALVE
13-011-107	RELAY VALVE or DASH VALVE
13-011-108	RELAY VALVE

Appendix B
Probability of Survival

Two sources for vehicle survival were uncovered: (1) the 1995 Economic Assessment[23] used values derived from R.L. Polk & Co. data, but these were based on light trucks; and (2) the Transportation Energy Data Book[27] based its data on a method derived from the Federal Reserve for determining scrappage rates, which might be based on financial calculations rather than the actual number of vehicles in service.

A method was devised to determine a more accurate survival timeline for the vehicles in this study. Data from Polk were used here, except that they were specifically filtered to include only tractors. Polk reports the number of registered vehicles by make, model, and model year, among other variables. The annual survey is a snapshot on July 1 of the respective year. Due to timing of model-year production and sales of vehicles, there is lag in vehicles entering the registration database. For example, the survey year 2005 contains counts of model years up to 2006. However, the counts for 2005 and 2006 are not usable because of time involved in the production-sale-registration process. The most recent model year, therefore, with valid counts from the 2005 survey would be 2004. The survey year 2005 thus becomes the baseline (age 0) for model year 2004 vehicles (114,501 in number). The 2006 survey then gives the number of 2004 model year vehicles surviving to year 1 (110,486). The year-to-year ratio is the survival estimate to year 1 (110,486 ÷ 114,501 = 0.965).

Survival probabilities are calculated on a moving basis. That is, each annual rate is determined, e.g., years 1-to-2, years 2-to-3, 3-to-4, etc. These are conditional probabilities, i.e., the probability of surviving to year $N+1$ **given that** the vehicle was present in year N.

The Polk survey years from 1997 to 2006 were used (there may have been a change in methodology from earlier years, because 1996 counts appear too high in some instances). Each annual survival rate thus has nine values. For example, survival from year 1-to-2 can be calculated using model years 2003 (ratio of 2006 to 2005 survey counts) down to 1995 (ratio of 1998 to 1997 counts). The nine values are averaged and become the estimate of the survival probability from year N to $N + 1$.

Model year counts are available back to 1975. This gives a maximum vehicle age of 30 years, using the ratio of 1975 model year counts from the 2006 survey to that of the 2005 survey. However, the advanced ages have fewer estimates to use in the average. In the case of 30 years, there is only this one estimate. For age 29, there are two estimates, etc. For all ages below 23, nine values are used in the average. Calculating survival probability up to year 25 is reasonable, though further extensions are purely model-based (discussion forthcoming).

To determine the probability of a vehicle surviving through year X, the individual year-to-year probabilities are multiplied up to and including year X. For example, the probability of a tractor surviving through year 10 is the product of survival from year 0-

to-1, 1-to-2, …, 9-to-10. This method is compatible with that used in epidemiology for construction of a life table,[34] for example, as the CDC reports for the human life expectancy,[35] such as in Table 18. The outcome of the present analysis is to produce this same type of table for tractors.

Table 18: Life Table for humans, reproduced from CDC data

Age	Probability of dying between ages x to x+1	Number surviving to age x	Number dying between ages x to x+1	Person-years lived between ages x to x+1	Total number of person-years lived above age x	Expectation of life at age x
	q(x)	l(x)	d(x)	L(x)	T(x)	e(x)
0-1	0.006865	100,000	687	99,394	7,743,016	77.4
1-2	0.000469	99,313	47	99,290	7,643,622	77.0
2-3	0.000337	99,267	33	99,250	7,544,332	76.0
3-4	0.000254	99,233	25	99,221	7,445,082	75.0
4-5	0.000194	99,208	19	99,199	7,345,861	74.0
5-6	0.000177	99,189	18	99,180	7,246,663	73.1
6-7	0.000160	99,171	16	99,163	7,147,482	72.1
7-8	0.000147	99,156	15	99,148	7,048,319	71.1
8-9	0.000132	99,141	13	99,134	6,949,171	70.1
9-10	0.000117	99,128	12	99,122	6,850,036	69.1
10-11	0.000109	99,116	11	99,111	6,750,914	68.1
11-12	0.000118	99,105	12	99,100	6,651,803	67.1
12-13	0.000157	99,094	16	99,086	6,552,704	66.1
13-14	0.000233	99,078	23	99,067	6,453,618	65.1
14-15	0.000339	99,055	34	99,038	6,354,551	64.2
15-16	0.000460	99,022	46	98,999	6,255,513	63.2
16-17	0.000577	98,976	57	98,947	6,156,514	62.2
17-18	0.000684	98,919	68	98,885	6,057,566	61.2
…..						
94-95	0.192080	10,519	2021	9,509	38,901	3.7
95-96	0.207636	8,499	1765	7,616	29,392	3.5
96-97	0.224075	6,734	1509	5,980	21,776	3.2
97-98	0.241387	5,225	1261	4,594	15,796	3.0
98-99	0.259552	3,964	1029	3,449	11,202	2.8
99-100	0.278539	2,935	818	2,526	7,752	2.6
100+	1.00000	2,118	2118	5,226	5,226	2.5

The columns are defined and calculated as follows:

- **x** is the beginning **Age**, e.g., $x = 0$ on the first row.

[34] http://en.wikipedia.org/wiki/Life_table

[35] The direct link to the 2003 Life Table is http://www.cdc.gov/nchs/data/nvsr/nvsr54/nvsr54_14.pdf. The linking page at http://www.cdc.gov/nchs/fastats/deaths.htm is a better resource for readers seeking newer information.

- **q(x)** is the probability of dying (failing to survive). This is empirical. All other columns are calculated from this value.
- **l(x)** is the number surviving to age **x**, with a baseline of 100,000 newborns.
  - $l(x) = (1 - q(x-1)) \times l(x-1)$
- **d(x)** is the number dying in the year beginning **x**.
  - $d(x) = q(x)l(x)$
- **L(x)** is the number of person-years lived (or tractor-years in service) by individuals alive at the beginning of age **x**. It is assumed that deaths during age **x** occur, on-average, at the middle of year (except at age 0, where more deaths occur very close to the beginning, i.e., neonatal).
  - $L(x) = l(x) - \frac{1}{2}d(x)$
- **T(x)** is the number of years lived including and beyond age **x**, e.g., T(10) is the number of cumulative person-years lived from years 10 to infinity.
  - $T(x) = \sum_{a=x}^{\infty} L(a)$
- **e(x)** is the life-expectancy for an individual alive at year **x**, e.g., e(10) is the expected number of years of life remaining for a 10 year-old individual (68.1).
  - $e(x) = T(x) \div l(x)$

The survival probability to the end of year **x** can be taken as the ratio of the number surviving, **l(x)**, to the baseline population of 100,000. It can be calculated by multiplying the individual-year survival rates, as follows:

$$S(x) = \prod_{a=0}^{x-1} (1 - q(a))$$

Table 19 applies these methods to the Polk data for tractors. When this same method is applied to data for passenger cars, the survival probabilities are within one percent of those reported in the 2006 report up to year 11. Such strong agreement suggests the method applied in this report is valid.

Table 19: Life Table for tractors, unadjusted

Age	Probability of retirement between ages x to x+1 q(x)	Number surviving to age x l(x)	Number retired between ages x to x+1 d(x)	Tractors-years in service between ages x to x+1 L(x)	Total number of tractors-years in service above age x T(x)	Expectation of life at age x e(x)
0-1	0.031446	100,000	3145	98,428	1,755,719	17.6
1-2	0.024134	96,855	2338	95,687	1,657,291	17.1
2-3	0.001563	94,518	148	94,444	1,561,605	16.5
3-4	0.002227	94,370	210	94,265	1,467,161	15.5
4-5	0.012030	94,160	1133	93,594	1,372,896	14.6
5-6	0.023950	93,027	2228	91,913	1,279,302	13.8
6-7	0.029246	90,799	2656	89,471	1,187,389	13.1
7-8	0.035618	88,144	3139	86,574	1,097,918	12.5
8-9	0.036581	85,004	3110	83,449	1,011,344	11.9
9-10	0.040060	81,895	3281	80,254	927,894	11.3
10-11	0.045155	78,614	3550	76,839	847,640	10.8
11-12	0.047910	75,064	3596	73,266	770,801	10.3
12-13	0.056960	71,468	4071	69,432	697,535	9.8
13-14	0.068821	67,397	4638	65,078	628,102	9.3
14-15	0.068906	62,759	4324	60,596	563,024	9.0
15-16	0.073576	58,434	4299	56,285	502,428	8.6
16-17	0.077821	54,135	4213	52,028	446,143	8.2
17-18	0.081691	49,922	4078	47,883	394,115	7.9
18-19	0.084807	45,844	3888	43,900	346,232	7.6
19-20	0.099516	41,956	4175	39,868	302,332	7.2
20-21	0.085609	37,781	3234	36,163	262,464	6.9
21-22	0.104579	34,546	3613	32,740	226,300	6.6
22-23	0.114099	30,933	3529	29,169	193,560	6.3
23-24	0.127171	27,404	3485	25,661	164,392	6.0
24+	1.000000	23,919	23919	138,730	138,730	5.8

An interesting phenomenon is what might be described as “infant mortality” of tractors – the probability of removal from the registration rolls is high initially and reaches a minimum after year three, then increases (nearly) monotonically throughout the lifetime. Taking these values literally would imply the analog of “childhood diseases,” which might be catastrophic mechanical failures during the first three years resulting from poor manufacture. Considering that passenger cars do not exhibit this curiosity,[25] a more likely scenario is that variability in registration policies and procedures causes some vehicles to move in-and-out of registered status during the first few years. The cause of this phenomenon is beyond the scope of the present report.

Because the probabilities are multiplicative, application of the higher retirement rates during the first three years would (slightly) lower survival for all ages. These values have been fixed as 0.999, which would mean that only 1 in 1000 vehicles are retired in each of the first two years. This would generally represent vehicles involved in totality accidents. It also occurs occasionally that the number registered vehicles *increases* from one survey year to the next, leading to a survival probability of greater than one. This is sufficiently rare that the average survival rates in Table 19 are all less than one. When survival probabilities are greater than one, they are reset to exactly one before being averaged with other values for that age.

Table 20 shows the life table for tractors which was used in calculations of the lifetime discount factors in Table 7. To eliminate noise in the data, the year-to-year retirement rate from year three onwards was modeled by a function of the form $p(t) = A\,e^{bt} + c$. The constant c was assumed to be 0.001, representing a constant rate for the probability of involvement in totality accidents. The constants A and b in the time-varying term were found using Solver in Microsoft Excel. A sum-of-squares discrepancy function served as the objective for the optimization. The data was modeled on the range from years 2-3 to 23-24, over which the Polk data are (nearly) monotonic. The solution is $p(t) = 0.00451\,e^{1.0509\,t} + 0.0001$, where t is zero at year two ("age 1-2"). It may be more realistic to allow the constant c to decrease with time, to represent a decreasing likelihood of accident-involvement due to decrease mileage. When included in the model, this additional complication changes the individual survival probabilities only in the third or fourth decimal place. Quadratic and cubic models are nearly identical to the exponential model, as well. The exponential model is commonly encountered in population dynamics, though there are others models which would result in the same interpretations for this analysis.

Table 20: Life Table for tractors, modeled

Year	Probability of retirement between ages x to x+1	Number surviving to age x	Number retiring between ages x to x+1	Tractors-years in service between ages x to x+1	Total number of tractors-years in service above age x	Expectation of life at age x
	q(x)	l(x)	d(x)	L(x)	T(x)	e(x)
0-1	0.001	100,000	100	99,950	1,840,788	18.4
1-2	0.001	99,900	100	99,850	1,740,838	17.4
2-3	0.0055	99,800	550	99,525	1,640,988	16.4
3-4	0.0103	99,250	1,027	98,737	1,541,462	15.5
4-5	0.0153	98,224	1,504	97,472	1,442,725	14.7
5-6	0.0204	96,720	1,969	95,736	1,345,254	13.9
6-7	0.0255	94,751	2,414	93,544	1,249,518	13.2
7-8	0.0306	92,338	2,829	90,923	1,155,974	12.5
8-9	0.0359	89,508	3,209	87,904	1,065,051	11.9
9-10	0.0411	86,299	3,547	84,525	977,147	11.3
10-11	0.0464	82,752	3,839	80,832	892,622	10.8
11-12	0.0517	78,913	4,080	76,873	811,789	10.3
12-13	0.0570	74,833	4,269	72,699	734,916	9.8
13-14	0.0624	70,564	4,404	68,362	662,218	9.4
14-15	0.0678	66,160	4,486	63,917	593,856	9.0
15-16	0.0732	61,675	4,515	59,417	529,938	8.6
16-17	0.0786	57,159	4,495	54,912	470,521	8.2
17-18	0.0841	52,664	4,428	50,450	415,609	7.9
18-19	0.0896	48,236	4,320	46,076	365,159	7.6
19-20	0.0950	43,916	4,174	41,830	319,083	7.3
20-21	0.1005	39,743	3,995	37,745	277,253	7.0
21-22	0.1060	35,747	3,791	33,852	239,508	6.7
22-23	0.1116	31,956	3,565	30,174	205,657	6.4
23-24	0.1171	28,391	3,325	26,729	175,483	6.2
24-25	0.1227	25,066	3,075	23,529	148,754	5.9
25-26	0.1282	21,991	2,820	20,581	125,226	5.7
26-27	0.1338	19,171	2,565	17,889	104,644	5.5
27-28	0.1394	16,606	2,315	15,449	86,755	5.2
28-29	0.1450	14,291	2,072	13,255	71,307	5.0
29-30	0.1506	12,219	1,840	11,299	58,051	4.8
30-31	0.1562	10,379	1,621	9,568	46,752	4.5
31-32	0.1619	8,758	1,417	8,049	37,184	4.2
32-33	0.1675	7,340	1,229	6,725	29,135	4.0
33-34	0.1731	6,111	1,058	5,582	22,410	3.7
34-35	0.1788	5,053	903	4,601	16,828	3.3
35-36	0.1844	4,149	765	3,767	12,227	2.9
36+	1.0000	3,384	3,384	8,460	8,460	2.5

DOT HS 811 109
March 2009

U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA
www.nhtsa.gov